ICORR-CSCP First Joint Webinar Week in November 2024

Corrosion Research Progress in Oil & Gas and New Energy Industry

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National Key Laboratory of Oil & Gas Drilling, Production and Transmission Equipment

Nov. 2024

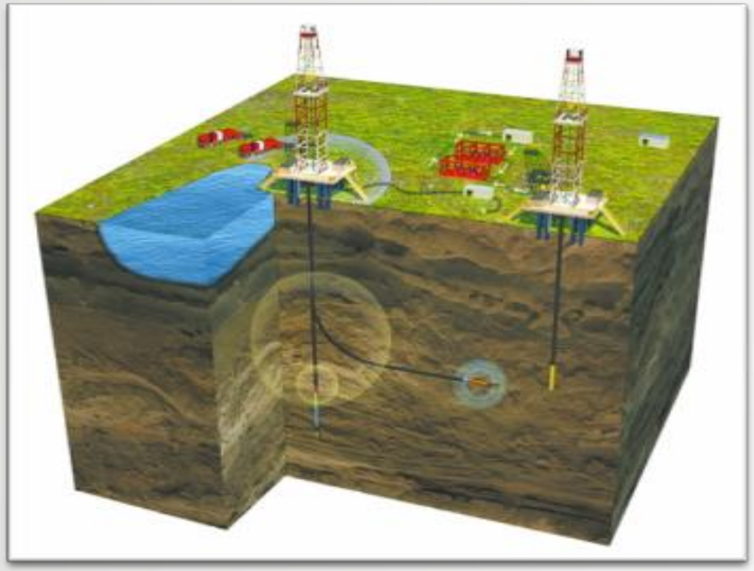
OUTLINE

Importance of Corrosion in Oil and Gas Industry

Introduction of oil and gas industry

Oil and Gas Field

Upstream



Transmission Pipeline

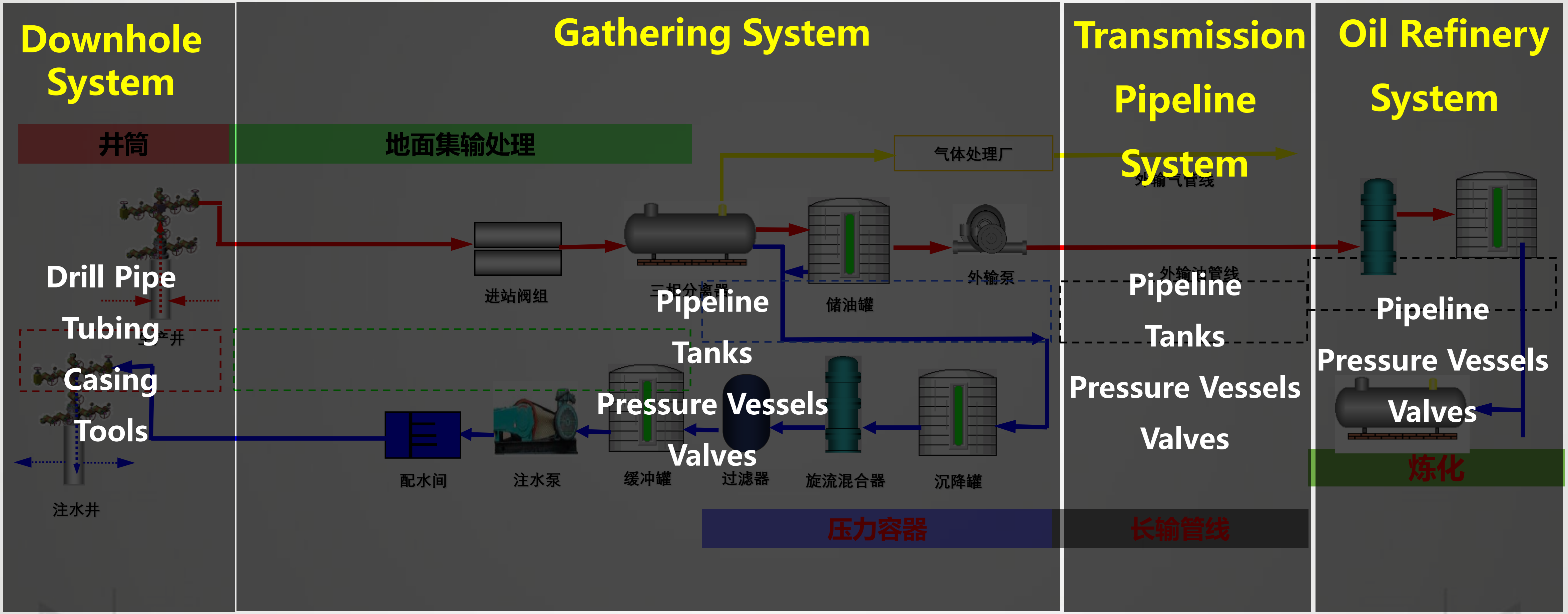
Middlestream

Oil Refinery

Downstream

Importance of Corrosion in Oil and Gas Industry

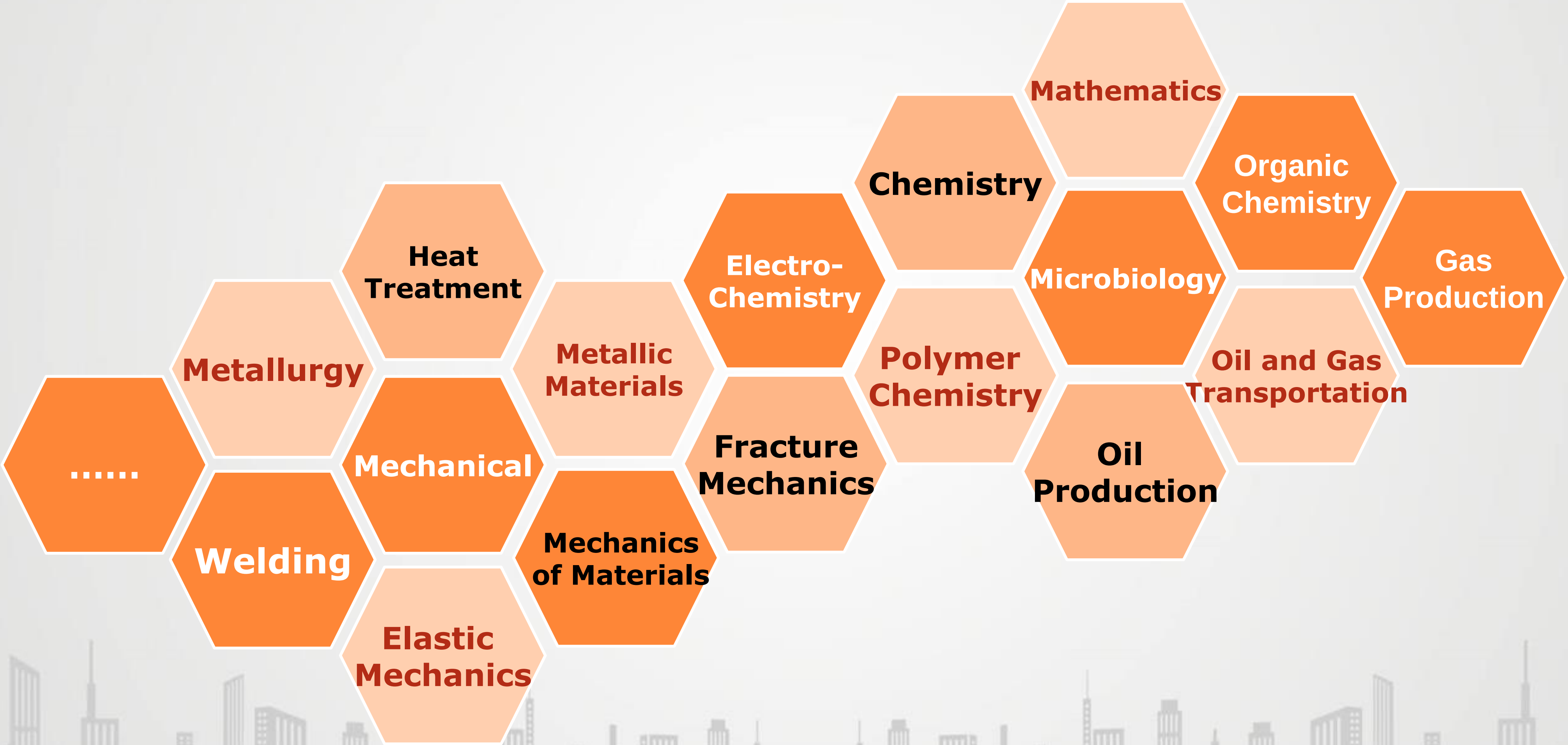
□ Infrastructures of oil and gas industry



Tubular Goods are the **lifelines** of the oil and gas industry.

Importance of Corrosion in Oil and Gas Industry

- Corrosion is an interdiscipline in oil and gas industry



Importance of Corrosion in Oil and Gas Industry

Uniform Corrosion

Stress corrosion cracking

Pitting Corrosion

Sulfide Corrosion Cracking

Erosion-Corrosion

Crevice Corrosion

High Temp. High Pressure Corrosion

Coupling Corrosion

Under-deposit Corrosion

Microbiologically Influenced Corrosion

Erosion

Differential Aeration Corrosion

Corrosion Under Insulation

Hydrogen Induced Cracking

Corrosion Fatigue

Importance of Corrosion in Oil and Gas Industry

Over 60% failures of tubular goods used in oil and gas industry are related to corrosion.

Importance of Corrosion in Oil and Gas Industry

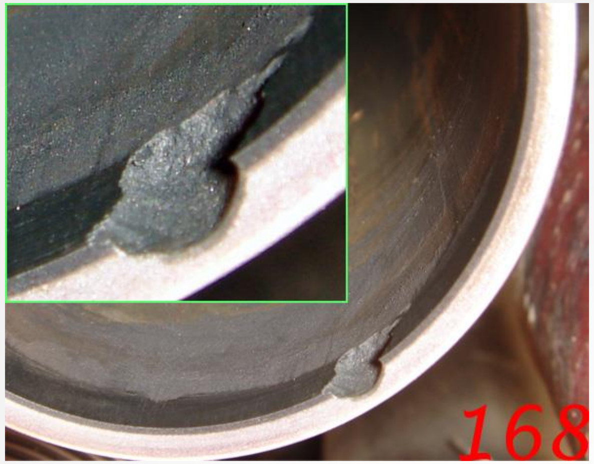
□ The cost of corrosion is more than money

Safety	Environment	Economy
⇩	⇩	⇩

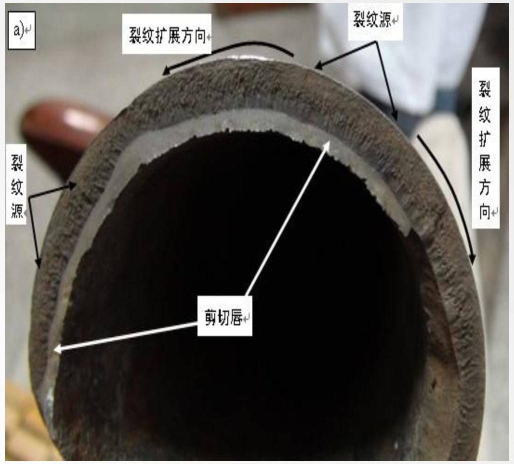
OUTLINE

Typical corrosion failures of downhole tubing and gathering pipeline

Tubing CO_2 Corrosion



Tubing Thread Crevice Corrosion



H_2S Induced SCC

Pipeline Weld SCC

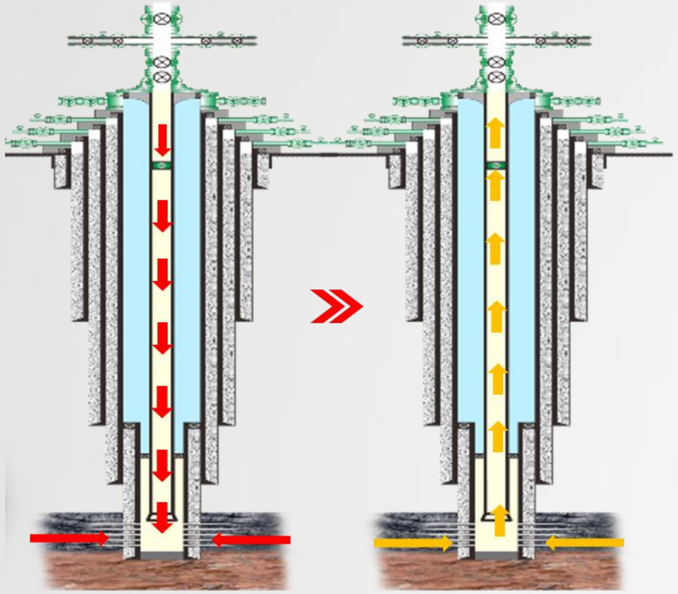
Gathering Pipe Corrosion Perforation

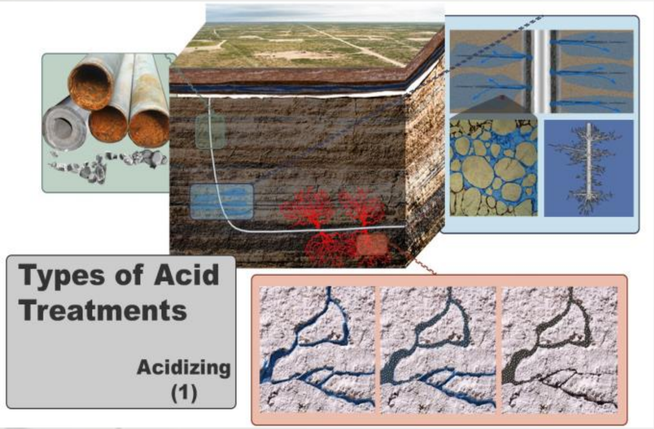
Clad Pipe Weld Corrosion

Gathering Pipe Erosion-Corrosion

Clad Pipe Bursting

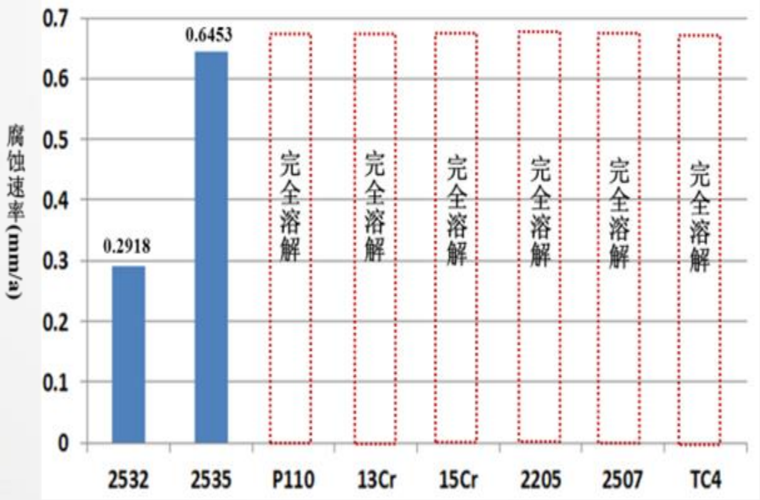
Case 1: Downhole Tubing Corrosion Due to Acidizing





Acidizing Fracture
Enhance oil & gas production

10~15%HCl+1.5HF+3%Hac+3~5%Inhibitor

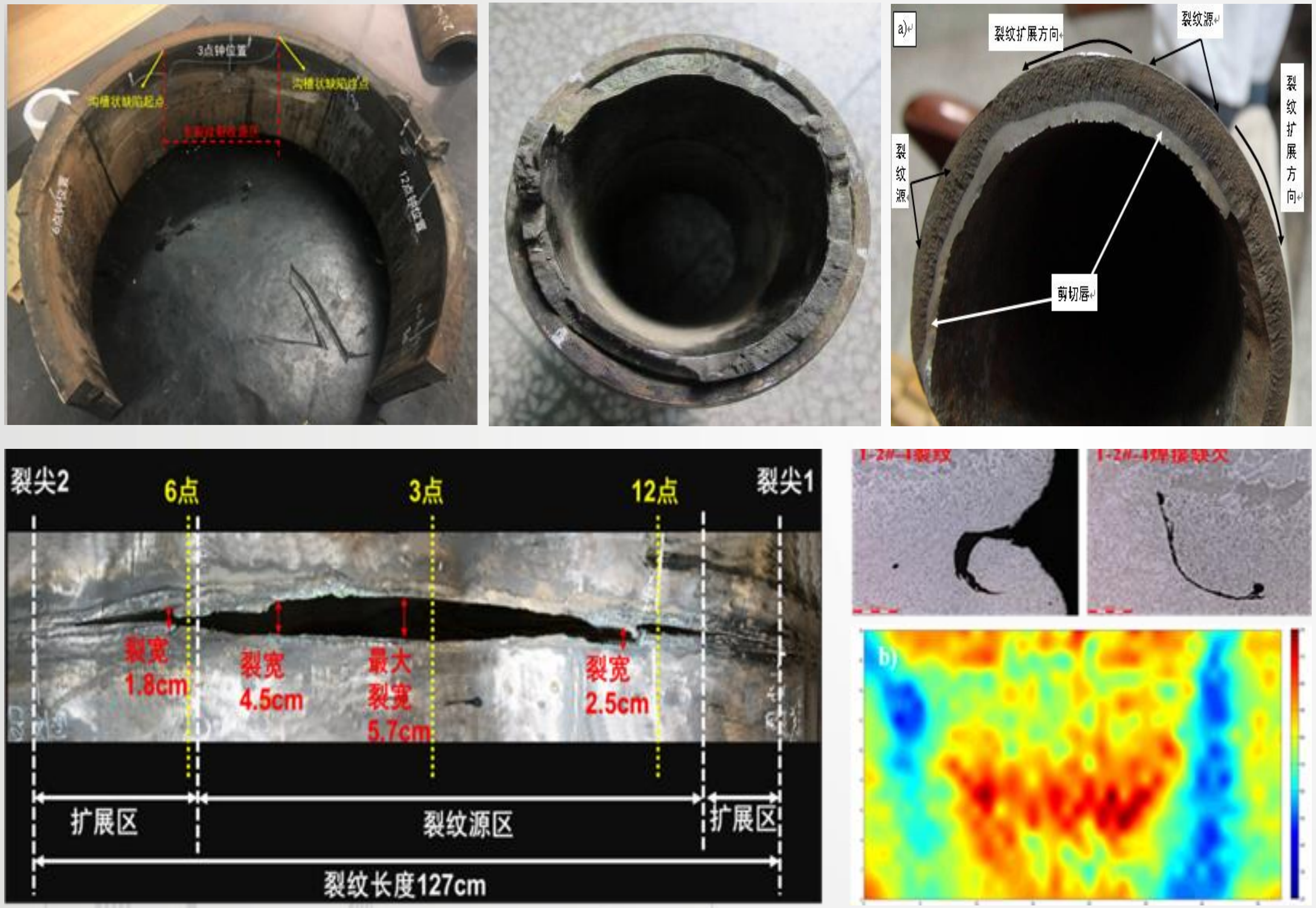


Acidizing process is highly corrosive to tubing

Research Activities

1. Tubing material(CS, 13Cr, CRAs)
2. Acidizing inhibitor
3. Corrosion evaluation facility
4. Standard for conduct test

Case 2: Drill pipe, tubing, casing, gathering pipeline SCC due to H_2S

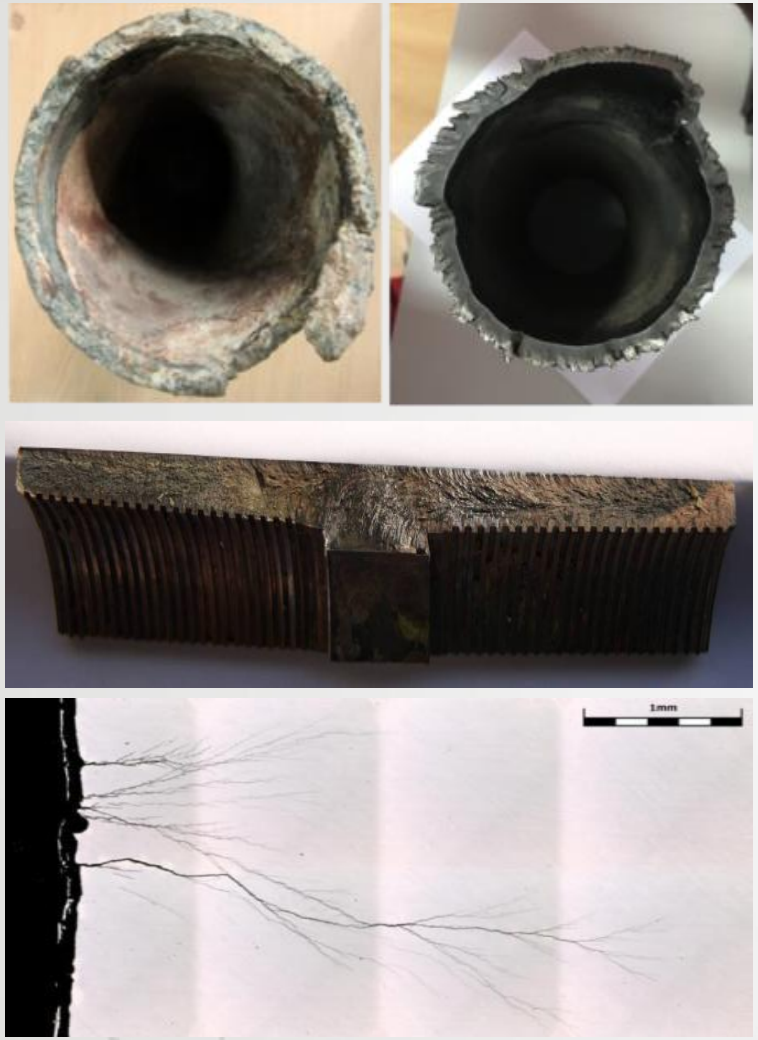


Typical H_2S induced SCC of tubular goods used in oil and gas field

Research Activities

1. Anti-SCC material R&D
2. Test method optimization
3. OCTG manufacturing process optimization
4. New chemicals R&D

Case 3: Downhole tubing SCC due to pack fluid



13Cr Tubing SCC

30~50 billion RMB lost of each well

Halide salt

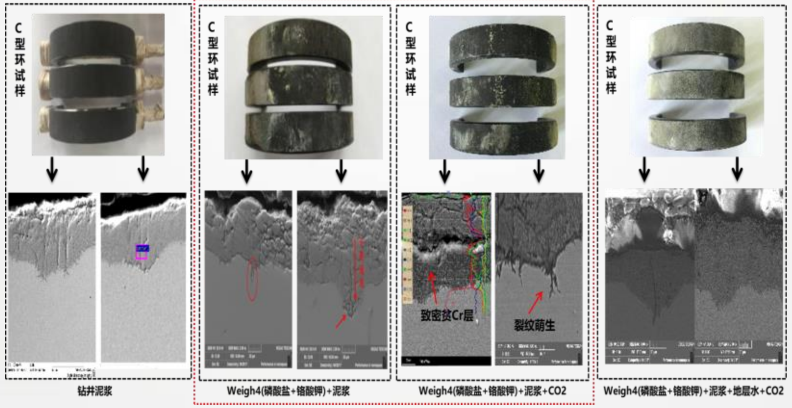
$CaCl_2$、 $NaBr$、 $CaBr_2$、 $ZnBr_2$

Formate

HCOONa、HCOOK、HCOOCs

Phosphate

Na_3PO_4、 $K_3PO_4+K_2CrO_4$

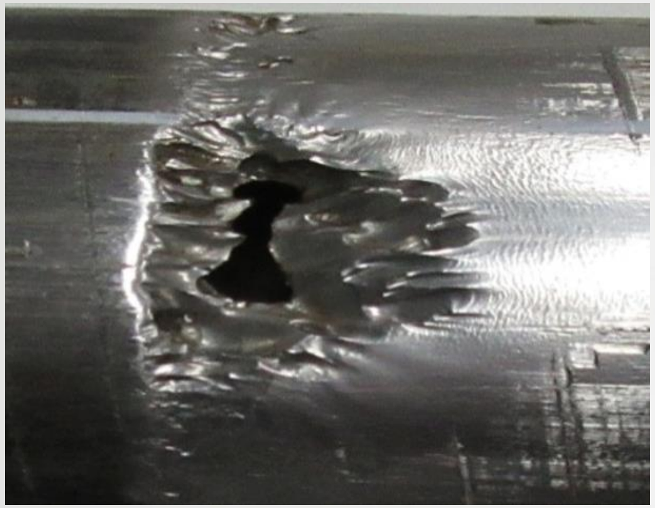


13Cr Tubing SCC simulation in various pack fluid

Research Activities

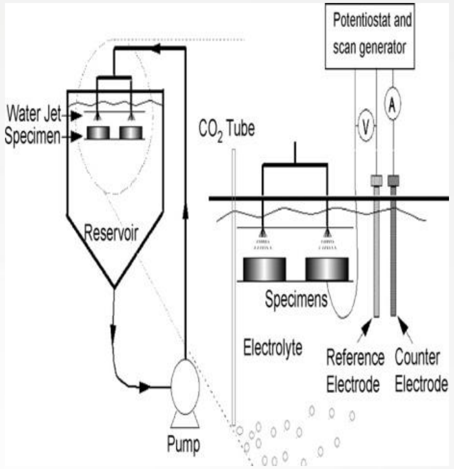
1. Pack fluid selection and quality control
2. Test method optimization
3. Tubing material optimization
4. OCTG manufacturing process optimization

Case 4: Tubing and gathering pipeline erosion-corrosion

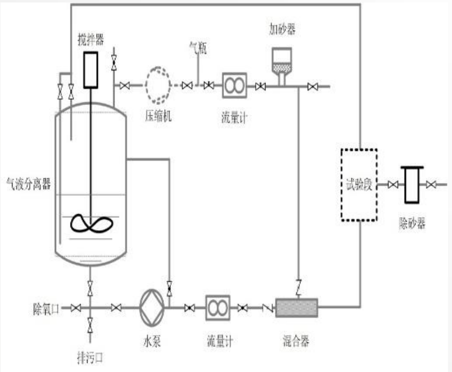


Erosion-corrosion caused by high pressure high velocity fluids

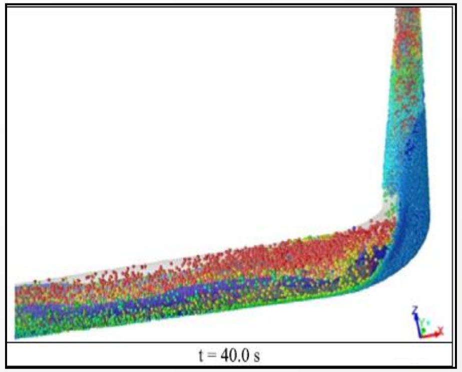
Rotating disk electrode



Impinging jet



Flow loop



CFD Simulation

Erosion-corrosion test methods

Research Activities

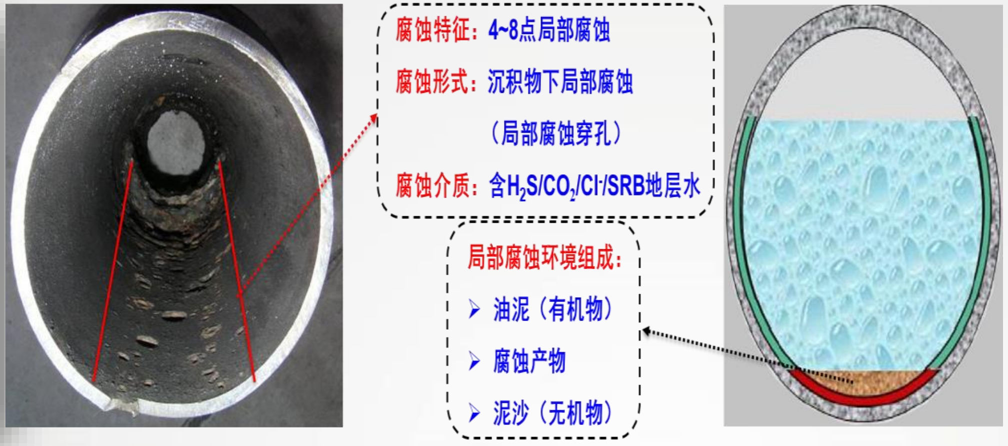
1 Self-design test facility

2 Full-scale test loop with HPHT

3 CFD simulation optimization

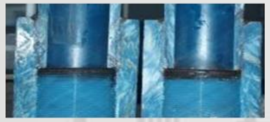
4 Materials or coatings with resistance to abrasion

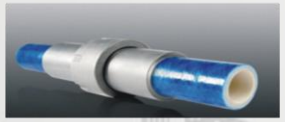
Case 5: Gathering Pipeline Under-deposit Corrosion

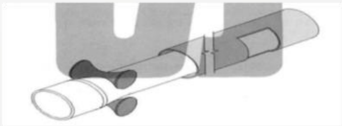


Corrosion located at 4~8 o' clock under deposit

- 油气田地面集输用非金属管
  - 塑料管
  - 增强塑料管
    - 增强热固性塑料管
      - 玻璃钢管
      - 塑料合金复合管
    - 增强热塑性塑料管
      - 钢骨架复合管
      - 柔性复合管
  - 内衬管
    - 非金属内衬金属管
      - 地面修复管







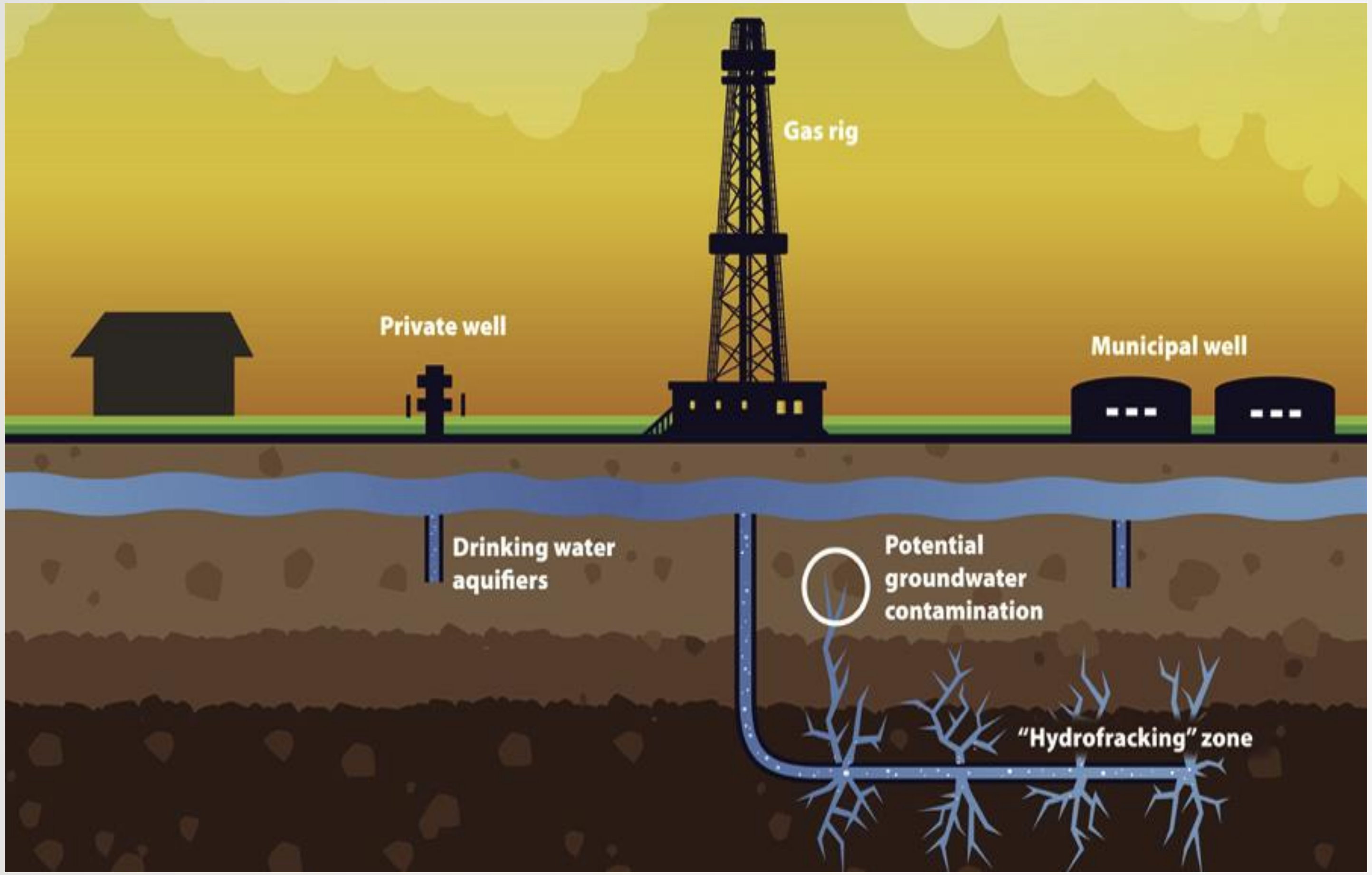
Nonmetallic composite pipe

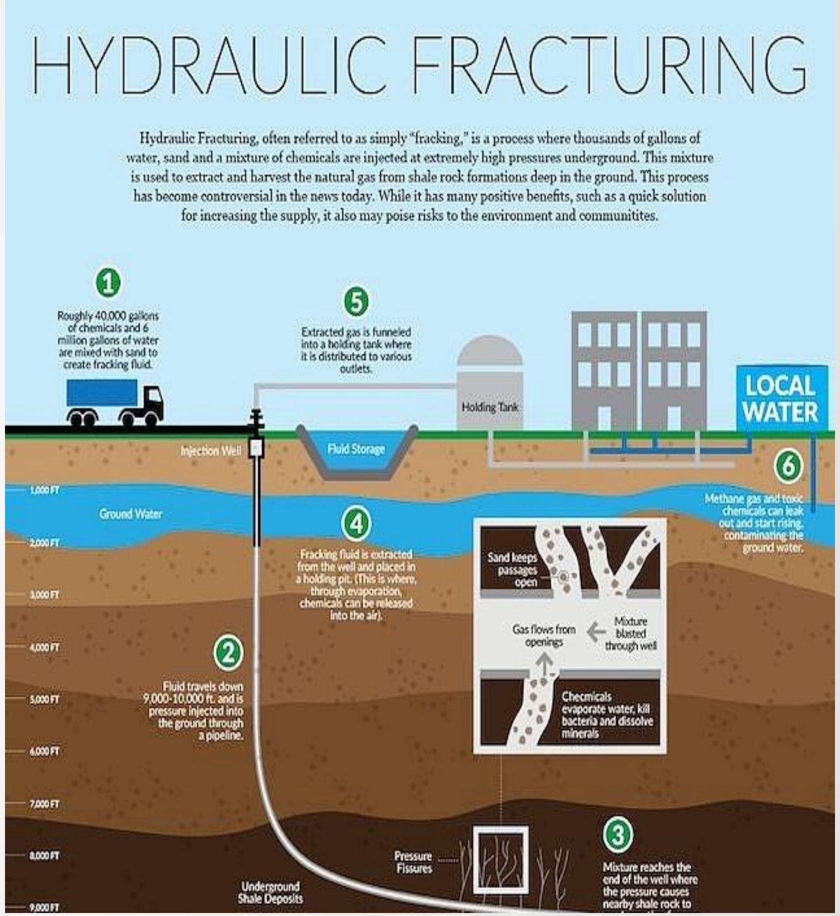
Research Activities

1. New inhibitor and coating
2. Nonmetallic composite and clad pipe
3. Small-diameter pipe inspection tools
4. Quick repair techniques

OUTLINE

MIC in shale gas due to fracturing fluid

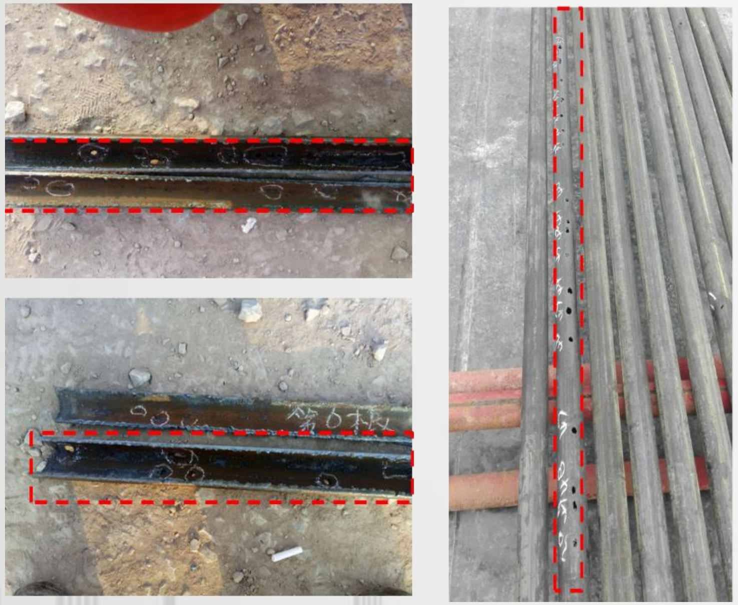




Hydraulic fracturing in shale gas exploitation, **ten thousand tons of water (Fracture fluid)**and **one thousand tons of sand** are needed for a single well.

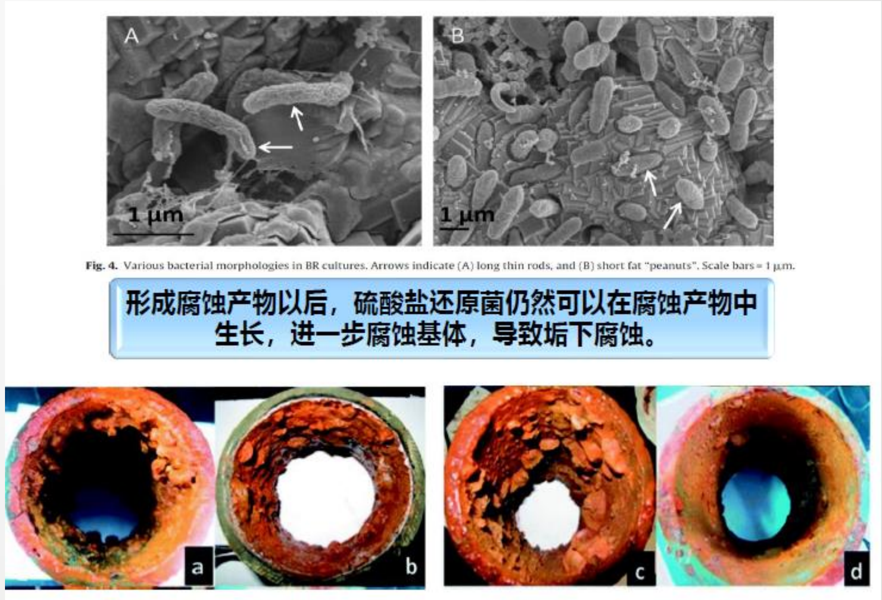
MIC in shale gas due to fracturing fluid

- **Fracture fluid** was repeatedly used for hydraulic fracturing, which could **breed various bacteria**, **SRB**, **TGB**, **FB**, etc.
- The **MIC** frequently occurred, the CR is prohibitively high, **5mm thick** tubing was perforated **within 58 days** in CNPC and Sinopec shale gas well.



Downhole Tubing MIC Corrosion

Gathering Pipeline MIC Corrosion

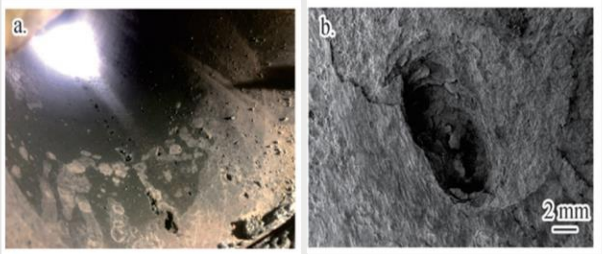


MIC-induced Under-deposit Corrosion

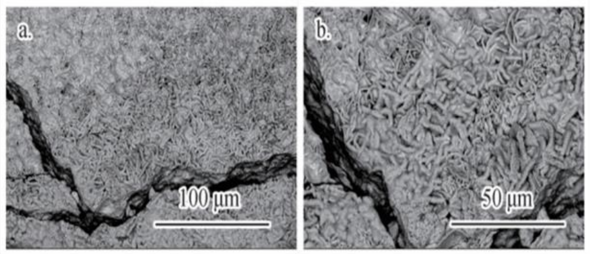
MIC in shale gas due to fracturing fluid

MIC Failure Analysis of Gathering Pipeline

- 川南页岩气气质中低含 CO_2 且不含 H_2S，返排液中硫酸盐还原菌（SRB）含量严重超标。
- 集气管线腐蚀产物中主要为 $FeCO_3$、FeS 以及 Fe_3O_4 等腐蚀产物。
- 集气管线腐蚀形貌与 SRB 腐蚀形貌高度一致，且腐蚀坑内存在大量 SRB 菌落。



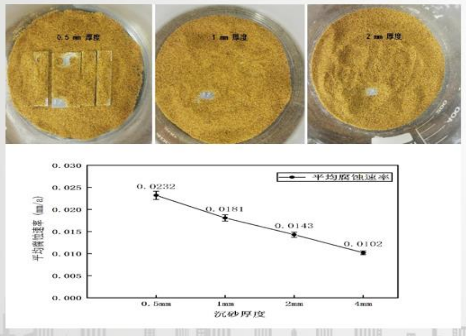
某页岩气平台集气管线腐蚀形貌图



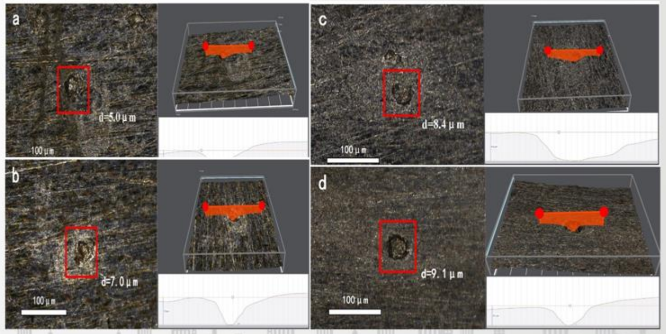
腐蚀坑内硫酸盐还原菌（SRB）菌落图

Lab Simulation Test of MIC+UDC

研究了L245N-RCB抗菌钢在$CaCO_3$混合沉砂的沉积层环境中的腐蚀行为，通过改变沉砂厚度，研究沉砂厚度的变化对钢种微生物腐蚀行为的影响。



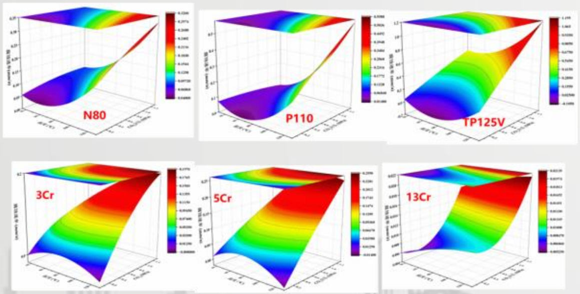
不同厚度沉砂中连续浸泡7d后的均匀腐蚀速率



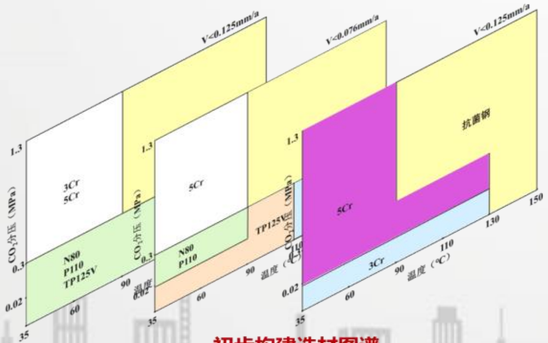
不同厚度沉砂中连续浸泡7d的局部点蚀坑形貌图

Material Evaluation and Selection

模拟不同温度和二氧化碳分压开展碳钢、含Cr钢、抗菌钢腐蚀评价实验，构建了初步选材图谱。



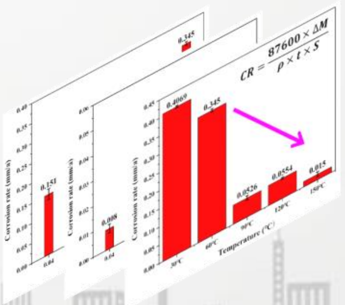
基于多元回归分析构建温度、CO_2分压与腐蚀速率之间的关系，对比预测和实测结果，具有较好一致性



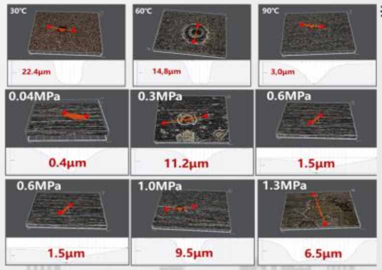
初步构建选材图谱

Anti-MIC Steel R&D and Evaluation

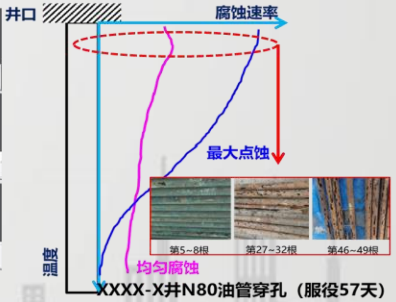
模拟页岩气高温高压工况下腐蚀评价实验，评价了抗菌钢在不同温度、不同CO_2分压对抗菌油管微生物腐蚀性能的影响。



不同温度、CO_2分压下抗菌油管均匀腐蚀速率



不同温度、CO_2分压下试样点蚀形貌



现场工况油管腐蚀情况与实验结果相匹配

MIC in shale gas due to fracturing fluid

The CNPC-TGRI **MIC lab** is capable of conducting SRB, FB TGB **culture**, **isolation**, **sterilization**, and **analysis**, as well as the **MIC test** under various conditions.

Anaerobic Incubator

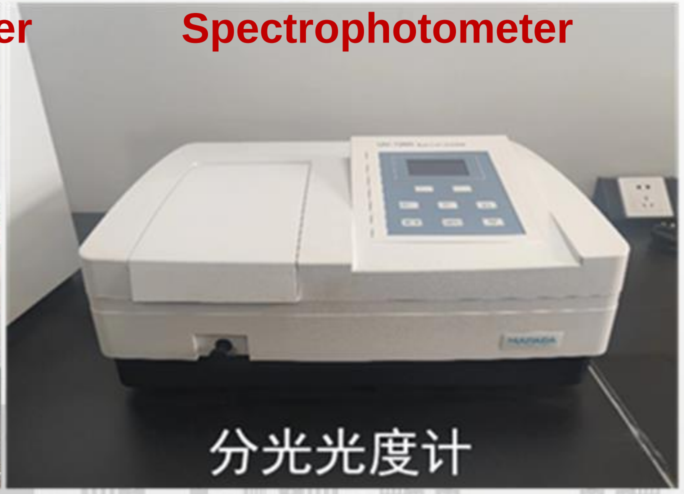
Automatic Colony Counter

Fluorescence Microscope

High Pressure Steam Sterilization Pot

Fluorescence Microscopy Analyzer

Spectrophotometer

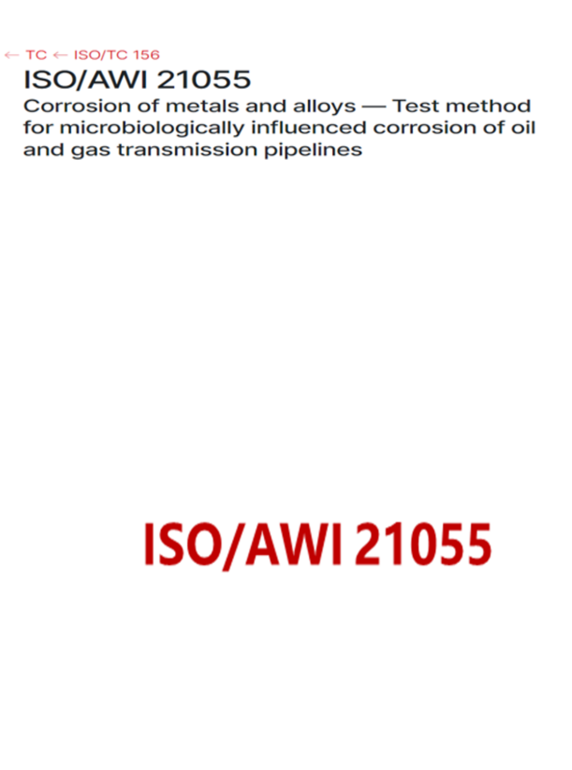


Tabletop Centrifuge

Drying Sterilizers

MIC in shale gas due to fracturing fluid

ISO/AWI 21055 **Corrosion of metals and alloys — Test method for microbiologically influenced corrosion of oil and gas transmission pipelines is the** **first ISO standard** **related to** **pipeline MIC test method.**


← TC ← ISO/TC 156

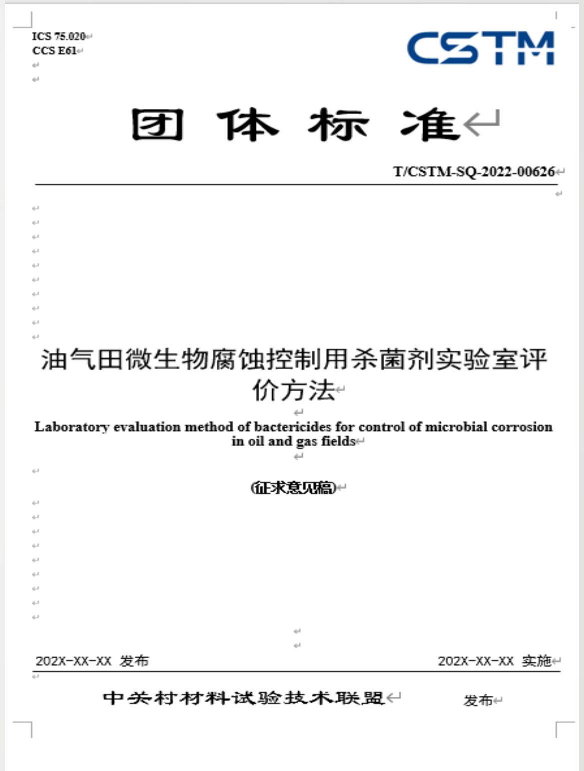
ISO/AWI 21055

Corrosion of metals and alloys — Test method for microbiologically influenced corrosion of oil and gas transmission pipelines

ISO/AWI 21055

ISO Standard for Pipeline MIC Test Method

ISO TC 156 Summer Annual Conference in Switzerland, 2023


ICS 75.020
CCS E61

CSTM

团 体 标 准

T/CSTM-SQ-2022-00626

油气田微生物腐蚀控制用杀菌剂实验室评价方法

Laboratory evaluation method of bactericides for control of microbial corrosion in oil and gas fields

(征求意见稿)

202X-XX-XX 发布 202X-XX-XX 实施

中关村材料试验技术联盟 发布

CSTM Standard of Bactericide Test Method

OUTLINE

Corrosion in CCUS-CO_2 Oil Displacement

1

Why we care CCUS?

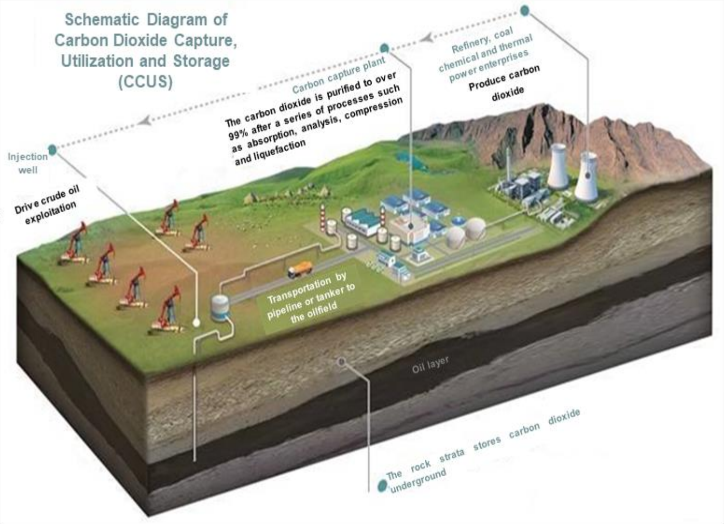
中美加强合作应对气候危机的阳光之乡声明

两国争取到2030年各自推进至少5个工业和能源等领域碳捕集利用和封存（CCUS）大规模合作项目。

Carbon Peak and Neutrality

2

Why ‘U’ is oil displacement?



Schematic Diagram of CO_2 Oil Displacement

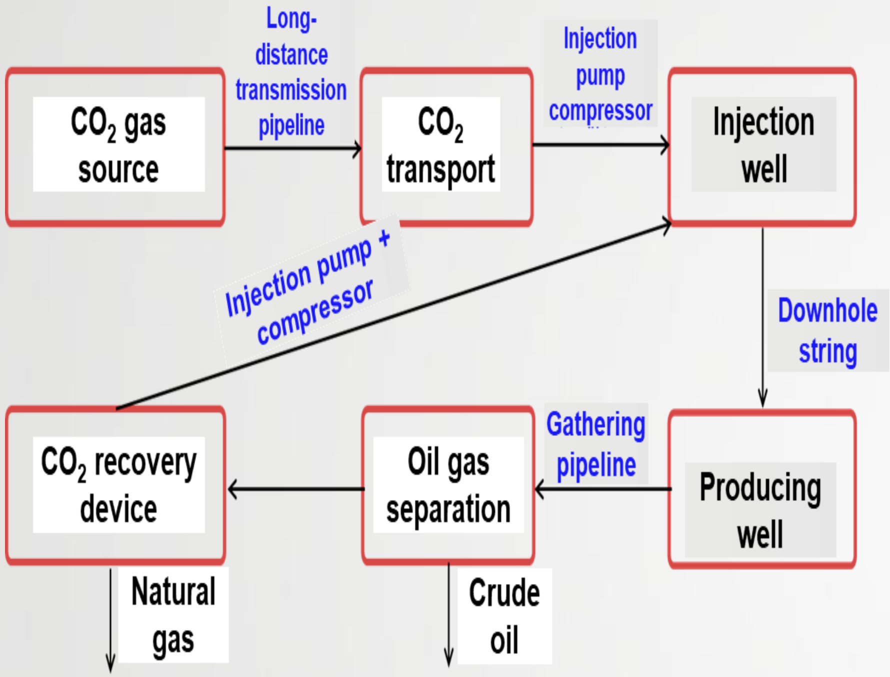
CO_2 Storage
Enhanced Oil Recovery
Win-Win Strategy

3

Why concern corrosion?

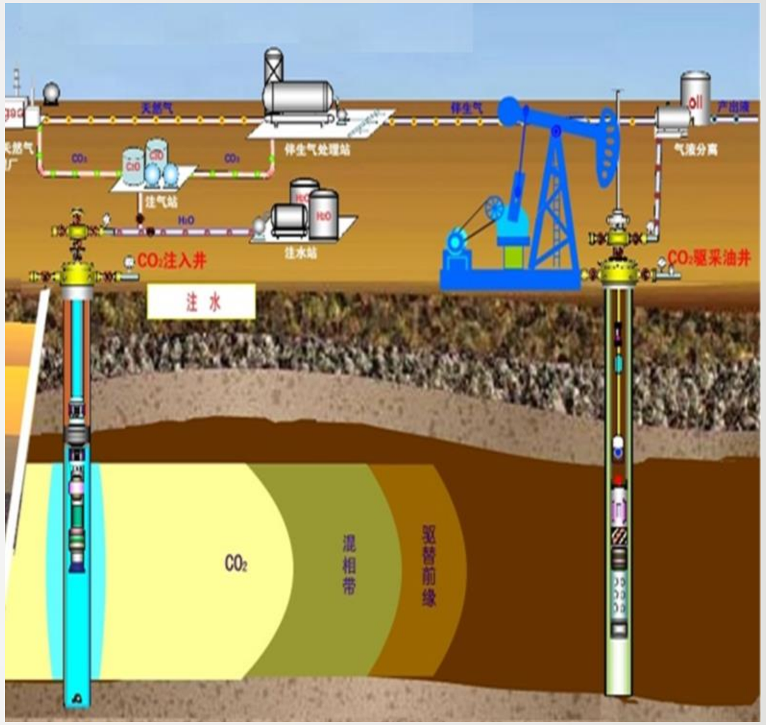
Corrosion is one of the ten key techniques of CCUS-EOR

Corrosion in CCUS-CO_2 Oil Displacement



Schematic Diagram of the CO_2 Oil Displacement

CO_2 pipeline
(parallel to ground)



CO_2 injection/production tubing
(Vertical to ground)

Pipeline and tubing are the lifelines of CCUS-CO_2 oil displacement.

Corrosion in CCUS-CO_2 Oil Displacement

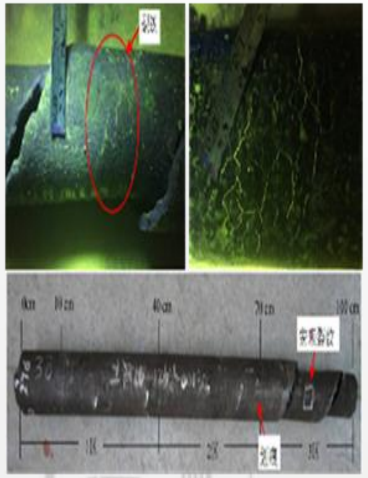
Conventional CO_2 Corrosion VS CCUS-CO_2 Corrosion

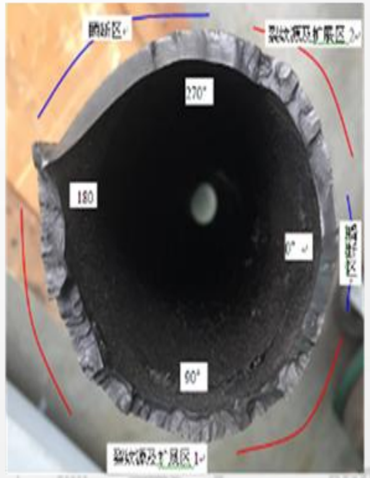
1. Supercritical CO_2 induced tubing and casing corrosion
2. CO_2 containing acidic impurities induced SCC (Coal-fired power plants)
3. Supercritical CO_2 injection led to low temperature
4. Supercritical CO_2 induced packer rubber failure

Corrosion in CCUS-CO_2 Oil Displacement

CCUS-CO_2 corrosion

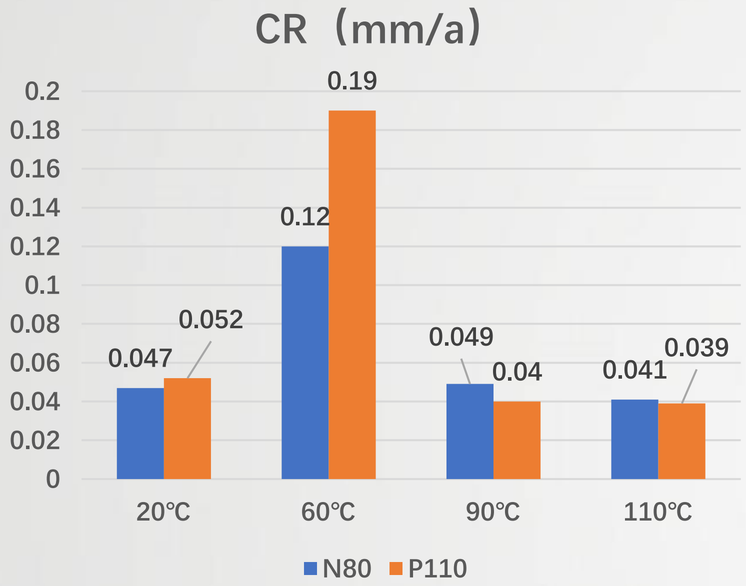
- **Corrosion**
  - CO_2 corrosion of string/pipeline
  - Selection of anti-corrosion materials of string/pipeline
  - R&D and evaluation of corrosion inhibitor
- **Fracture**
  - Stress corrosion cracking of string
- **Scaling**
  - Under-deposit corrosion mechanism
  - R&D and evaluation of scale inhibitor
- **Rubber sealing**
  - Expansion and cracking mechanism of rubber tube
- **Low temperature**
  - Low-temperature mechanical properties of pipes

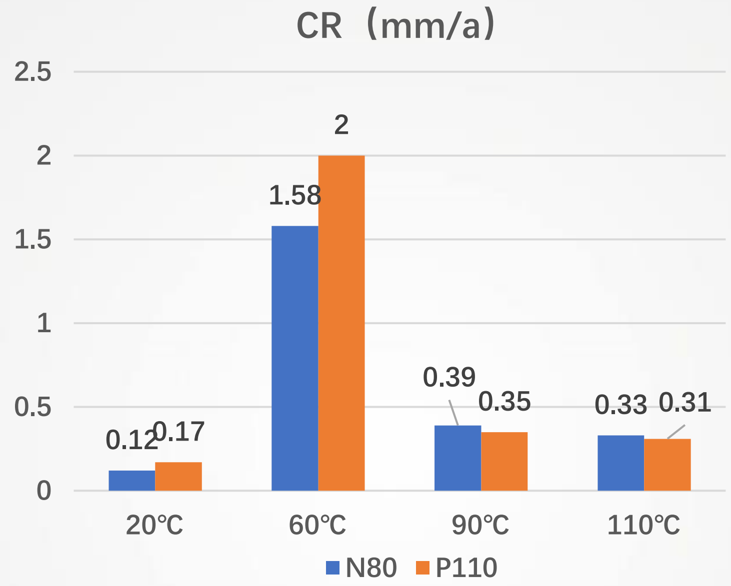


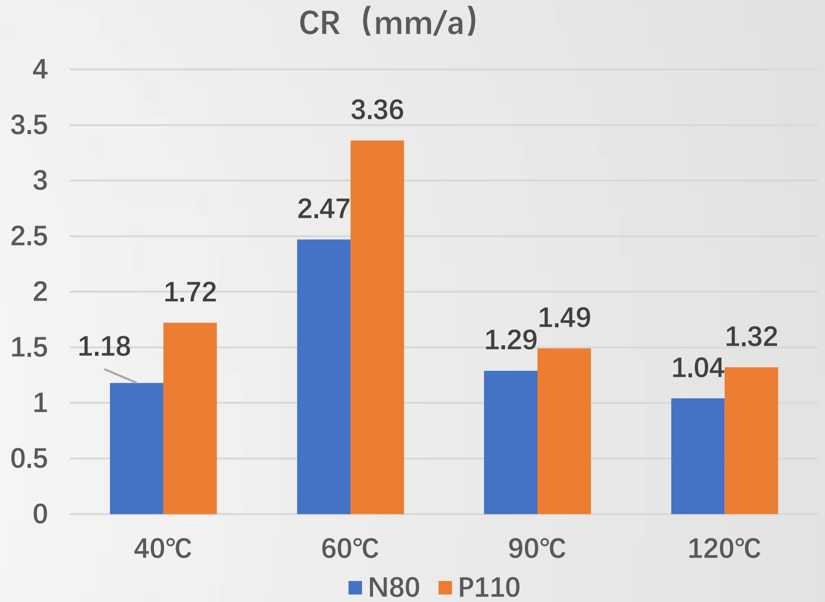


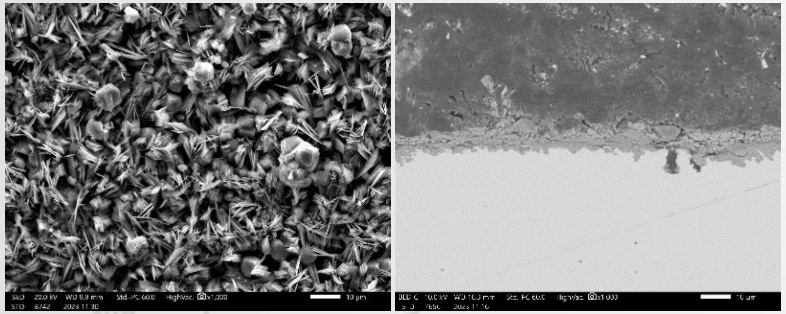
Corrosion in CCUS-CO_2 Oil Displacement

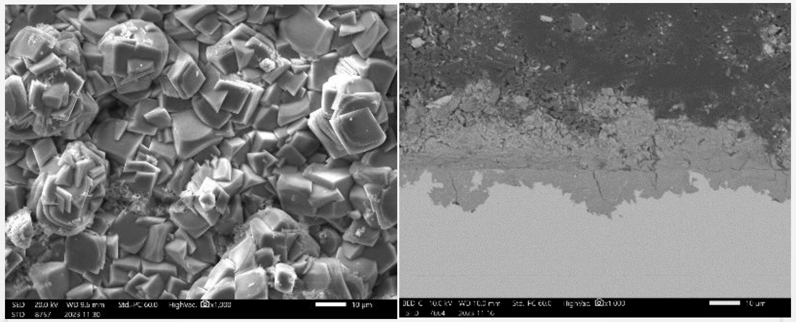
The Influence of CO_2 Pressure on Corrosion Rate

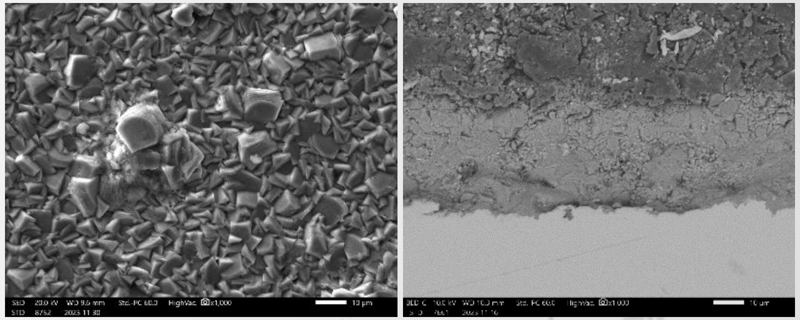












0.005MPa CO_2

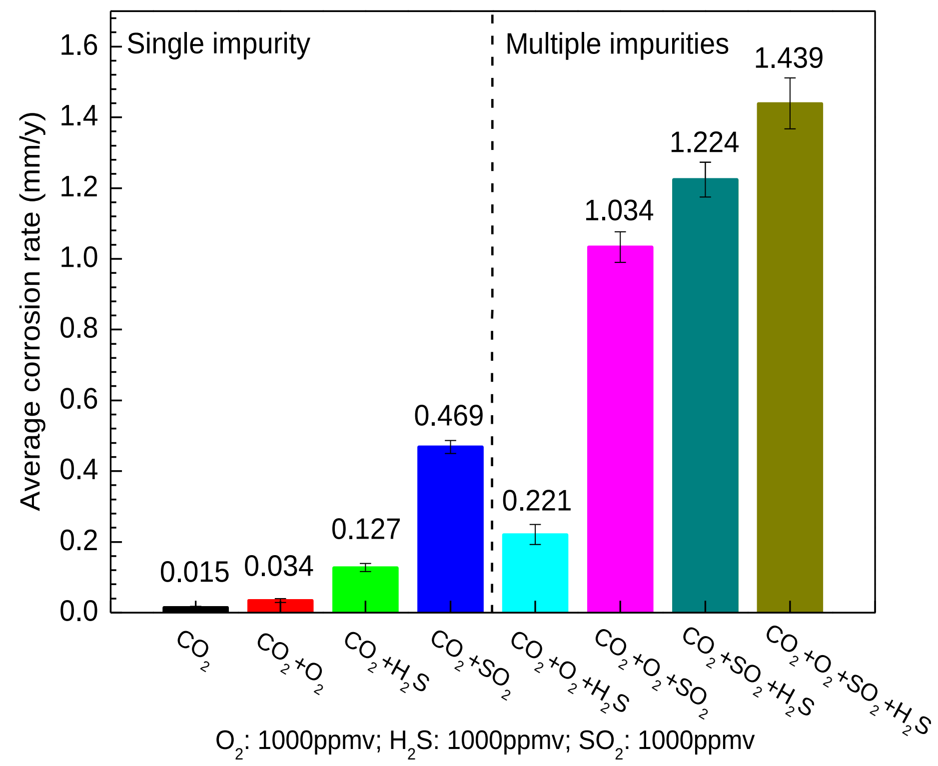
2MPa CO_2

20MPa CO_2 (Supercritical)

Corrosion in CCUS-CO_2 Oil Displacement

The Influence of impurity on Corrosion Rate

- **Single Impurity: $SO_2 > H_2S > O_2$**
- **Multi-impurities ($H_2S/O_2/SO_2$): $O_2+SO_2+H_2S$ > SO_2+H_2S > O_2+SO_2 > $O_2 + H_2S$**

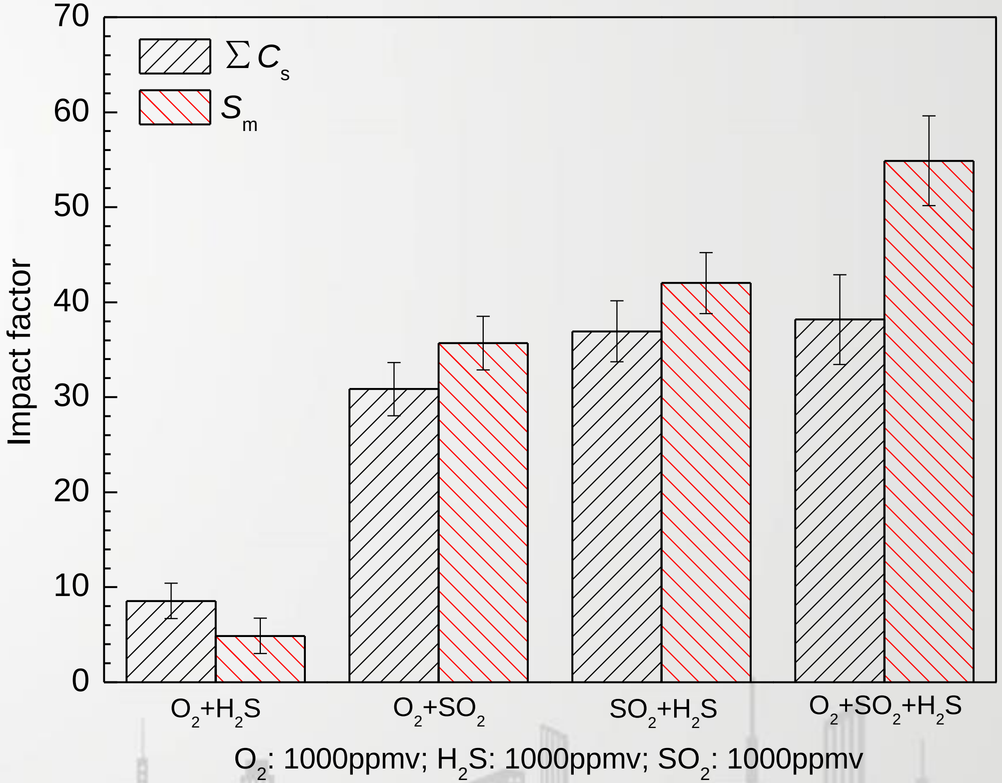


Corrosion Impact factor, C_i

$$C_i = \frac{V_i - V_0}{V_0}$$

Synergistic Impact Factor, S_m

$$S_m = C_m - \sum C_s$$

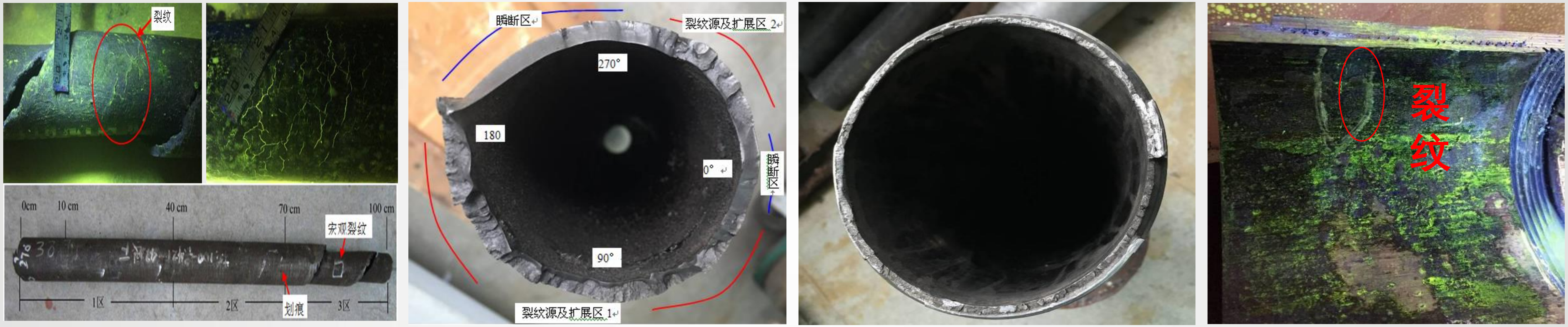


Corrosion in CCUS-CO_2 Oil Displacement

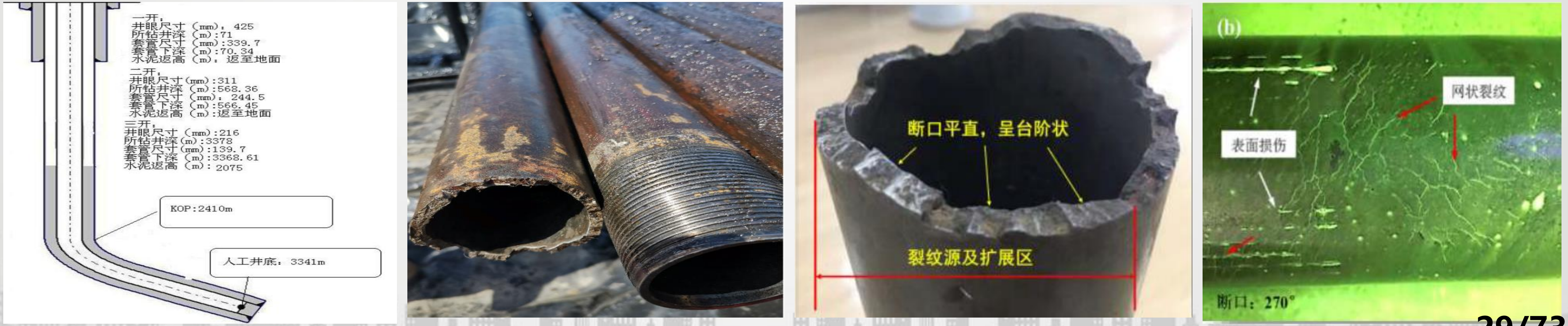
□ The Influence of impurity on stress corrosion cracking

Acidic impurities induced SCC failures were founded in several oilfields.

XXX Oilfield 1



XXX Oilfield 2



Corrosion in CCUS-CO_2 Oil Displacement

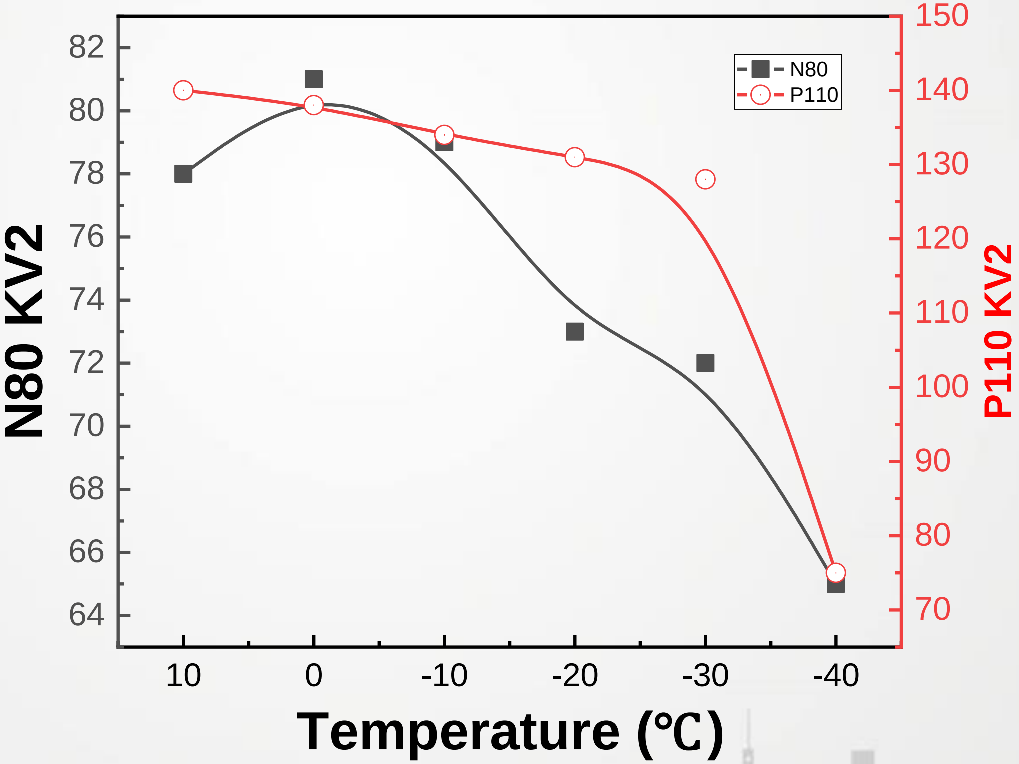
□ The Influence of Supercritical CO_2 on Packer Rubber

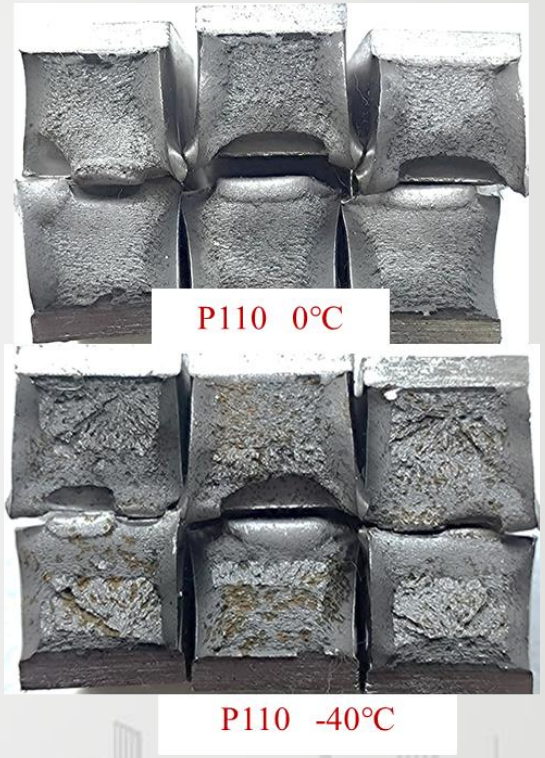
Corrosion in CCUS-CO_2 Oil Displacement

◻ The Influence of Low Temp. on Tubing Mechanical Performance

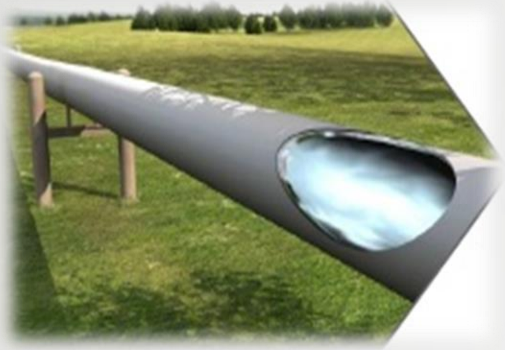
- The lowest temp. in oilfield is **-20℃** when CO_2 was injected.
- CO_2 injection has no substantial influence on N80/P110 tubing mechanical performance.

温度 (℃)	N80		P110	
	Impact Energy	Shearing Area	Impact Energy	Shearing Area
10	78	100	140	100
0	81	100	138	100
-10	79	100	134	100
-20	73	100	131	100
-30	72	100	128	100
-40	65	100	75	70





Corrosion in CCUS-CO_2 Oil Displacement

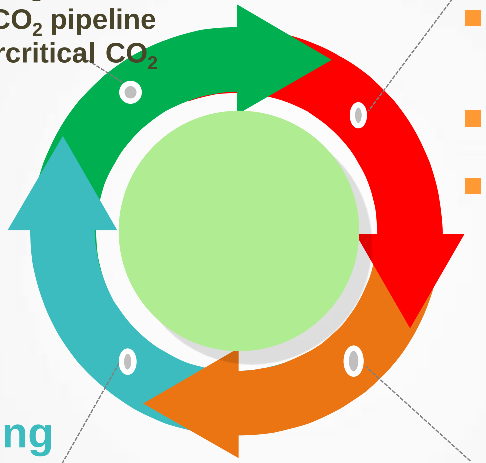


CO_2 Pipeline

- Corrosion of supercritical CO_2 and gas containing impurities
- Fracture control of supercritical CO_2 pipeline
- Micro-leakage monitoring and detection of supercritical CO_2 pipeline
- Safety evaluation of supercritical CO_2 pipeline

CO_2 Injection Tubing

- Thread seal of supercritical CO_2 string
- Failure of packer rubber tube caused by supercritical CO_2
- Fatigue of CO_2 multi-round injection and production string
- Deterioration of mechanical properties of pipes caused by low-temperature CO_2 injection
- Christmas tree safety caused by phase state and temperature changes
- Sealing reliability of packer caused by phase state and temperature changes



CO_2-enhanced Oil Production String

- Corrosion and scaling of supercritical CO_2 and gas containing impurities
- Stress corrosion cracking of acid gas containing impurities
- Crevice corrosion of threaded joint of string
- Failure of packer rubber tube caused by supercritical CO_2

CO_2-enhanced oil gathering pipeline

- Corrosion of supercritical/high-concentration CO_2 pipeline
- Scaling of supercritical/high-concentration CO_2 pipeline
- Failure of supercritical/high-concentration CO_2 pipeline joint
- Matching between supercritical CO_2 pipeline and non-metallic pipes

OUTLINE

H_2 induced damage to transportation and storage infrastructure

1

Why we need H_2?

Carbon Peak and Neutrality
Hydrogen is considered an extremely clean energy

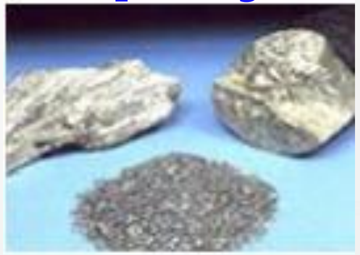
2

Which infrastructures can be potentially damaged by H_2?

Pipeline

Underground H_2 storage

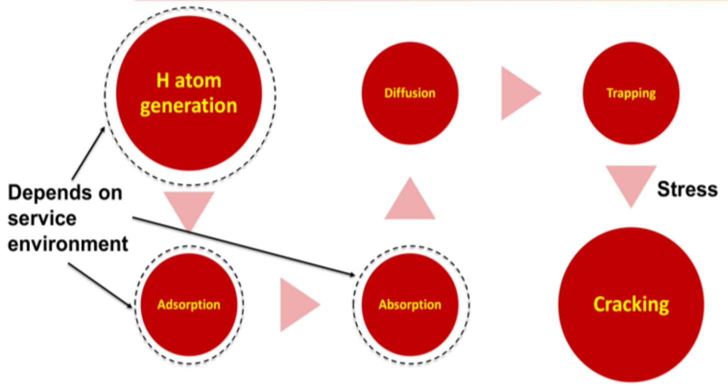
Liquified H_2 Vessel



Solid H_2 Storage

3

Why we need to re-investigate hydrogen damage?



$$H_2 \rightarrow 2H \neq H^+ \rightarrow H$$

Gaseous ≠ Cathodic

The differences between Gaseous Hydrogen and Cathodic Hydrogen *

- The amount of **"gaseous"** hydrogen that adsorbs and absorb to steels is usually limited.
- The "gaseous" H_{ads}/H_{abs} process is sometimes reversible.
- The results obtained from "gaseous" hydrogen-charging are frequently scatter, and sometimes, even controversial.

- The amount of **"cathodic"** hydrogen that adsorbs and absorbs to steels is usually substantial.
- The "cathodic" H_{ads}/H_{abs} process is basically one-way.
- The results obtained from electrochemical hydrogen-charging are usually reproducible.

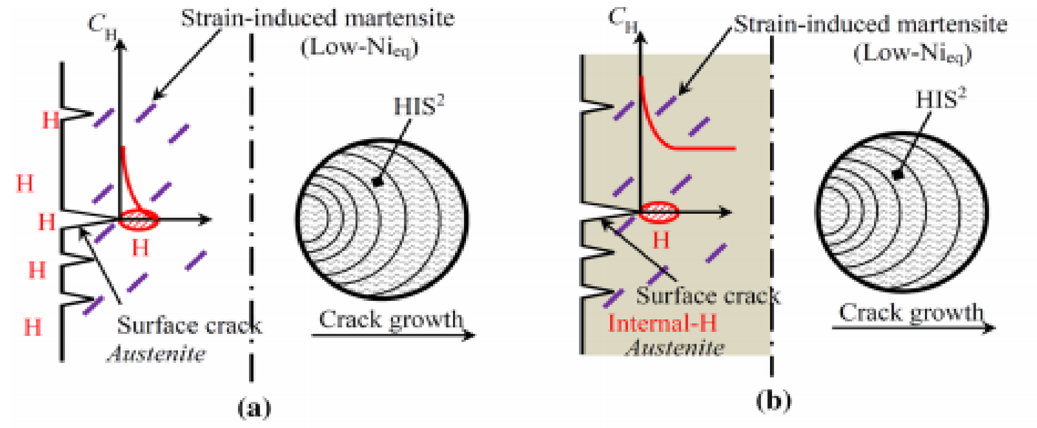
Highlight 7: The testing results upon electrochemical hydrogen-charging are not applicable to "gaseous" hydrogen conditions.

Gap 1: The standardized method for "gaseous" hydrogen-charging testing is yet established.

- **"Gaseous"** hydrogen, once permeating into steels, mostly occupies tetrahedral void sites in Fe lattice. The H_{abs} then diffuse towards various hydrogen traps.
- There is no well-accepted model that can derive hydrogen permeating parameters in "gaseous" environments.

- **"Cathodic"** hydrogen, once permeating into steels, rapidly accumulate both lattice void sites and metallurgical traps, while a diffusive process is negligible.
- Both constant-concentration model and constant-flux model are well established for derivation of "cathodic" hydrogen permeating parameters.

Gap 2: The numerical models enabling analysis of "gaseous" permeating behavior and quantification of hydrogen permeating parameters are yet developed.

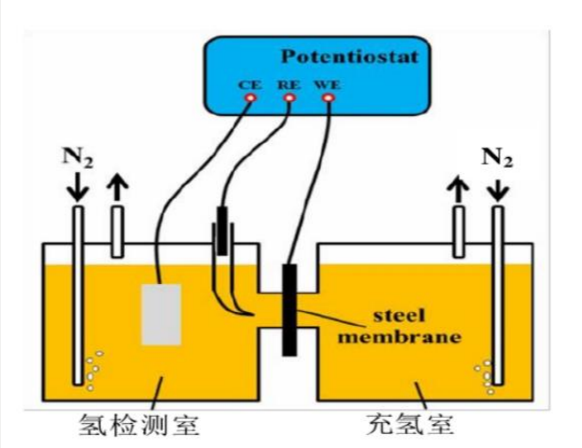


	'Gaseous' hydrogen	'Cathodic' hydrogen
Amount generated to adsorb on steel surface	Limited	Substantial
Permeation pathway	Reversible between adsorption and absorption	One way from adsorption to absorption
Testing results	Scattering, and sometimes, controversial	Reproducible
Numerical model to derive hydrogen permeating parameters	None	Constant concentration model and constant flux model

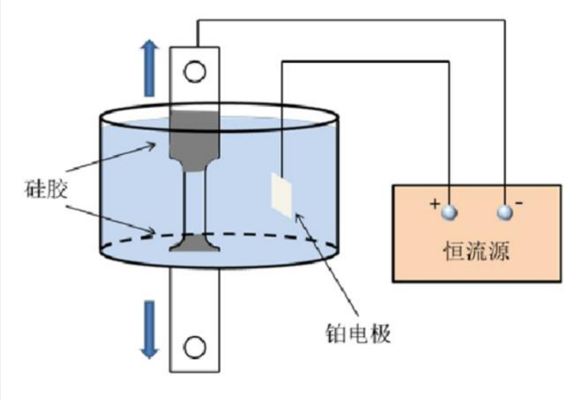
*Essence of gaseous hydrogen embrittlement of pipelines and the technical challenges, Dr. Frank Cheng (University of Calgary)

H_2 induced damage to transportation and storage infrastructure

Cathodic Hydrogen Test Facilities VS Gaseous Hydrogen Test Facilities



Devnathan-Stachurski Double Cell



SSRT with Hydrogen Charging

HPHT H_2 SSRT Test
【高温高压气态充氢慢拉伸实验系统】

200℃/15MPa H_2 or Mixture

气态充氢符合实际氢能储存输运环境，可进行气相氢环境慢应变速率拉伸、恒载荷拉伸、低周疲劳、裂纹扩展等测试。

HPHT H_2 Permeation Test
【高温高压气态氢渗透实验系统】

600℃/10MPa H_2 or Mixture

测试金属材料在高压氢环境中的氢渗透行为，包括氢扩散系数、扩散激活能、渗透系数、渗透激活能等。

HTDS Test System
【热脱附法氢含量及氢分布测试系统】

Hydrogen Thermo Desorption Spectrum

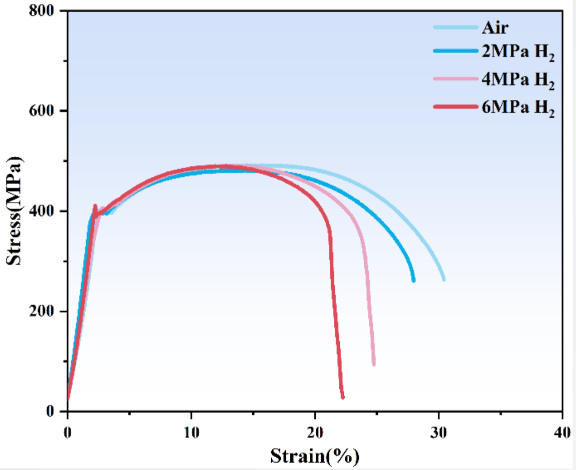
1000℃, H Content, 0.001ppm

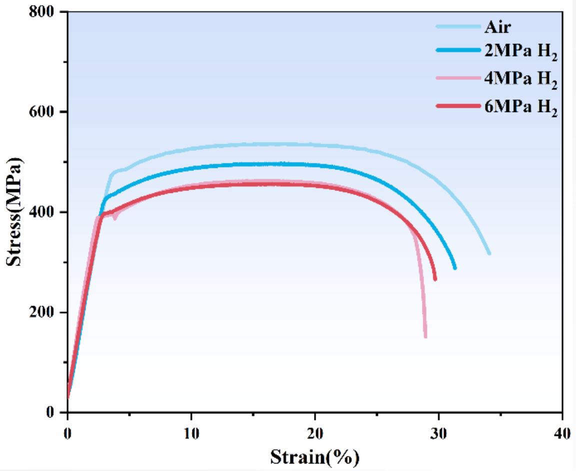
可以明确电化学充氢和气态充氢后材料的总氢含量，结合微观组织观察计算，可明确氢分布行为。

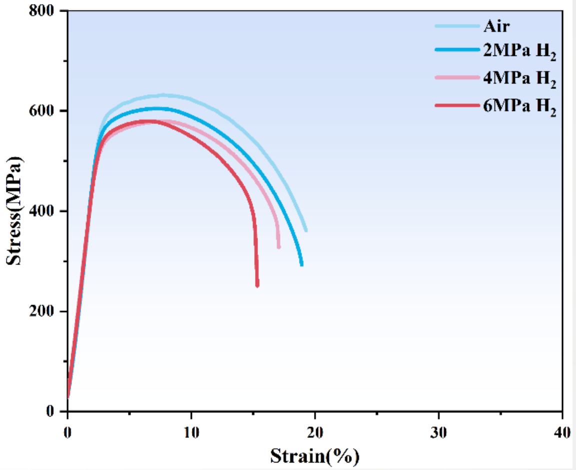
H_2 induced damage to transportation and storage infrastructure

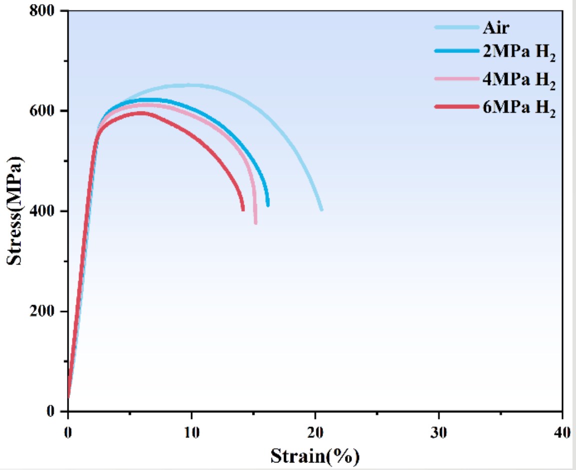
□ The Influence of H_2 on Mechanical Properties

Different Pure H_2 Pressure

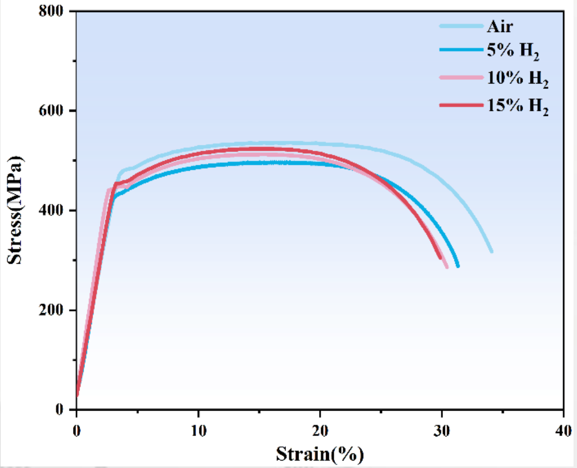


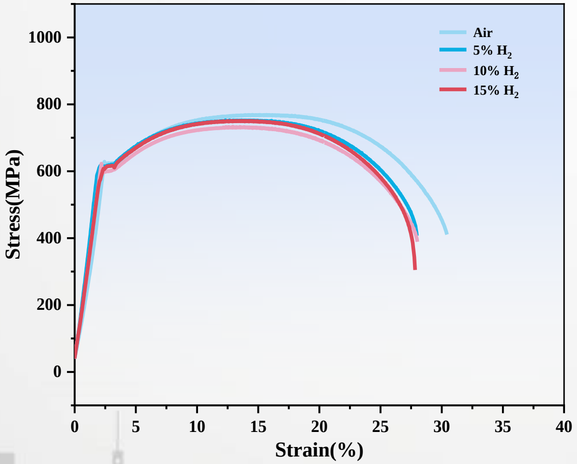


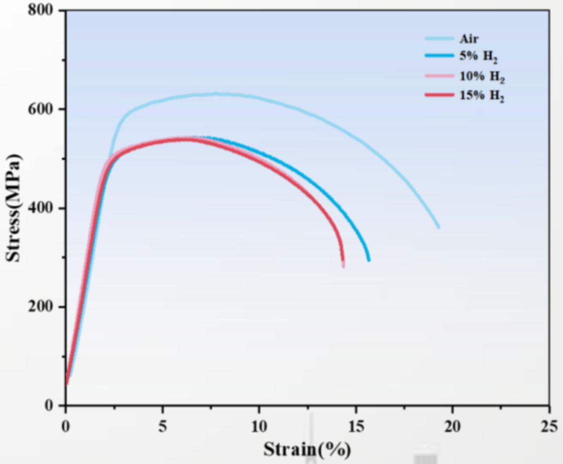


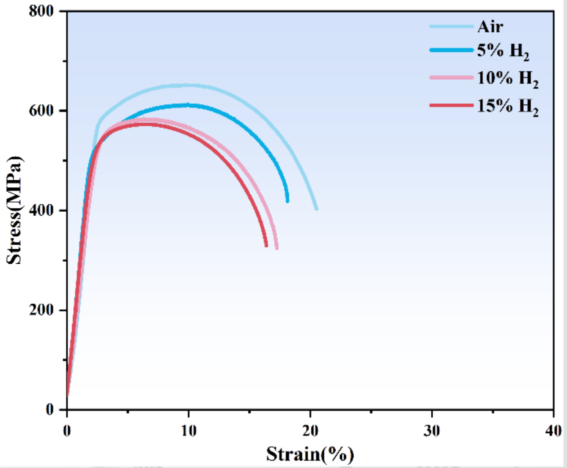


Different H_2 Partial Pressure









X52 Pipeline SSRT Curve

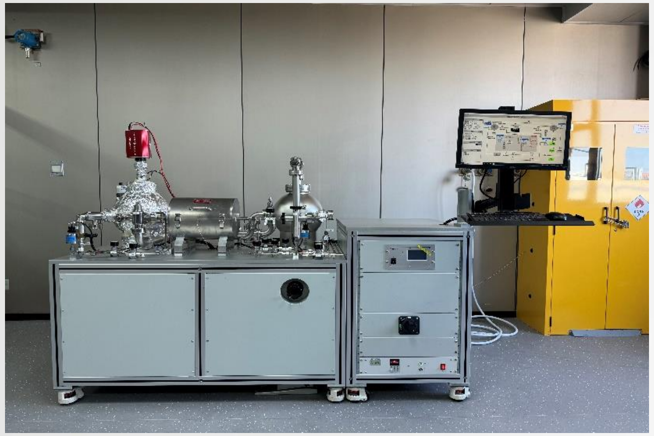
X65 Pipeline SSRT Curve

X70 Pipeline SSRT Curve

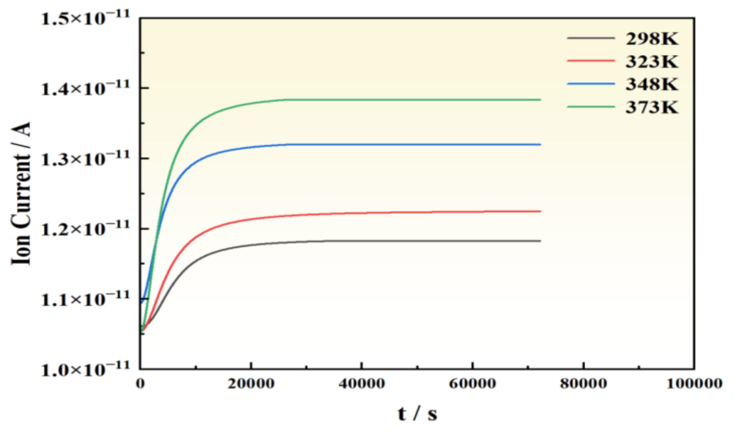
X80 Pipeline SSRT Curve

H_2 induced damage to transportation and storage infrastructure

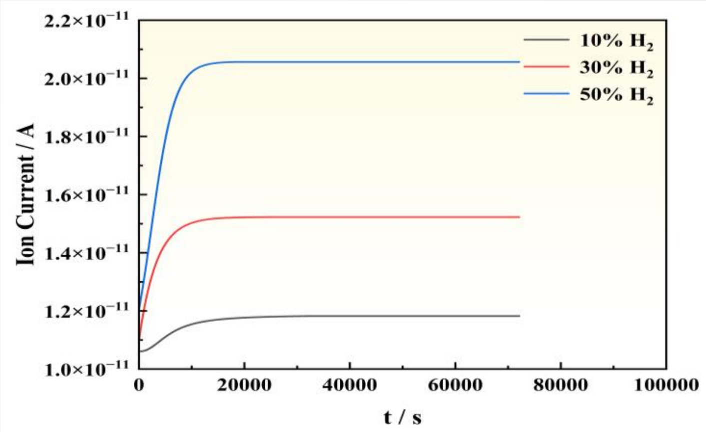
◻ Hydrogen Permeation



HTHP Gaseous H Permeation Test System



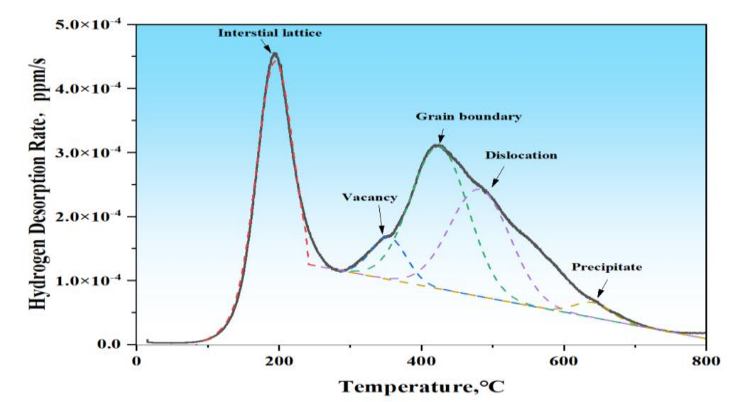
The Influence of T on H Permeation



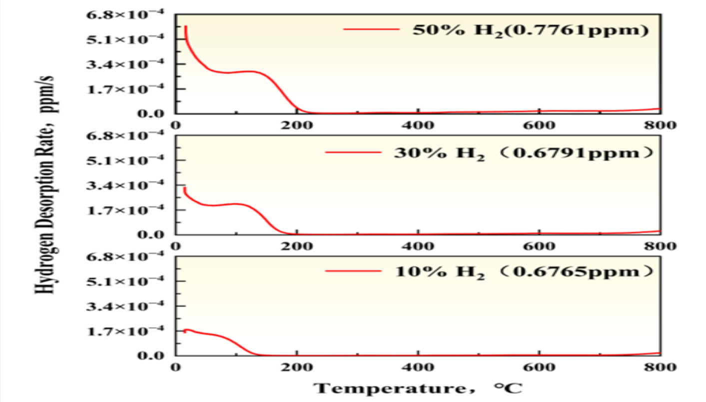
The Influence of H Blending Ratio on H Permeation

◻ Hydrogen Content

HTDS H Content Test System



TDS H Content Test Results



H Content in X80 under different percentage of H_2

OUTLINE

Case 1: Corrosion and Scale Inhibitors

Various problems encountered in oil and gas field

Foaming

Stratification

Poor Compatibility with other Additives

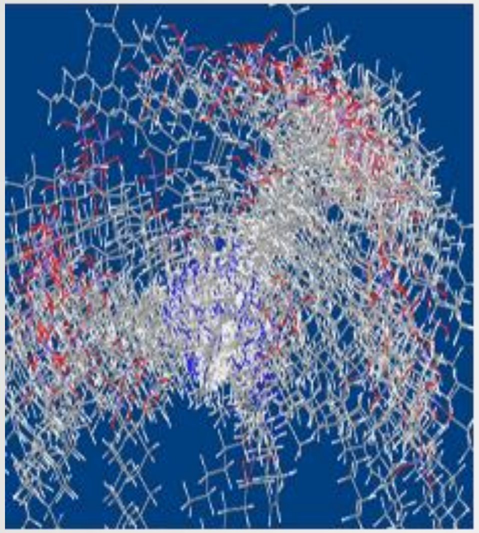
Poor Compatibility with MDEA

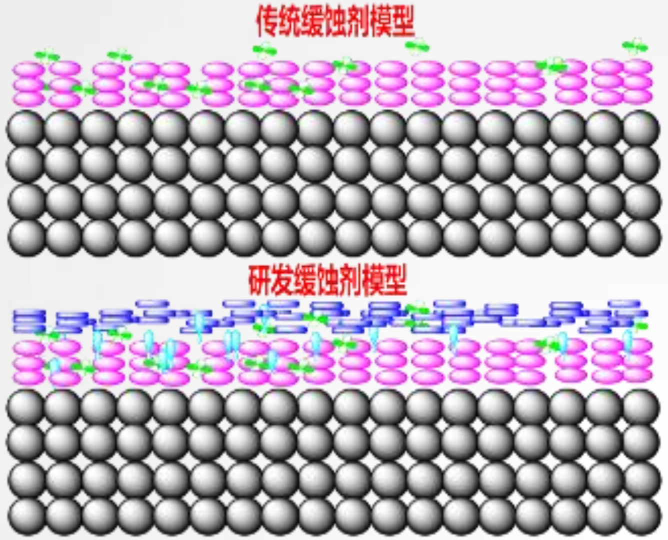
Poor Solubility

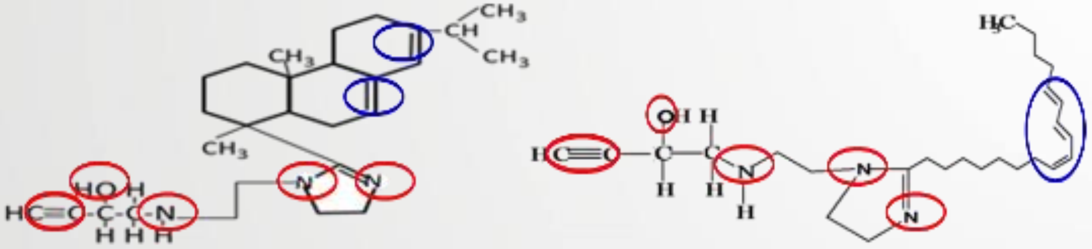
Inhibitor Type Mis-choose

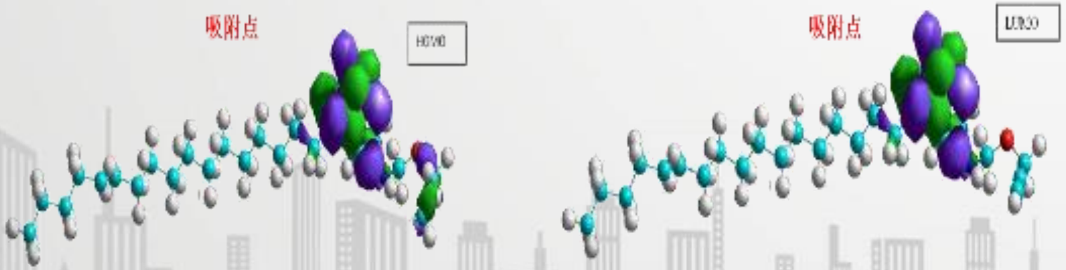
Case 1：Corrosion and Scale Inhibitors

□ Inhibitor molecular design and synthesis

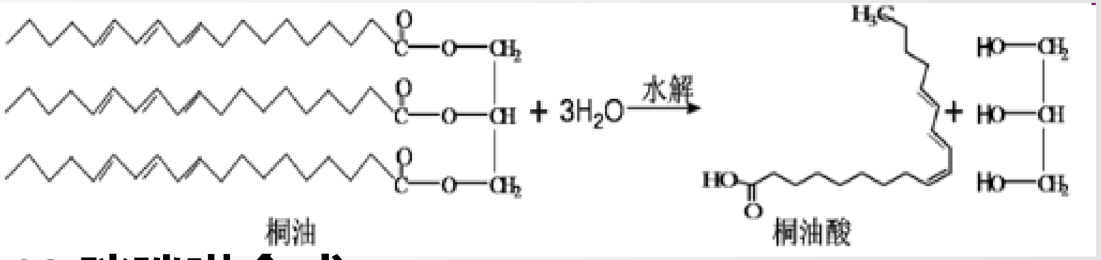




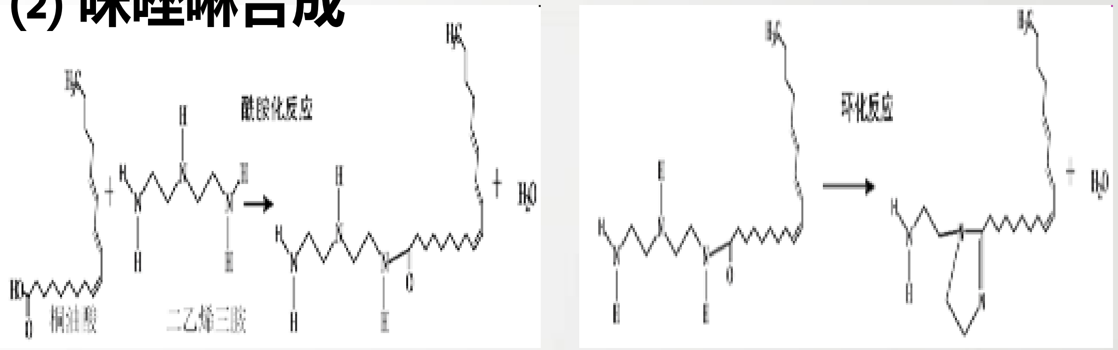




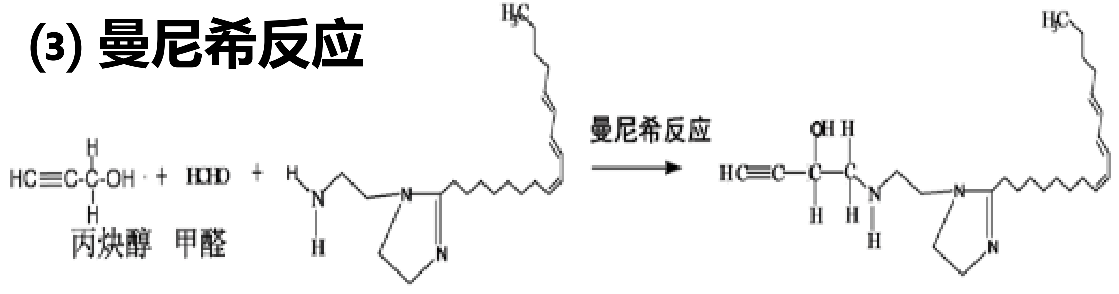
(1) 桐油水解



(2) 咪唑啉合成



(3) 曼尼希反应



Case 1: Corrosion and Scale Inhibitors

Inhibitor Types

Acidizing Inhibitor

TG200系列 井筒酸化缓蚀剂

主要的产品为TG201/TG201-II，从2007年开始使用，已经在塔里木油田应用10年，取得了良好的口碑和社会效应，钛合金缓蚀剂也是我们研发的一项重大成果

Gathering Pipeline Inhibitor (CO_2/H_2S/Cl^-)

TG500系列 地面集输缓蚀剂

主要产品有TG510、TG512、TG520、TG530，在今年的产品推广过程中，都取得了良好的效果，目前应用较多的是TG530

Downhole Tubing Inhibitor

TG700系列 油气井缓蚀剂

主要成果应用于中海油TG705，成功解决了气举过程中的连续油管断裂问题

Injection water Inhibitor (O_2 and SRB)

TG300系列 污水（注水）缓蚀剂

主要的产品型号为TG301，预计在2018年3月推广应用于塔里木油田

Ti Alloy Inhibitor

TG400系列 钛合金缓蚀剂

主要应用于钛合金油管在酸化作业过程，已在现场示范应用

Circulating Water Inhibitor

TG500系列 循环水系统缓蚀剂

主要应用于工业循环水系统，也可用于油气田联合站

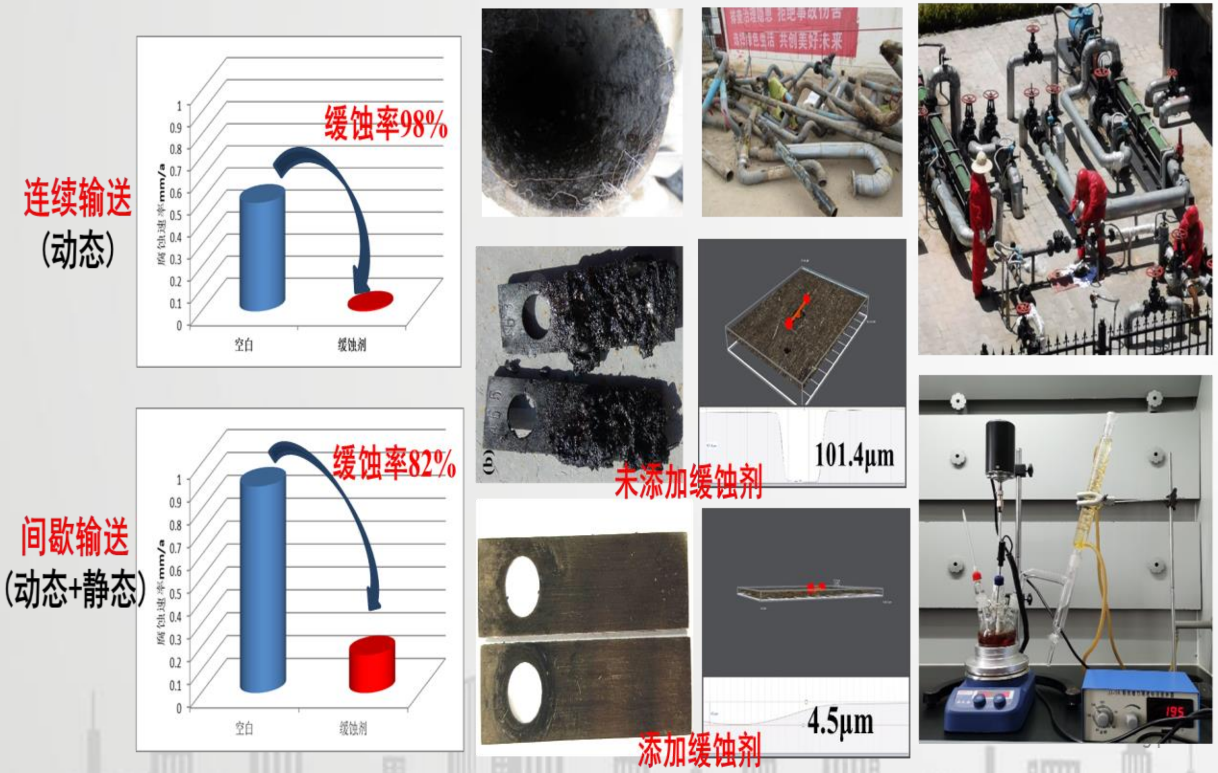
Refinery Inhibitor (High Temperature)

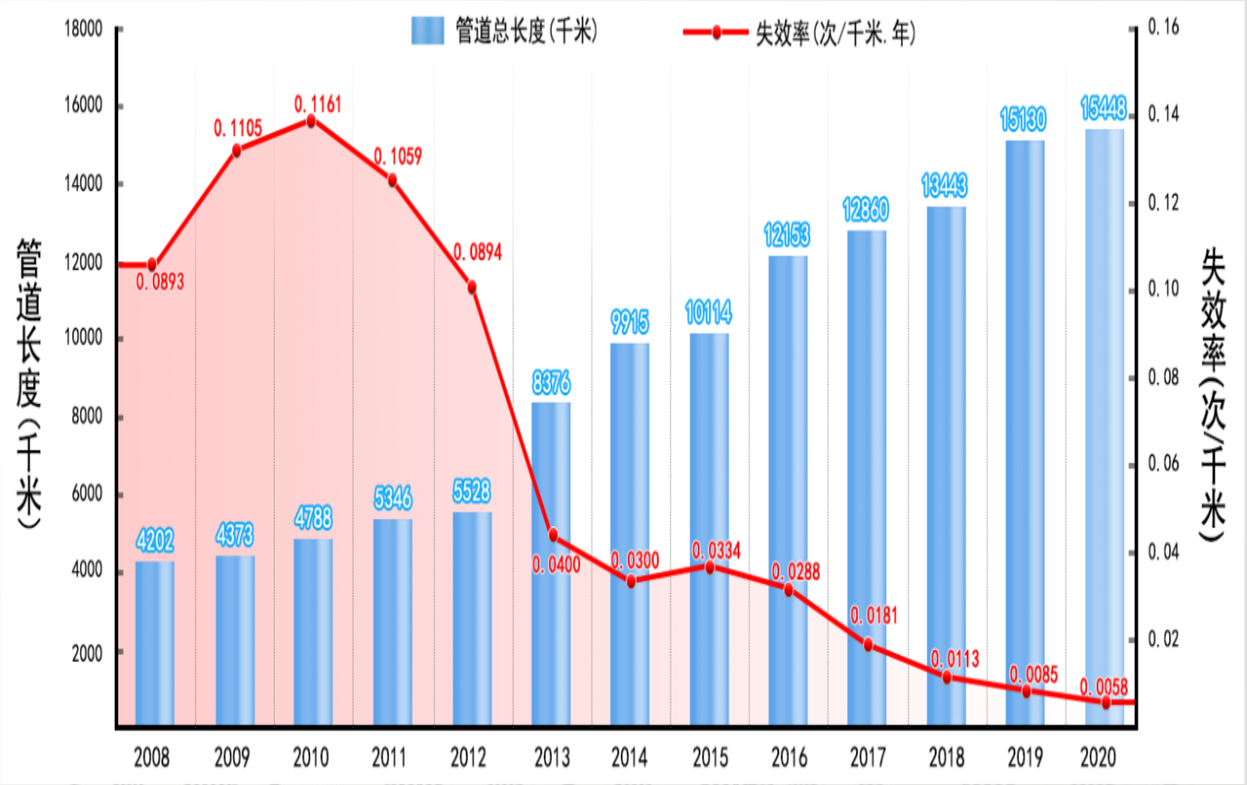
TG600 炼化用缓蚀剂

目前主要研发的产品只有常减压塔用缓蚀剂TG601，在长庆石化推广应用

Inhibitor Applications

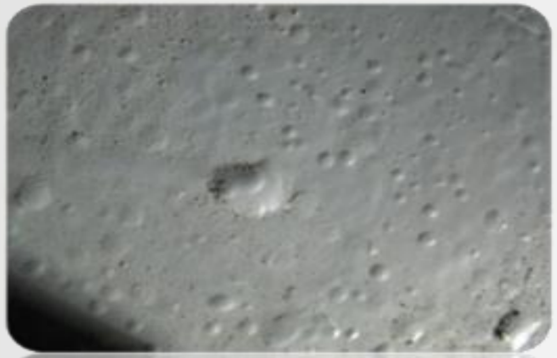
Various types of inhibitor have been applied in Tarim Oilfield, Changqing Oilfield, Qinghai Oilfield since 2007, over 400 oil & gas wells, and over 5000 km gathering pipelines.





Case 2: Room Temperature Curing Organic Coatings with No Solvent

□ Various problems encountered in oil and gas field

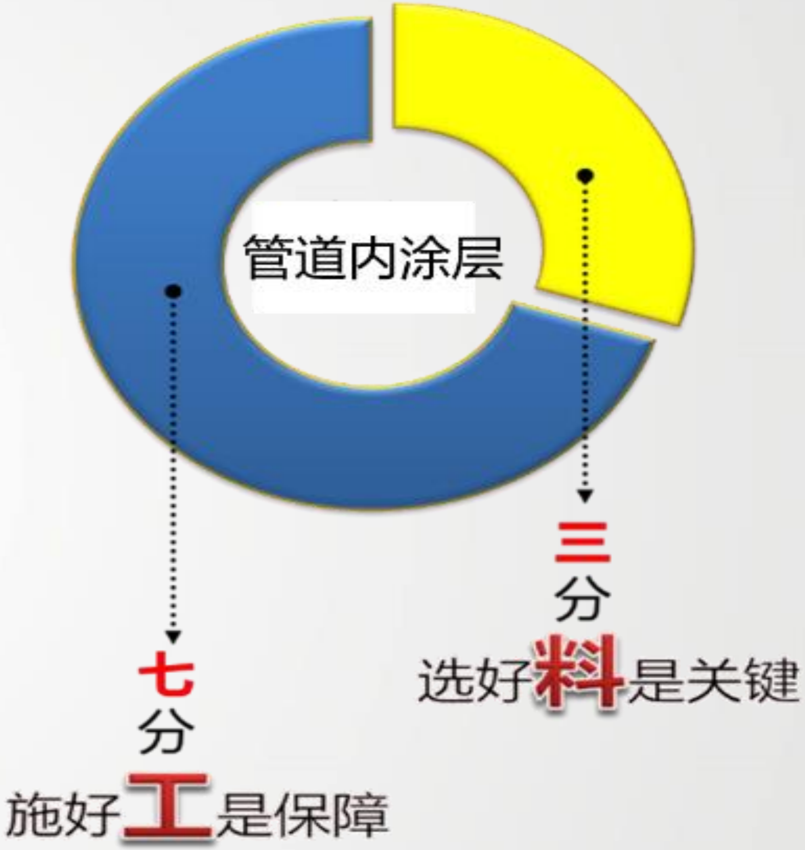


Blistering

Peeling off

Pinhole

Cracking

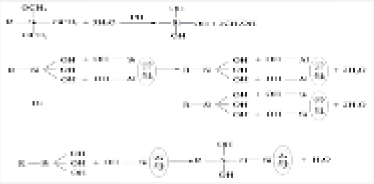


Room Temperature Curing→ Energy Saving (No Need Electric Heat)

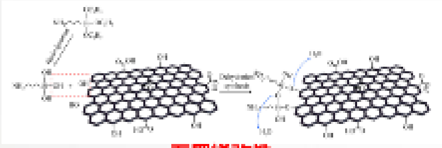
No Solvent→Environmental Friendly (No Toxic Chemicals)

Case 2: Room Temperature Curing Organic Coatings with No Solvent

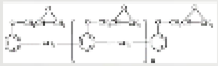
Coating Molecular Design and Synthesis



云母改性



石墨烯改性



酚醛环氧树脂分子结构 + 双酚A环氧树脂分子结构

有机硅接枝改性氨类固化剂

波数	2943	2841	1596	1460	1451	1261
基团	CH[illegible]	CH[illegible]	苯环（共轭环）			C-O-C
波数	1193	1130	1028	799	739	698
基团	N-H	脂肪C-N	N-H	C-H苯环间二取代	C-H苯环邻二取代	C-H苯环间二取代

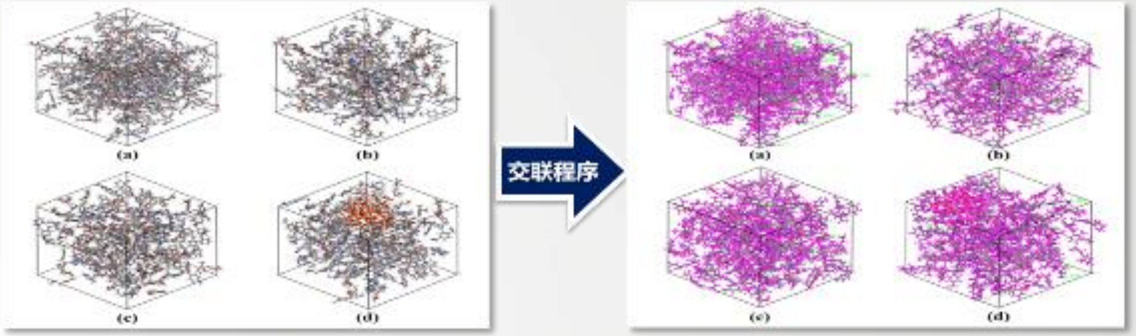
固化剂2020
为含有醚键的胺类固化剂

波数	3012	2925	2855	1602	1585	1487	1450
基团	-C=C-H	$-CH_2-$	$-CH_2-$	苯环骨架	苯环（共轭环）		
波数	1268	1167	1048	911	776	723	695
基团	芳香C-N	脂肪C-N	C-O-C	环氧基	C-H苯环间二取代		

稀释剂513
为含有苯环，醚键，C=C，环氧基的环氧稀释剂

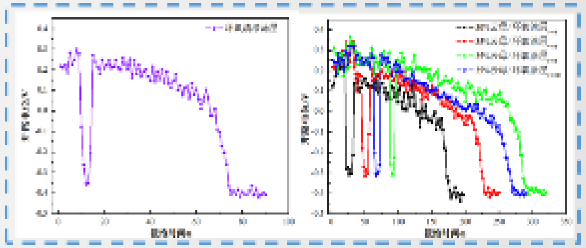
波数	2914	2847	1614	1517	1446	1574
基团	NH_2	CH[illegible]	苯环骨架			CH[illegible]
波数	1279	1076	898	832	784	700
基团	芳香C-N	脂肪C-N	C-H苯环间二取代			苯环单取代

固化剂MX1966
为含有苯环的胺类固化剂



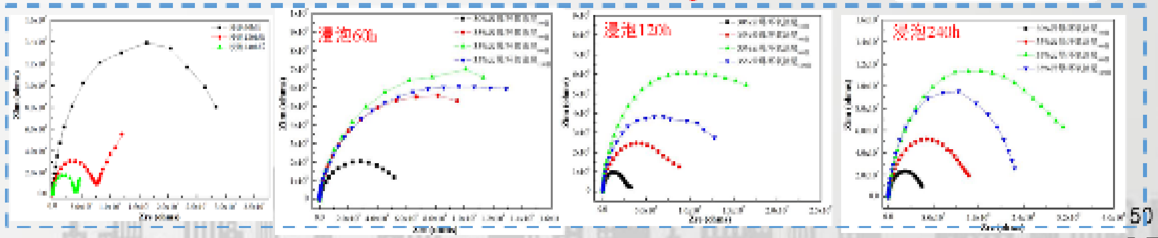
(a) ——双酚A型环氧树脂/固化剂I体系（双酚A环氧体系）
(b) ——酚醛型环氧树脂/固化剂I（酚醛环氧α体系）
(c) ——酚醛型环氧树脂/固化剂II（酚醛环氧β体系）
(d) ——填料/酚醛型环氧树脂/固化剂I复合材料体系（环氧复合材料体系）

- 添加云母/环氧涂层在各个阶段的起始时间要晚于环氧清漆涂层，说明云母/环氧涂层耐蚀性减弱的过程较为缓慢，涂层防护性能较好。
- 云母/环氧涂层的耐蚀性要强于于环氧清漆涂层。云母/环氧涂层中800目35%加量制备的云母/环氧涂层浸泡后涂层电阻Rc均高于其他组云母/环氧涂层。这表明涂层内填料的加入能够有效减缓涂层耐蚀性能减低，提升涂层对金属基体的防护能力，且合理匹配填料尺寸/含量可以使得涂层具备良好的耐蚀性。



交流阻抗

开路电位



Case 2：Room Temperature Curing Organic Coatings with No Solvent

Coating Lab Test and Spray

模拟长庆油田CO_2环境

试验条件	Cl- (mg/L)	CO_2分压 (MPa)	H_2S浓度 (MPa)	温度 (℃)
工况一	31877	0.8	0.5	90

模拟西南油气田H_2S-CO_2共存环境

试验条件	Cl- (mg/L)	CO_2分压 (MPa)	H_2S浓度 (MPa)	温度 (℃)
工况一	80059	1.2	0.35	120

HPHT Simulation Test

Coating Spray in Lab

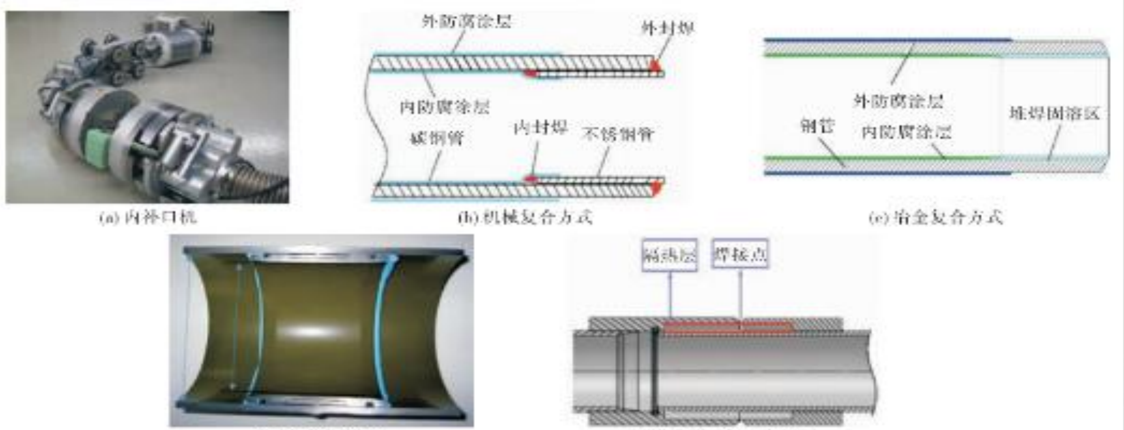
油管内涂层工厂预制设备

管道内涂层工厂预制设备

储罐内涂层现场喷涂设备

涂覆工艺流程：管材入厂 → 高温清洁 → 喷砂除锈 → 喷砂检测 → 内壁喷涂 → 静置放置 → 成品检测 → 标识打捆 → 成品发货

Coating Spray Process in Factory



(a) 内补口机

(b) 机械复合方式

(c) 冶金复合方式

Joint Design for Coated Line Pipes

Case 2: Room Temperature Curing Organic Coatings with No Solvent

☐ Coating Applications

Tanks and Vessels

压力容器、储罐内防腐

Gathering Pipelines

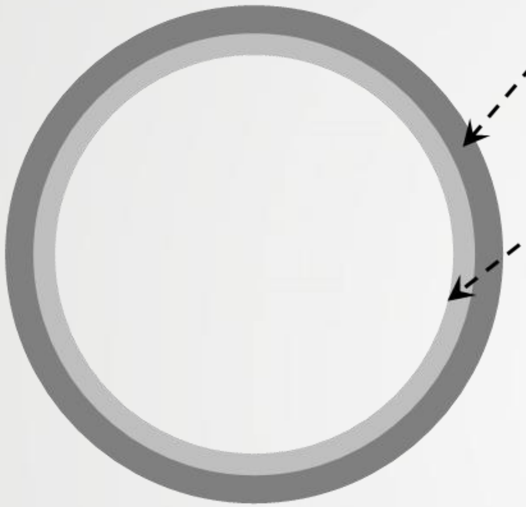
地面集输管道内防腐

Downhole Tubing/Casing

注水井、CO_2驱井油管内防腐

Case 3：Seamless Metallurgically Lined Pipe

◻ Two Types of Lined Pipe Used in Oil and Gas Field



- ■ 基管（Backing steel）
  - ● 碳钢或合金钢材料（Carbon steel or alloyed steel）
  - ● 机械性能（Mechanical properties）
- ■ 衬层/覆层（Lined/clad）
  - ● 耐蚀合金（CRA）
  - ● 耐蚀性能（Corrosion performance）
- ■ 复合方式（Composite type）
  - ● 机械复合（Lined: mechanical bond）
  - ● 冶金复合（Clad: metallurgical bond）

Mechanical Lined Pipe
衬里式复合管
（机械结合）

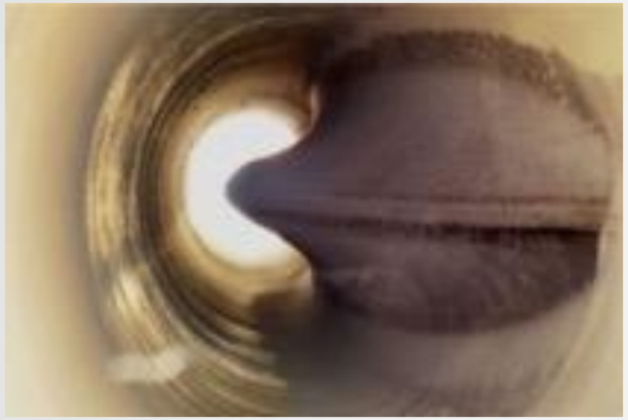
Metallurgically Clad Pipe
内覆式复合管
（冶金结合）

Case 3：Seamless Metallurgically Lined Pipe

□ The Failures of Mechanically Lined Pipe

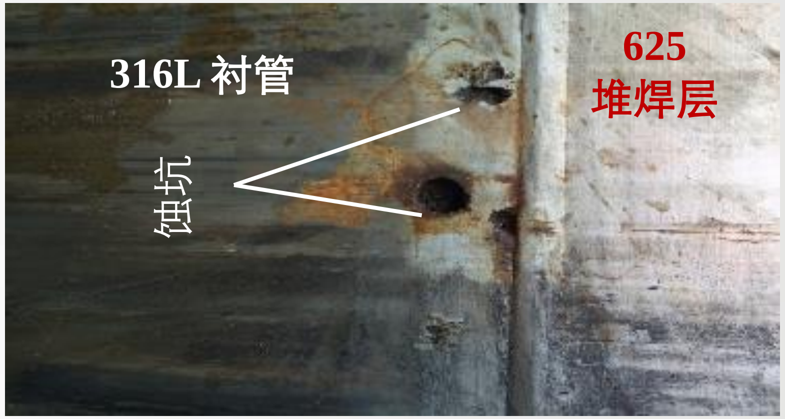
Onshore Oilfield
陆上油气田地面管道（中石油某油田）

Offshore Oilfield
海上油气田海底管道（中海油某油田）



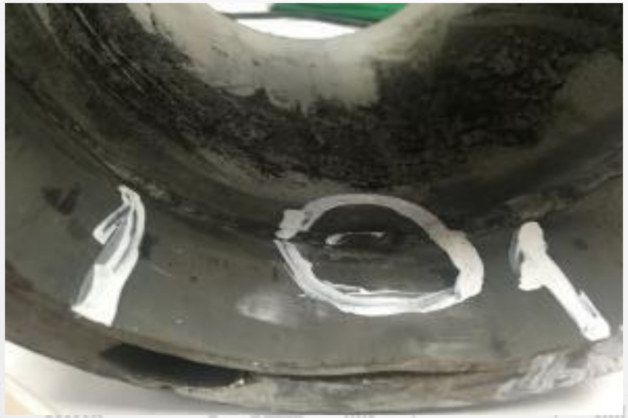
衬管鼓包 Liner Blister

衬管塌陷 Liner Collapse

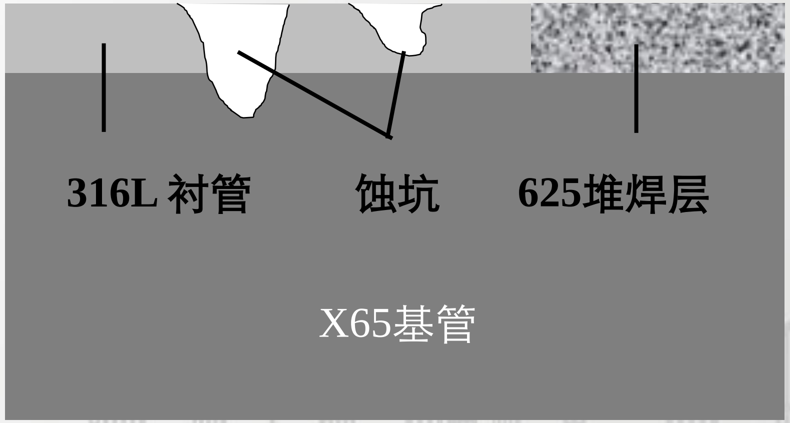


双金属复合海管失效实物图

焊缝开裂Weld Joint Cracking



焊缝腐蚀Weld Joint Corrosion



双金属复合海管失效示意图

Case 3: Seamless Metallurgically Lined Pipe

Manufacturing and Products

Carbon steel		Corrosion resistant alloy		Size	Standard	Application
K55 N80 R95 L80 C90 T95 C110 P110 P110SS	X42 X52 X46 X60 X65 X70 X80	Martensite	2Cr13、3Cr13、Super 13Cr etc	Diameter：Φ60.5mm~Φ406mm Thickness：4.24mm~31.75mm	API 5CT API 5L API 5LD GB 6369	Oil and gas drilling and production
		Austenite	304、304L、321、316L etc			
		Dual phase	2205、2507 etc			
		Nickel	825、G3 etc			


钻杆 Drill Pipe


油套管 Tubing/Casing

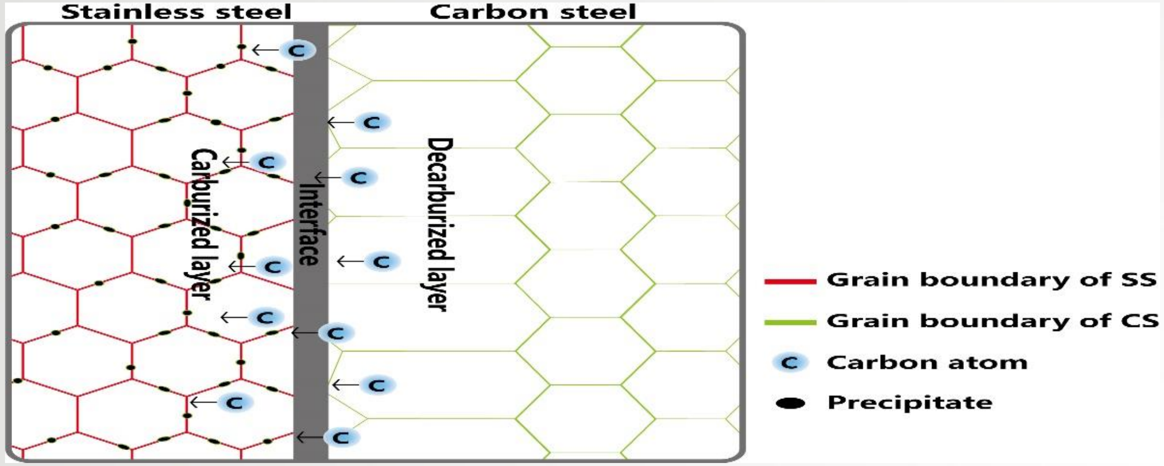

集输管 Gathering Pipe

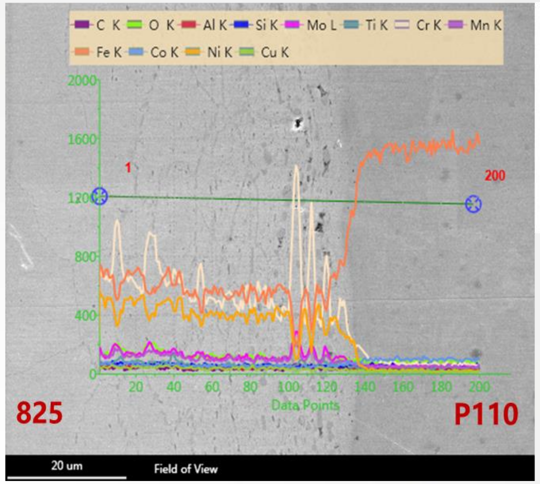

弯管　Bents

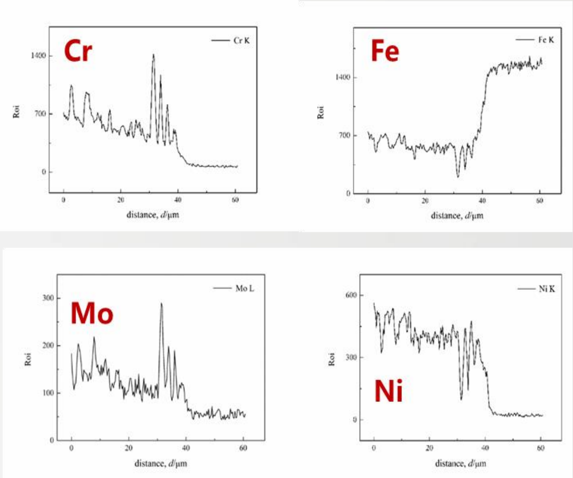

管件 Fittings

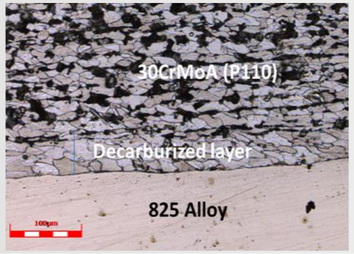
Case 3: Seamless Metallurgically Lined Pipe

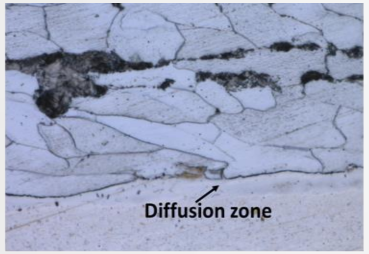
◻ Fundamental Research

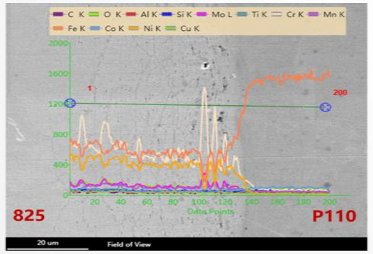


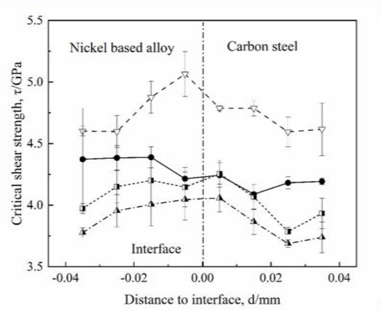


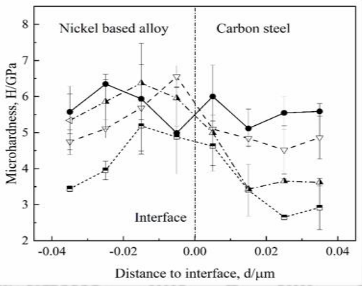


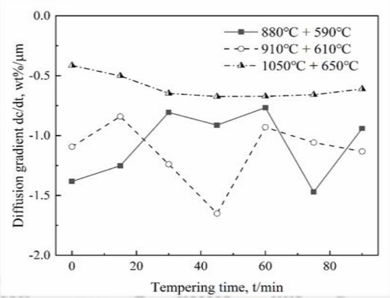


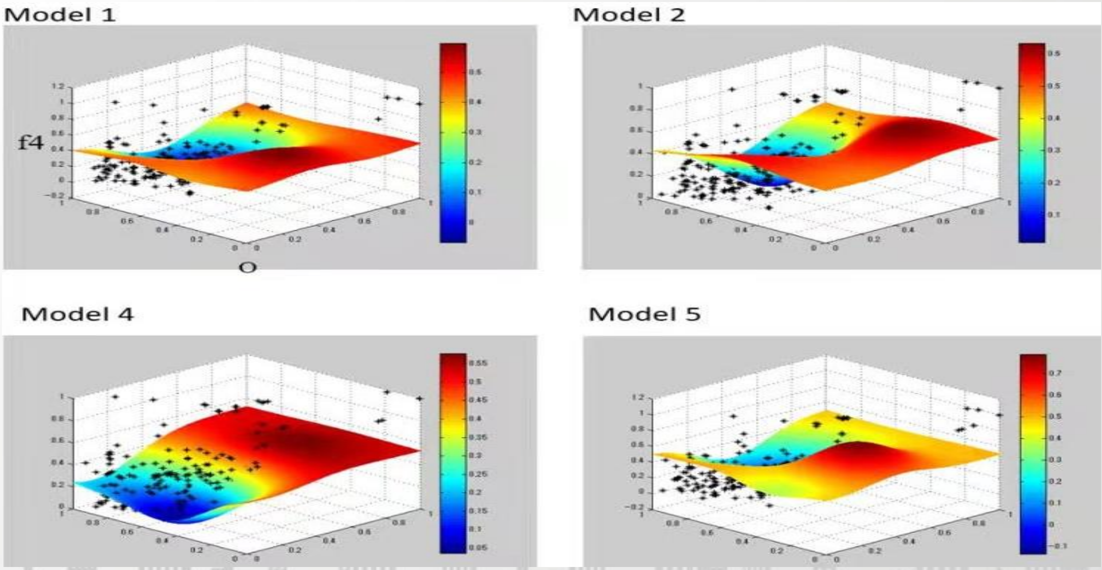












*Financially Supported by NSFC and CNPC

Case 3: Seamless Metallurgically Lined Pipe

Standard and Pilot project


INTERNATIONAL STANDARD ISO 24139-1

First edition 2022-11

Petroleum and natural gas industries — Corrosion resistant alloy clad bends and fittings for pipeline transportation system —

Part 1: Clad bends

Industries du pétrole et du gaz naturel — Coudes et raccords recouverts d'alliage résistant à la corrosion pour système de transport par conduites —

Partie 1: Coudes recouverts

Reference number ISO 24139-1:2022(E)

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INTERNATIONAL STANDARD ISO 24139-2

First edition 2023-02

Petroleum and natural gas industries — Corrosion resistant alloy clad bends and fittings for pipeline transportation system —

Part 2: Clad fittings

Industries du pétrole et du gaz naturel — Coudes et raccords recouverts d'alliage résistant à la corrosion pour système de transport par conduites —

Partie 2: Raccords recouverts

Reference number ISO 24139-2:2023(E)

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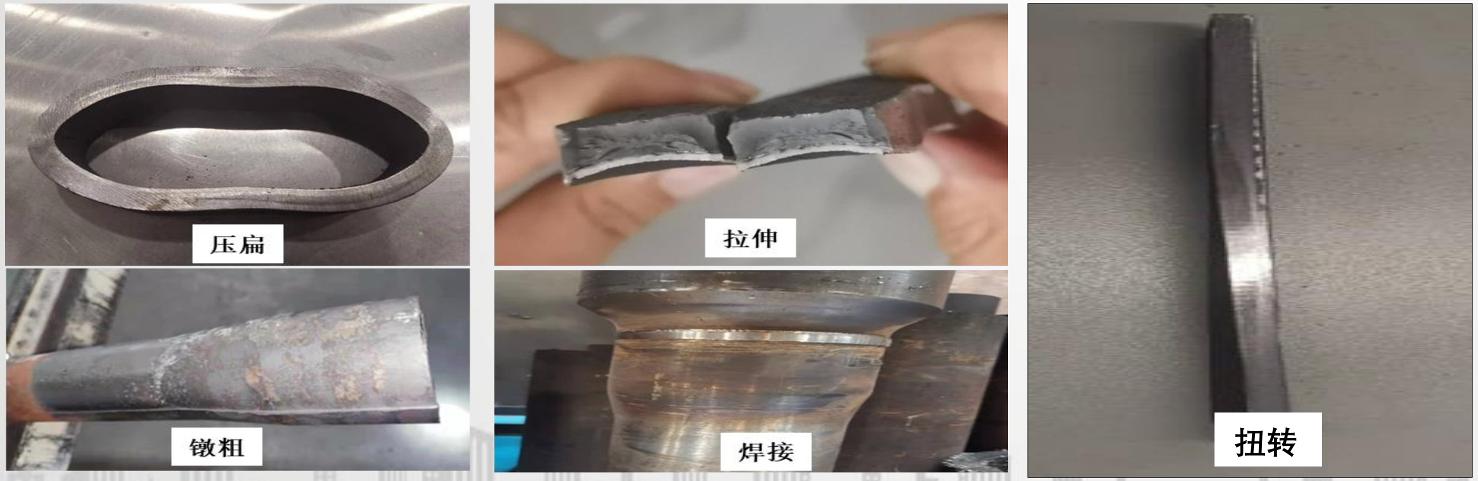
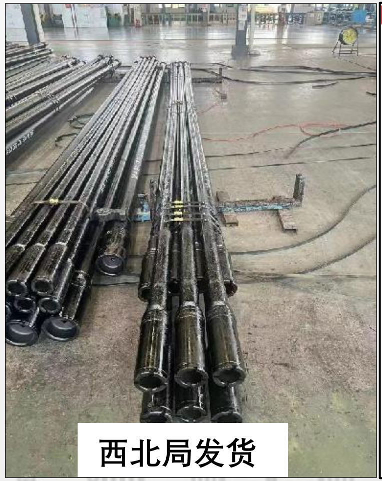
ISO Standards for MLP

Manufacturing, Lab Testing and Construction



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中国石油内网主站 > 企业要闻

工程材料研究院自主研制的国内首批
冶金无缝双金属复合钻杆成功生产

来源：工程材料研究院 | 日期：2023年7月31日 6:22 | 访问：5775 次

近日，由工程材料研究院自主研制的国内首批G105+316L冶金无缝双金属复合钻杆成功生产下线，将被用于新疆顺北区块8000米超深井开采，为我国万米深井勘探开发提供有力技术支撑。

在油气开采的过程中，钻杆在作业过程中可能会发生失效，其中腐蚀和腐蚀疲劳失效占到了钻杆失效的60%以上。常规的解决办法有两种：一是通过使用耐蚀材料的钻杆（铝合金/钛合金），但是耐蚀材料钻杆价格昂贵，经济效益差；二是钻杆内壁加入防腐内涂层，达到抑制腐蚀的效果，但是由于钻杆涂层为有机涂层，在深井特别是超深井下部高温、高压，高酸性环境下易发生剥落，因此造成钻杆使用寿命短，甚至容易引起钻头水眼、井下动力钻具（螺杆、涡轮）和随钻测井仪器故障。

针对这一难题，工程材料研究院自主创新研制了国内首个G105+316L冶金无缝双金属复合钻杆，即通过冶金复合制坯技术将钻杆外部的G105钢基体与内部的316L不锈钢耐蚀层结合，再通过热加工强化结合强度、冷加工成型，最后做热处理形成无缝双金属复合钻杆成品。

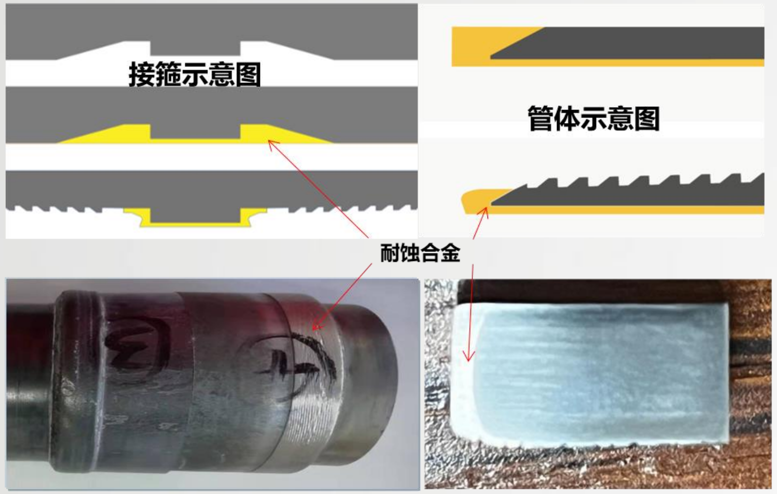
冶金无缝双金属复合钻杆成功解决了纯耐蚀材料钻杆价格昂贵和钻杆涂层高温易脱落的难题，并于2022年完成了完成钻杆试制工作的各项材料性能检测，试验结果取得预期效果，性能满足API Spec 5DP标准要求。研究成果已申报发明专利10项，含PCT国际专利2项。

此次成功生产下线的国内首批G105+316L冶金无缝双金属复合钻杆将被送往新疆顺北区块，试用于8000米深井开采，下一步将应用于10000米及更深的超深井，为助力我国深层、超深层油气资源油气勘探开发，保障国家能源安全贡献科技力量。

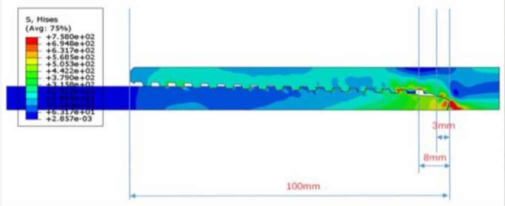
Drill Pipe (Thread Design and Machining) Applied in Sinopec Northwest Oilfield

Case 3: Seamless Metallurgically Lined Pipe

□ Standard and Pilot project



特殊扣开发总体方案及样品



应力分析


试验短节

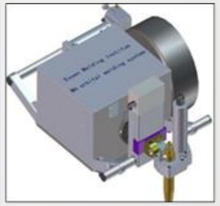
Tubing and Casing (Thread Design and Machining) Applied in Changqing Oilfield

试点管材	试点区域	规格	工程量	介质	压力	流量
L245N+316L 冶金复合管	采油一厂/杏十转	Φ159×(5+1.5) mm	1.6 km	65%含水油	2.5 MPa	1250 m³/d
	采油十一厂/镇37增	Φ89×(4.5+1.5) mm	1.6 km	32%含水油	3.0 MPa	280 m³/d


一厂试验段（志丹县、Y001桩~Y032桩）


十一厂试验段（镇原县、Y098桩~Y134桩）


现场焊接


多用MIG自动焊接接头

R450专用电源


双面齿轮导轨


焊接机器人


内对口器及充氩装置

Gathering Pipeline (Joint Design and Welding) Applied in Changqing Oilfield

OUTLINE

Challenges for Corrosion and Protection in Oil & Gas Industry

Challenge 1: The prerequisite of corrosion protection in oil and gas industry, economically acceptable is the first priority, and then technically requiring the corrosion resistance as high as it can be.

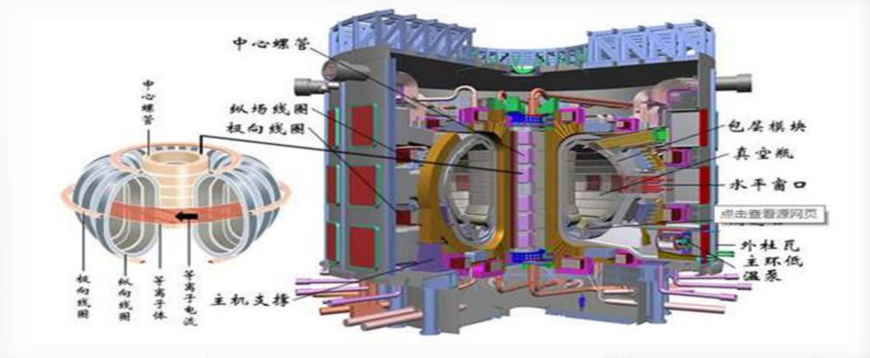
Oil and Gas Industry

≠

≠

Aerospace Industry

Nuclear Industry



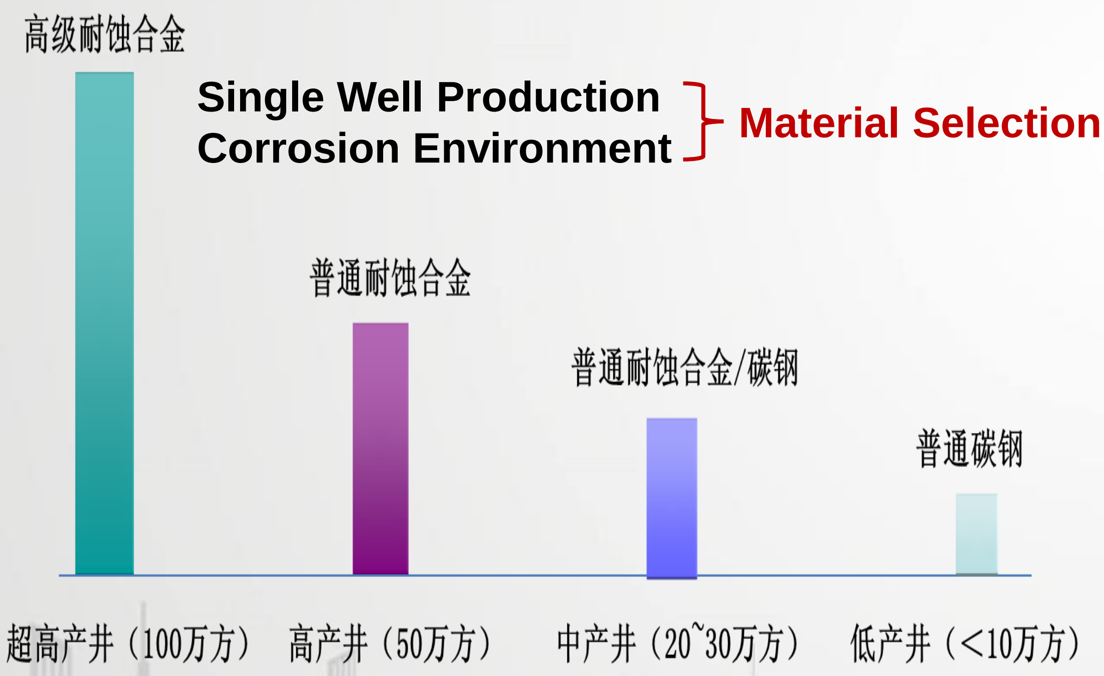
Money is indeed a problem

Money is not a big problem

Challenges for Corrosion and Protection in Oil & Gas Industry

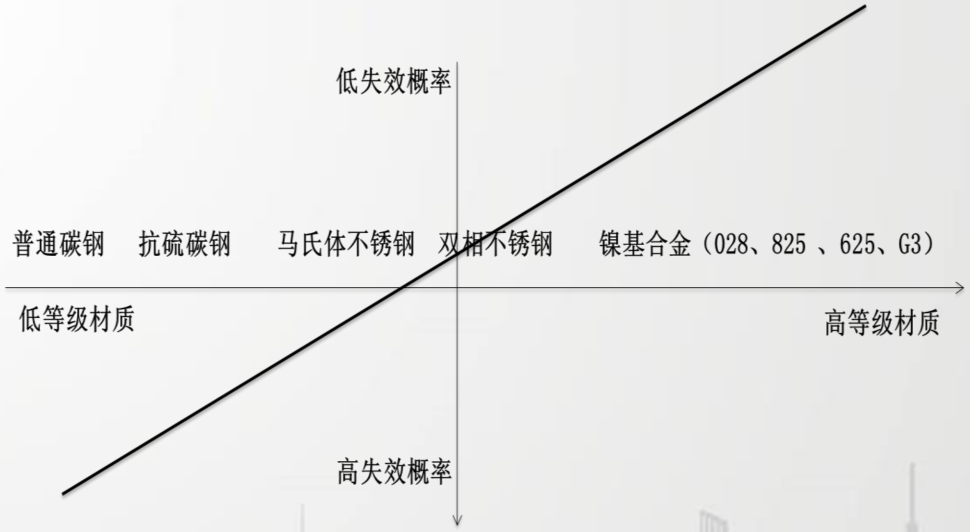
Challenge 2: The balance between cost and performance (Corrosion Resistance)

Carbon Steel	Austenite/Martensite Stainless Steel	Duplex Stainless Steel	CRAs
8~10 thousand RMB/ton	30~50 thousand RMB/ton	100~150 thousand RMB/ton	200~400 thousand RMB/ton



Input and output ratio

- 方案一：建井开始选用低等级管材，综合成本为：管材成本+维修费×失效次数+影响产量；
- 方案二：建井开始选用合适的高等级管材，综合成本为：管材成本。



Material Selection ~ Failure Probability

Challenges for Corrosion and Protection in Oil & Gas Industry

Challenge 3: The discrepancy between lab test and field application

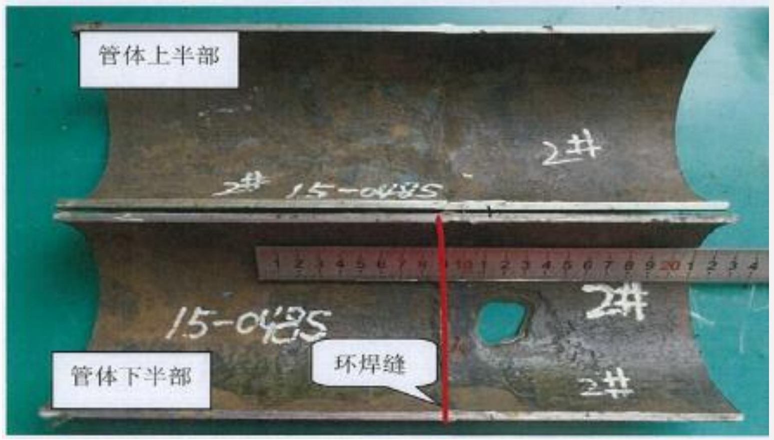
Lab Simulation Test

Slight with no localized corrosion

≠

NO SCC happened

Field Application



Severe localized corrosion

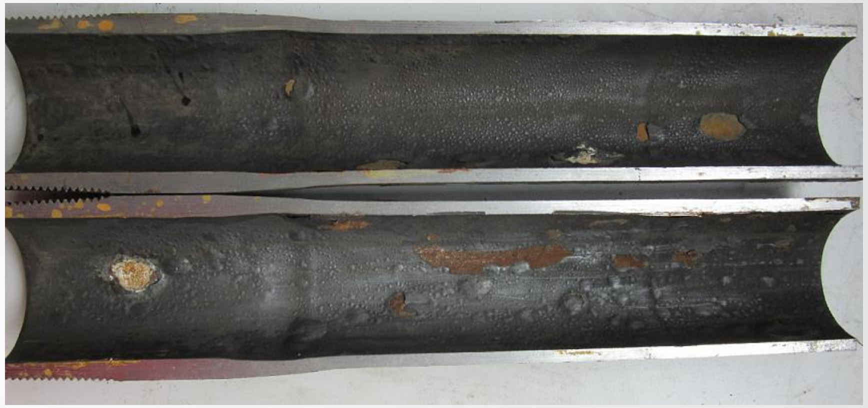
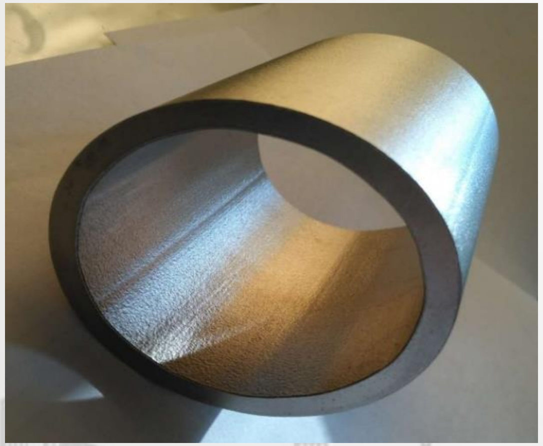
≠

SCC happened

Influencing factors

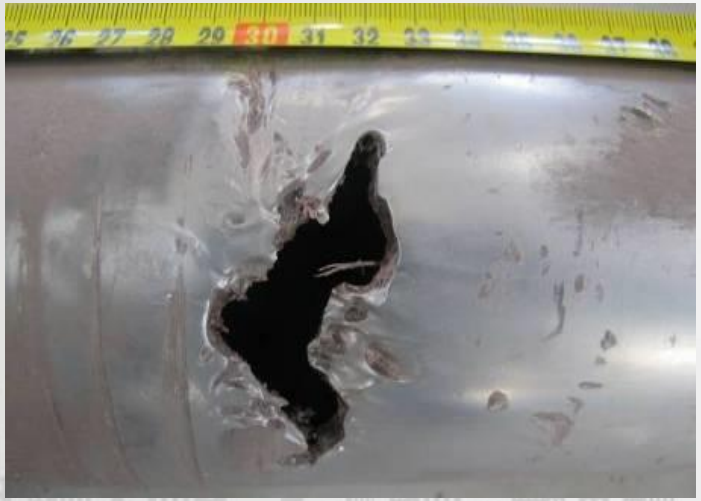
- Coupon surface state
- Sample geometry and structure
- Flow pattern
- Load/stress condition
- Liquid and gaseous fluid
- CO2/H2S partial Pressure
- Macro/Micro Defects
- Test methods and facilities

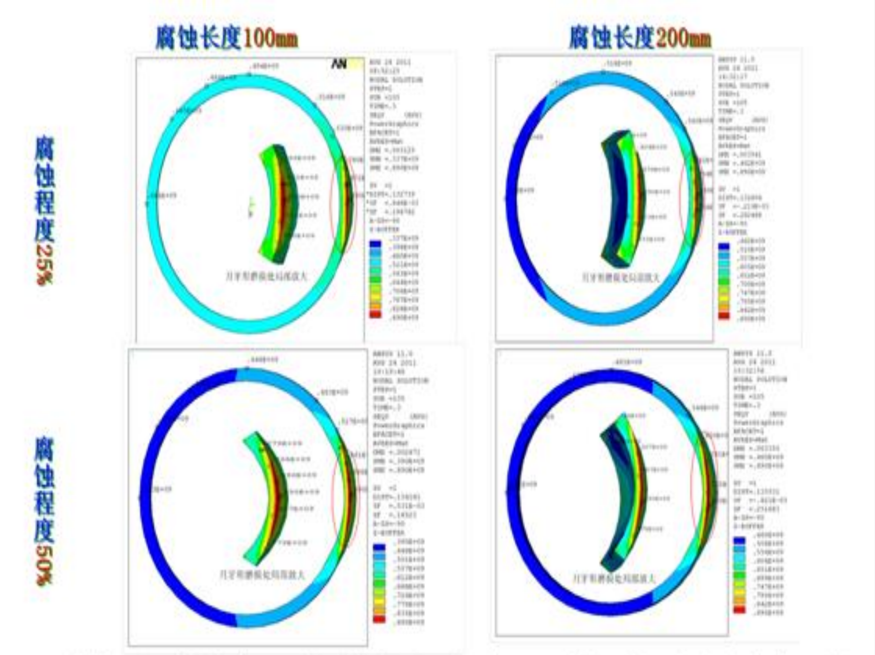
Challenge 4: How to improve the long-lasting corrosion resistance of coatings

	Before Use		Service After Certain Time
Organic Coating		→	
Metallic Coating		→	

Challenges for Corrosion and Protection in Oil & Gas Industry

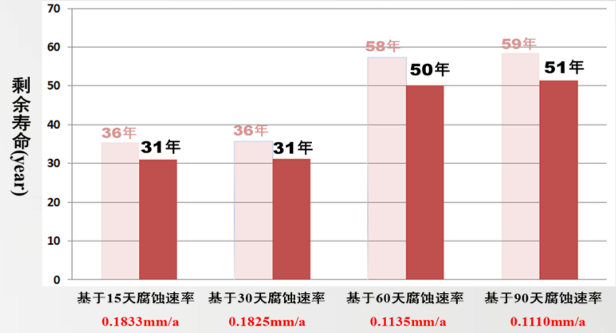
Challenge 5: How to improve the accuracy of the remaining life prediction



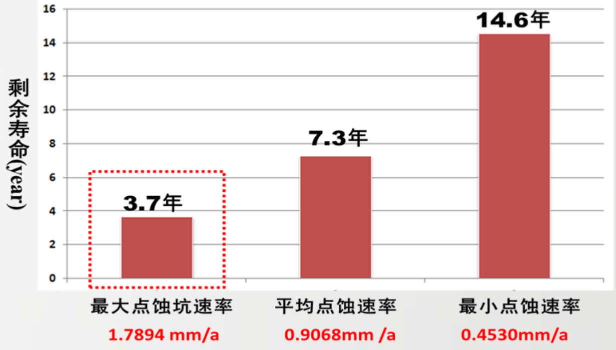


套管不同腐蚀度，受拉伸作用下内壁屈服破坏时应力分布与变形图

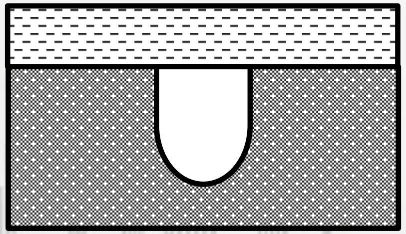
基于均匀腐蚀速率剩余寿命



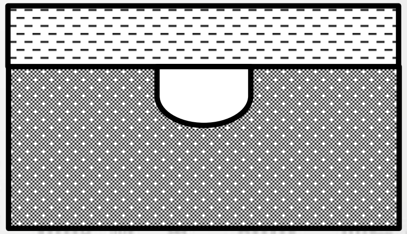
基于局部腐蚀速率剩余寿命



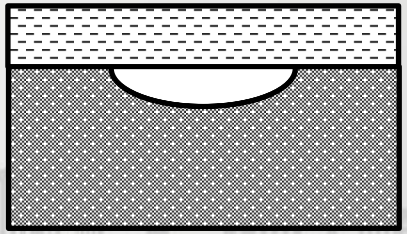
Model 1



Model 2



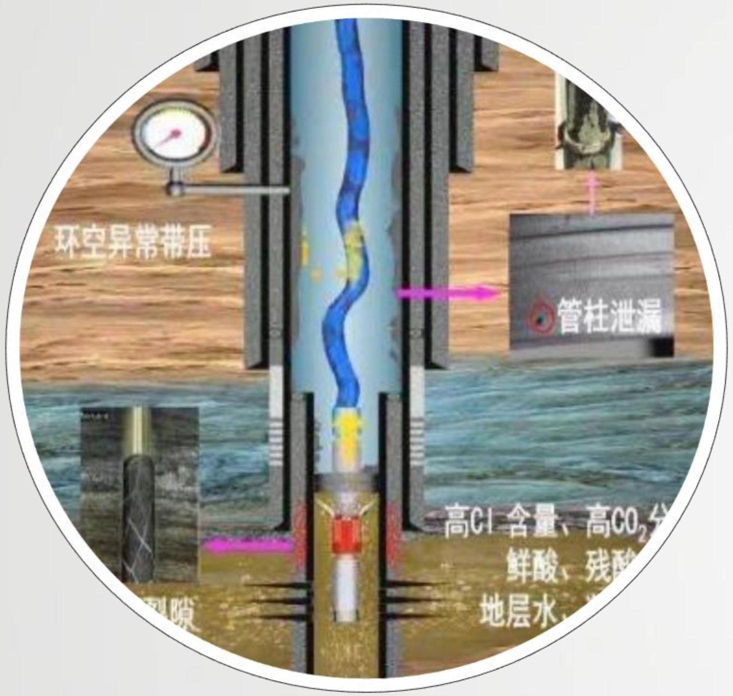
Model 3



OUTLINE

The Mission of CNPC TGRI Corrosion Research Team

The Doctor of Oil & Gas Facilities: Protect the tubing/casing, pipeline, tanks and vessels from corrosion



Tubing and Casing
(Vertical to ground)

Pipeline
(Parallel to ground)

Tanks and Vessels

Five Things 五件事

1 Why corrosion occur?	1	腐蚀机理	为什么发生腐蚀? 腐蚀原因
2 How to investigate corrosion?	2	腐蚀方法	如何研究腐蚀? 腐蚀规律
3 How to prevention before corrosion?	3	防腐产品	未腐蚀如何预防? 防腐措施
4 How to inspect or monitor corrosion?	4	腐蚀检测	如何掌握腐蚀程度? 腐蚀检测
5 what mitigation should be done to reduce corrosion?	5	腐蚀治理	腐蚀发生了如何办? 腐蚀治理

The Corrosion Research Methodology of CNPC TGRI Corrosion Research Team

Small Scale Coupon Screening Test

Full Scale Tubular Coupon Test for fitness-for-service

Field Pilot Test for Approve

小试样筛选 → 全尺寸适应性评价 → 现场试验段验证

The Member of CNPC TGRI Corrosion Research Team

- 35 Employees
- 17 PhDs
- 9 Research Teams

加拿大卡尔加里大学
博士，团队带头人

University of Calgary, Canada
PhD, Director

日本九州大学
博士，氢能材料

Kyushu University, Japan
PhD, H_2 Material

日本东北大学
博士，氢能材料

Tohoku University, Japan
PhD, H_2 Material

北京大学
博士，药剂研发

Peking University
PhD, Chemicals R&D

中科院金属所
博士，微生物腐蚀

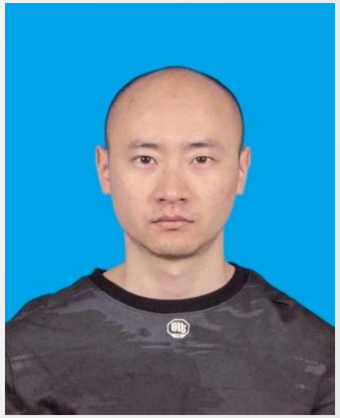
Institute of Metal Research, Academia Sinica, PhD, MIC

中科院金属所
博士，分子计算

Institute of Metal Research, Academia Sinica, PhD, DFT

西安交通大学
博士，涂层材料

Xian Jiaotong University
PhD, Erosion-Corrosion



西安交通大学
博士，氢能材料

Xian Jiaotong University
PhD, H_2 Material

西安交通大学
博士，现场服务

Xian Jiaotong University
PhD, Technical Service

The Member of CNPC TGRI Corrosion Research Team

1 Oil and Gas Field Corrosion Team

2 Pipeline Corrosion Team

3 Refinery Corrosion Team

4 MIC Corrosion Team

5 Chemicals R&D Team

6 Coating R&D Team

7 H2 Material Team

8 CCUS Corrosion Team

9 Technician Team

西北工业大学
博士，金刚石材料

Northwestern Polytechnical University, PhD, Advanced Coating R&D

北京航空航天大学
博士，炼化腐蚀

Beijing University of Aeronautics and Astronautics, PhD, Refinery Corrosion

哈尔滨工业大学
博士，油田腐蚀

Harbin Institute of Technology, PhD, Oil and Gas Field Corrosion

厦门大学
博士，油气田腐蚀

Xiamen University, PhD, Oil and Gas Field Corrosion

中国石油大学
博士在读，复合材料

China Petroleum University, PhD, Composite Pipe

哈尔滨工程大学
博士，油田腐蚀

Harbin Engineering University, PhD, Oil and Gas Field Corrosion

长安大学
博士，涂料研发

Changan University, PhD, Coating R&D

西安交通大学
博士，涂料研发

Xian Jiaotong University, PhD, Coating R&D

The Research Areas of CNPC TGRI Corrosion Research Team

Corrosion and Protection of Downhole Tubing and Casing

油气田井下油/套管腐蚀行为及完整性管理技术

- 管材腐蚀失效分析及预测预防技术
- 油套管柱选材及腐蚀完整性技术
- 油套管再制造和智能修复技术开发应用
- 油井管柱内涂/镀层开发及研究
- 油井管柱开发及推广应用
- 油井管柱经济型耐蚀合金开发及应用

Corrosion and Protection of Gathering and Transmission Pipeline

油气集输及长输管道腐蚀与控制技术研究

- 油气输送管道腐蚀预测、腐蚀监测和防腐工程技术
- 油田集输管网的腐蚀监测技术研究和腐蚀监控系统软硬件开发
- 长输管线杂散电流腐蚀及治理技术研究、土壤应力腐蚀开裂行为研究
- 不同防腐蚀技术经济性评估及防腐综合治理技术
- 管道外防腐层检测评价及阴极保护技术

四大领域

Corrosion and Protection of Refinery Pipeline and Equipment

石油炼制过程中设备的腐蚀行为研究与评价技术

- 炼化管道及装置失效分析及预测预防技术、腐蚀行为及机理、选材及适用性评价技术
- 不同防腐蚀技术经济性评估及防腐综合治理技术
- 加氢系统氢损伤机理研究
- 典型承压设备概率风险评价技术
- 炼化管道及装置防腐/防垢缓蚀剂、涂/镀层技术以及新型复合材料开发及应用

Corrosion and Protection of Unconventional and New Energy

非常规油气和新能源开发腐蚀机理及防治措施研究

- CCUS腐蚀机理研究及风险评估
- 氢环境腐蚀机理研究
- 注水、CO_2、空气、N_2、多元热流体井筒腐蚀评价及治理技术
- 页岩气H_2S、CO_2、细菌腐蚀行为与机理研究
- 经济型耐蚀-抗菌管材开发
- 煤层气管道腐蚀预测及控制技术

The Facilities of CNPC TGRI Corrosion Research Team

1. Autoclave

Autoclave Cortest, USA，5 Sets)

70MPa/350℃/H_2S/CO_2/5m/s

Autoclave（Dalian, China，15 Sets)

30MPa/250℃/H_2S/CO_2/3m/s

Twined-Autoclave（Dalian, China，1 Set)

30MPa/250℃/H_2S/CO_2/3m/s

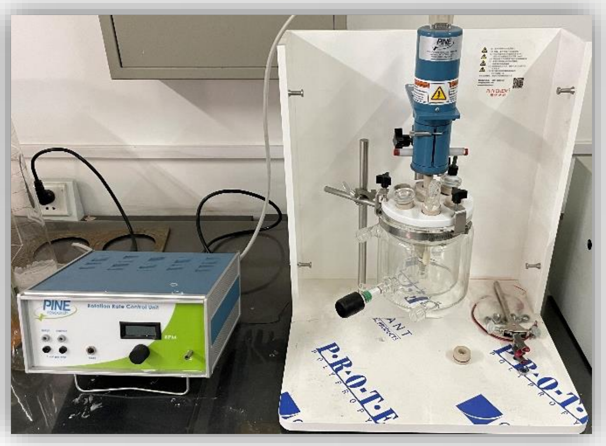
- Autoclave(650℃/70MPa/$H_2S+CO_2+H_2$): Underground Coal Gasification, Shale oil In-situ Transformation, heavy oil thermal recovery, etc.
- Autoclave(-50 ℃~300 ℃/70MPa/H_2S+CO_2): CCUS-CO_2 Pipeline, Tubing, Rubber sealing.

The Facilities of CNPC TGRI Corrosion Research Team

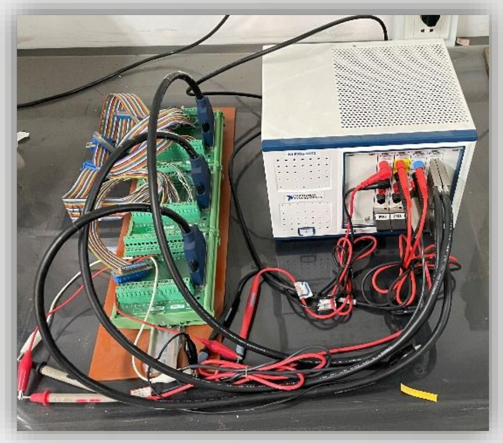
2. Electrochemistry Workstation

High Pressure High Temperature Electrochemistry Workstation


Micro-Scanning Electrochemistry Workstation



Rotating Disk Electrode


Array Electrode

Facility	TYPE	SETS	CAPACITY
Tradition Electrochemistry Workstation	Princeton P4000A、Wuhan Cortest	5	OCP, Polarization, Potentiostat, EIS, etc.
Micro-Scanning Electrochemistry Workstation	VersaSCAN	1	SVET, SCEM, LEIS, SKP
Rotating Disk Electrode	Pine	1	50~10000rpm
High Pressure High Temperature Electrochemistry Workstation	Princeton P4000A+CroTest Autocalve	1	OCP, Polarization, Potentiostat, EIS, etc. Under 0~35MPa, 0~350℃
Array Electrode	/	1	1~1000Hz

3. SCC Test Facilities

The List of All the SCC Test Facilities

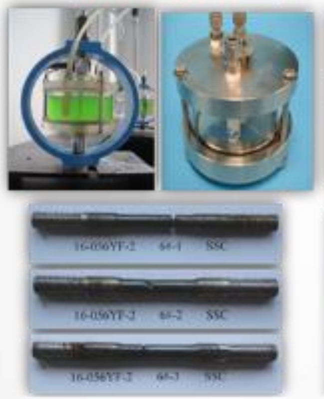
【石油管材应力腐蚀实验装备】

分类	设备名称及能力	数量
静态加载装置	应力环系统	45套
	四点弯曲、C型环、双悬臂梁夹具	120套
	高温高压应力环系统	3套
	高温氯化物应力环系统	3套
动态加载装置	慢应变速率腐蚀拉伸试验系统	1台
	高温电子蠕变持久松弛试验机	2台
	含H_2S实物拉伸应力腐蚀试验系统	1套
	实物拉伸应力腐蚀试验系统	1套
其他装置	氢环境服役模拟评价系统	1套
	O_2+H_2S环境的应力腐蚀测试装置	5套
	氯化镁应力腐蚀测试装置	6套
	裂纹扩展测试装置（DCPD）	16套

Room Temperature and Atmospheric Pressure Test

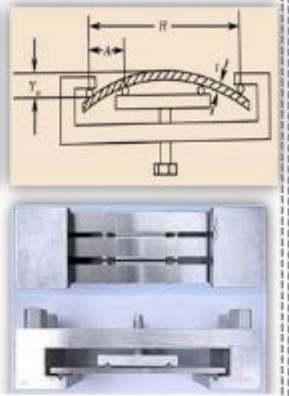
【常温常压SCC实验装置】

A法：应力环



应力环法

B法：四点弯

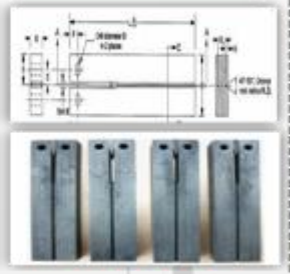


四点弯曲法

C法：C形环

C型环法

D法：双悬臂梁



双悬臂梁法

High Temperature and High Pressure Test

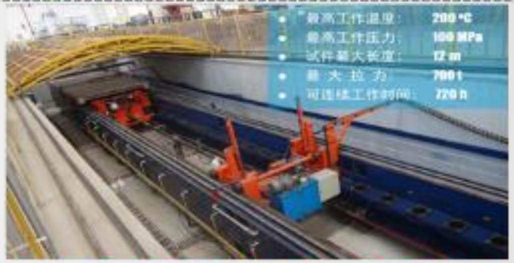
【高温高压SCC实验装置】

高温高压慢拉伸法

高温高压应力环法

Full-Scale Tubing/Pipe Test

【全尺寸SCC实验装置】



全尺寸高温高压CO_2应力腐蚀

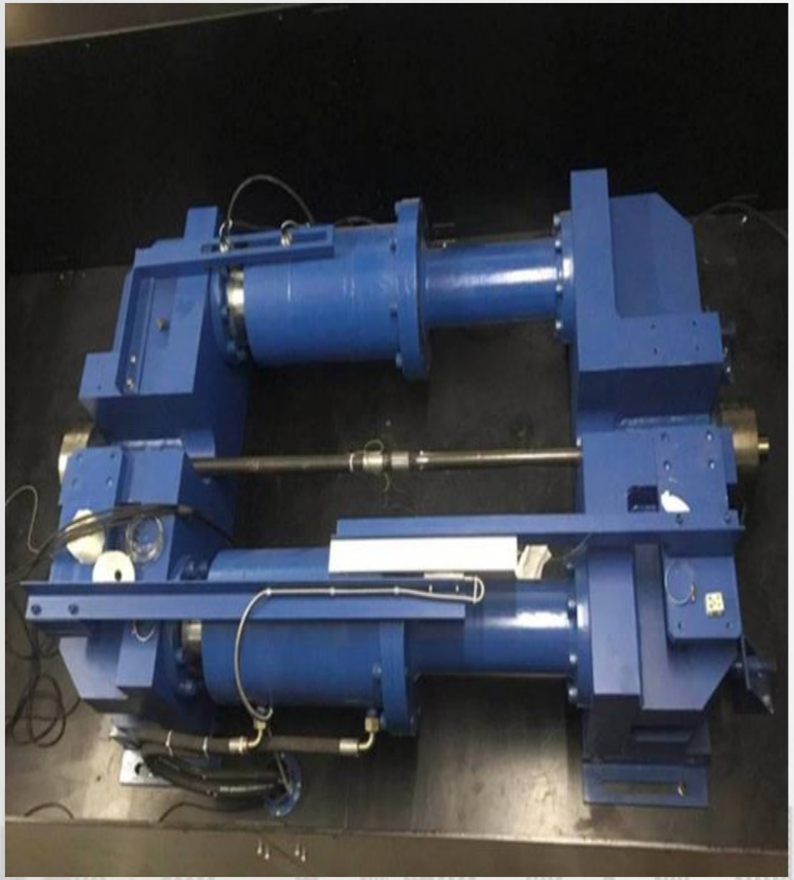
全尺寸高温高压H_2S应力腐蚀

全尺寸椭圆环H_2S应力腐蚀

The Facilities of CNPC TGRI Corrosion Research Team

3. Full-Scale Tubing SCC Test Facilities

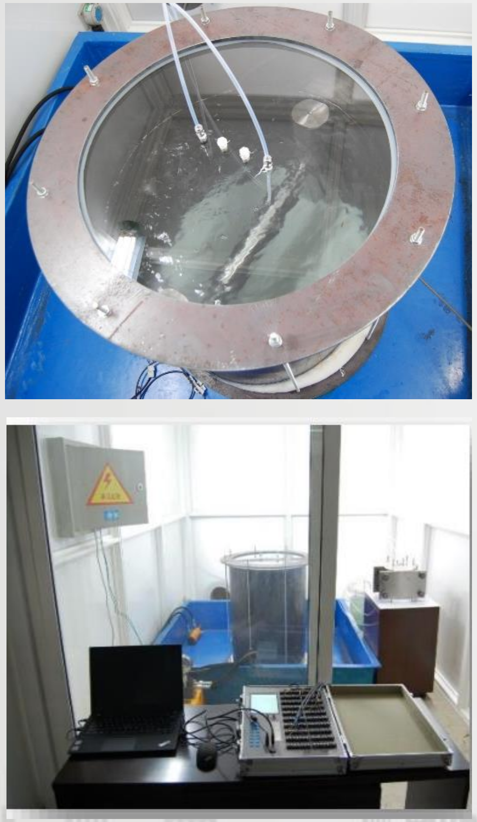
The full-scale tubing SCC test method has been approved as the AMPP Standard.



The Facilities of CNPC TGRI Corrosion Research Team

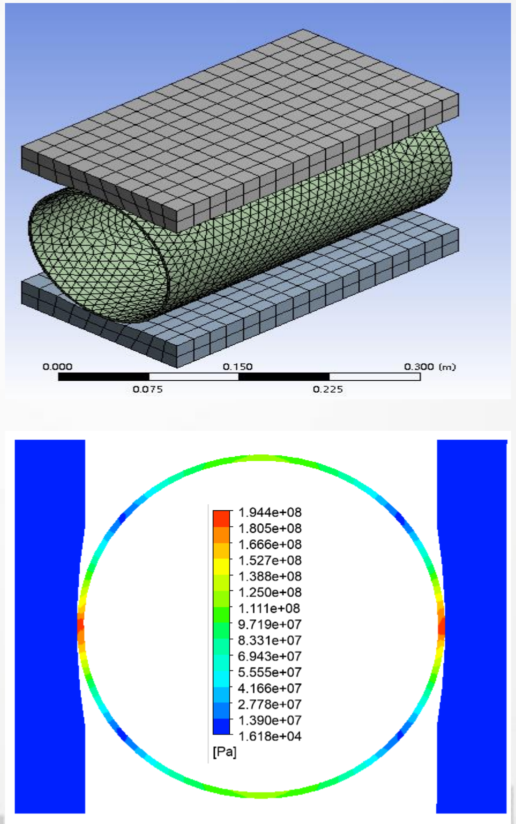
3. Full Ring Ovalization SCC Test Facilities

The Determination of the susceptibility to cracking of line pipe in sour service-Full ring ovalization test method has been approved as the China National Standard.

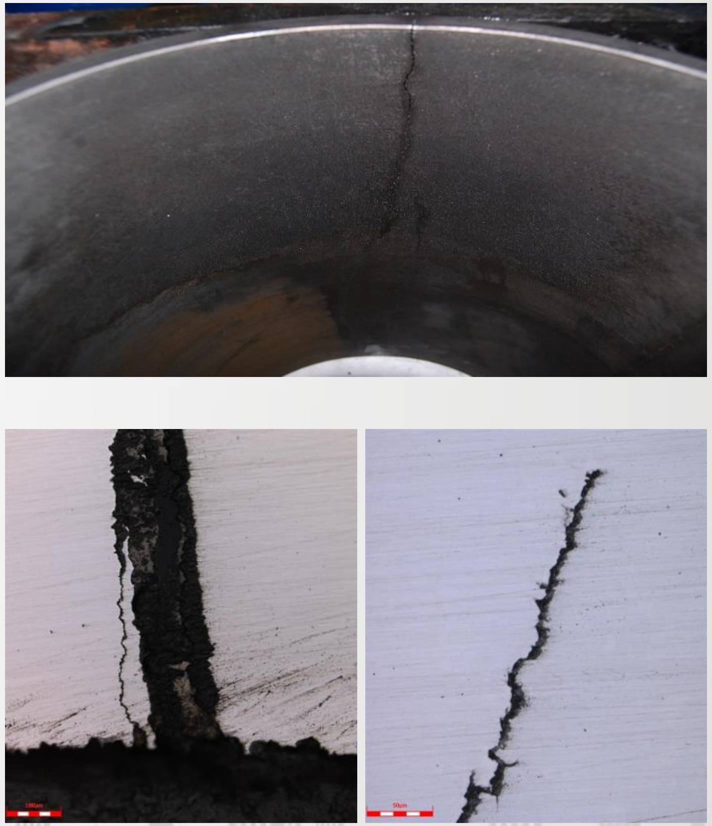


Large Diameter Pipe

Small Diameter Pipe



Stress FE Simulation



Cracking Characterization

4. Gaseous Hydrogen Test Facilities

HPHT H_2 SSRT Test
【高温高压气态充氢慢拉伸实验系统】

200℃/15MPa H_2 or Mixture

气态充氢符合实际氢能储存输运环境，可进行气相氢环境慢应变速率拉伸、恒载荷拉伸、低周疲劳、裂纹扩展等测试。

HPHT H_2 Permeation Test
【高温高压气态氢渗透实验系统】

600℃/10MPa H_2 or Mixture

测试金属材料在高压氢环境中的氢渗透行为，包括氢扩散系数、扩散激活能、渗透系数、渗透激活能等。

HTDS Test System
【热脱附法氢含量及氢分布测试系统】

1000℃, H Content, 0.001ppm

可以明确电化学充氢和气态充氢后材料的总氢含量，结合微观组织观察计算，可明确氢分布行为。

The Facilities of CNPC TGRI Corrosion Research Team

5. MIC Test Facilities

Thank you for your attention!

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CNPC Tubular Goods Research Institute