labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM ▪ PEMM ▪ Poli

Environmentally Assisted Cracking and Energy Transition - Expected Impact on Materials and Equipment

ponciano@metalmat.ufrj.br

Labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

SUMMARY

- BASIC DEFINITIONS – Energy transition and EAC
- CO_2 CORROSION - SCC - HYDROGEN EMBRITTLEMENT
- OUR BACKGROUND - LABCORR
- COMMENTS AND QUESTIONS

BASIC DEFINITIONS – Energy transition and EAC

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

Energy transition

- From Watt energy transition – SCC as cause of steam boilers explosions – mitigated by new welding technologies (Between the years 1760-1820, the Industrial Revolution took place in Great Britain)

- Present - Alternative energy sources (renewable) – new application conditions required, much more agressive or unknown (unexpected damage mechanisms)

    - Pure hydrogen at high pressure – Generation (green), transport and storage
    - H_2S build up and ageing facilities – pipeline grid worldwide – gas sources
    - CO_2 at high P and T – supercritical conditions, contaminants (greenhouse effect and oil and gas sector focus on better compliance)
    - Molten salts

GLOBAL SCENARIO

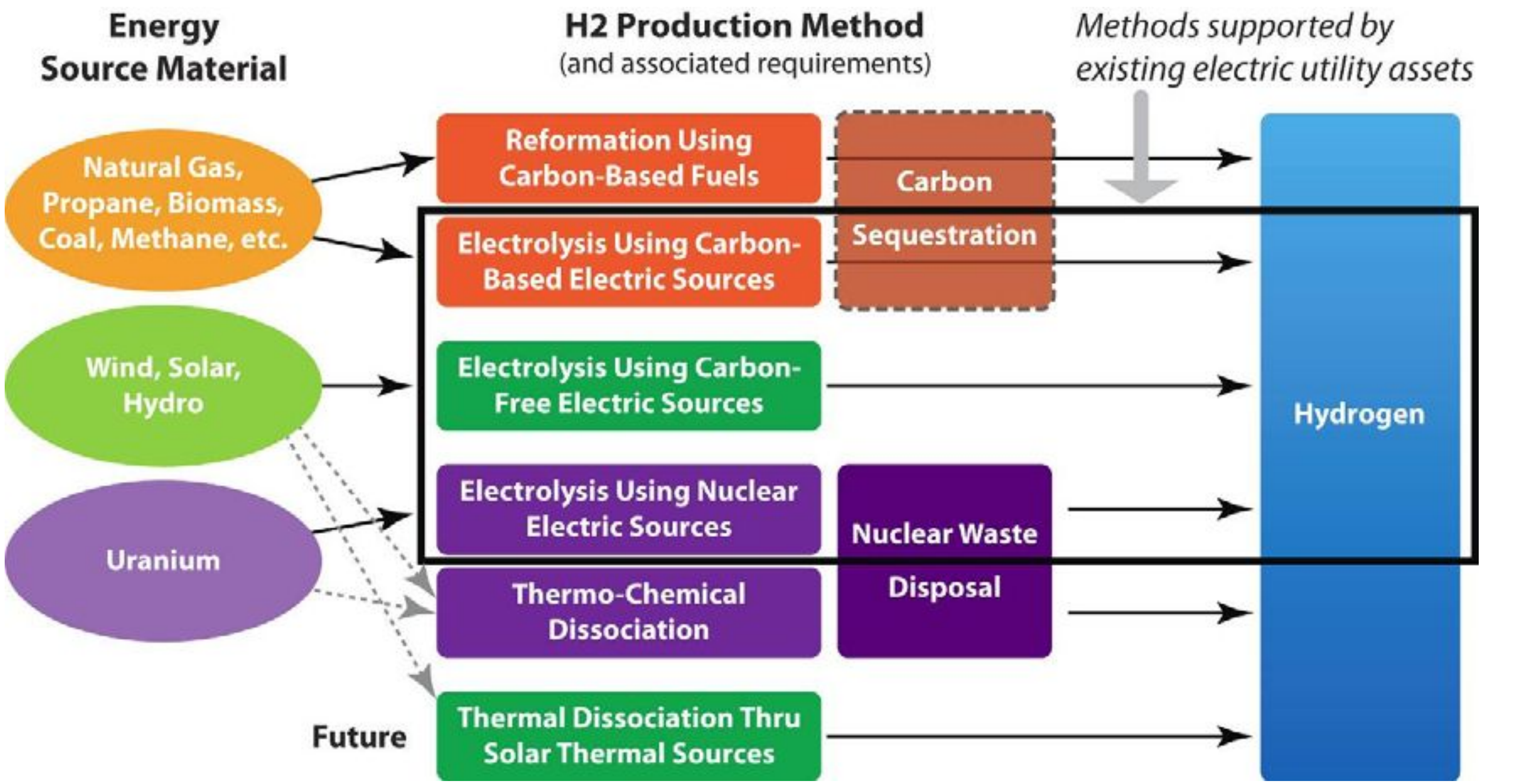
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

- **EUROPE – ageing gas pipeline grid / H_2S build-up / CO_2 management**
- **BRASIL – CO_2 Presalt – reinjection /storage/transportation**
- **BRASIL – Green hydrogen – huge investiment on eolic/electrolysis**
- **US – Wind to Power**

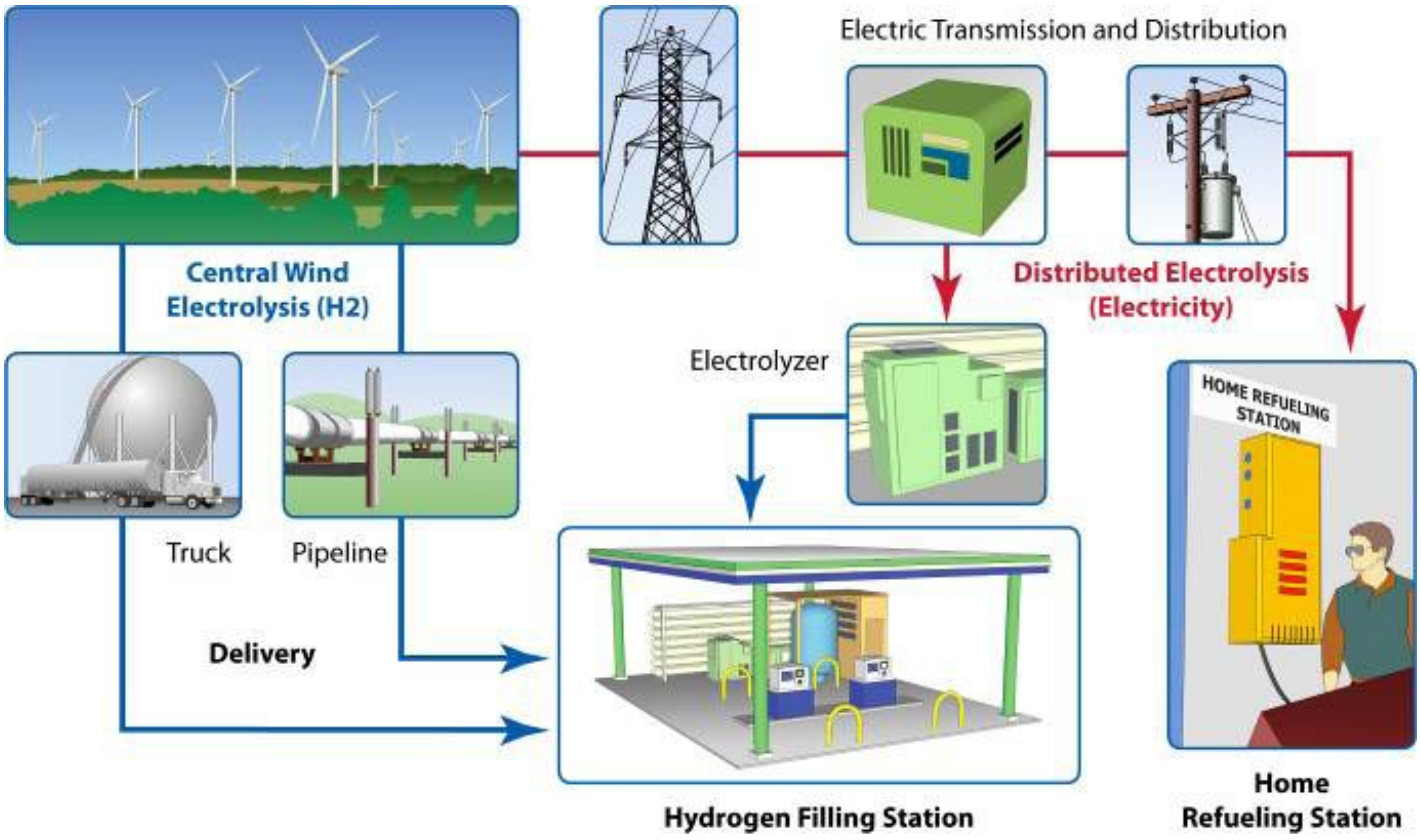
labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

WIND TO POWER

Hydrogen production pathway



Examples of wind electrolysis being produced centrally or distributed at the point of use



CARBON CAPTURE AND STORAGE

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

Carbon Capture and Storage (CCS) is a key available technology to mitigate emissions from large-scale fossil fuel use.

International Journal of Greenhouse Gas Control 114 (2022) 103601

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

ELSEVIER

Materials challenges with CO_2 transport and injection for carbon capture and storage

J. Sonke[a,*], W.M. Bos[b], S.J. Paterson[c]

[a] Shell Global Solutions International B.V., Amsterdam, the Netherlands
[b] Shell India Markets Pvt. Ltd
[c] Arbeadie Consultants, Banchory, Scotland UK

ARTICLE INFO

Keywords:
Materials Selection
Carbon Capture and Storage
Impurities
CO_2 transport
Dense phase CO_2
Corrosion

ABSTRACT

Carbon Capture and Storage (CCS) is a key technology to mitigate emissions from large-scale fossil fuel use. CCS primarily involves capturing the CO_2 arising from energy-related and industrial sources, treating of the CO_2 to remove impurities, and injecting it in a storage site to ensure long-term isolation from the atmosphere. The specific difference in relation to experience with relatively pure CO_2 injection is caused by the impurity of the CCS CO_2 which will be dictated by the CO_2 source and the capture technology employed.

The aim of this work is to identify an approach to materials selection and corrosion control that can address the specific requirements of a CCS project. Depending on the phase envelope and CO_2 composition, separate liquid phases may be formed. It has been identified that these phases can comprise of water (causing CO_2 corrosion) or reaction products including strong acids and elemental sulphur.

The type of liquids formed and shifts in the phase envelope can significantly influence materials integrity due to corrosion, and impact the flexibility and degradation of polymers. For this reason, it is recommended to start each project with the identification of the CO_2 specification and operating scenarios, including upsets that might occur during the service life. Other concerns include the impact of low temperature scenarios, and the possible presence of O_2 and a high salinity brine on materials used in wells.

1. Introduction and background to the CCS process

A substantial amount of the world's rising energy demand is forecast to still be met by fossil fuels over the next decade (IPCC, 2005). Carbon Capture and Storage (CCS) is a key available technology to mitigate emissions from large-scale fossil fuel use. Therefore, developing and commercialising this technology is essential to help reduce the impact on climate change (Barker et al., 2017; Bertels, 2015). CCS primarily involves capturing the CO_2 arising from energy-related and industrial sources, treating of the CO_2 to remove impurities, and compressing, transporting and injecting it in a storage site to ensure long-term isolation from the atmosphere (Paul, 2010; Gasda et al., 2004).

In using fossil fuels to generate power, the purity of CO_2 emissions is not an important parameter and as a result the quality of CO_2 for CCS transport and injection will be predominantly dictated by the CO_2 capture technology employed at the plant with secondary consideration of the pipeline and storage limitations.

1.1. CO_2 source

Removing impurities down to very low concentrations may create a significant energy requirement and cost penalty (Barker et al., 2017). Consequently, CO_2 captured from power generation and industrial sources for CCS is likely to contain many impurities. For CCS projects the threats related to the purity of the CO_2, can be classified by the gas source as:

- Relatively clean CO_2 gas. There is a lot of experience with CO_2 gas injection used for EOR (Enhanced Oil Recovery). This is a relatively clean CO_2 source and experience has shown that there are few operational problems provided the fluid is kept relatively pure and the water content is controlled (Barker et al., 2017; Paul et al., 2012; Dugstad and Halseid, 2011; DRET 2009).
- Impure CO_2 gas. For CCS the source of CO_2 can originate from combustion or from a range of industrial sources. The impurities include those present in the gas source (e.g. H_2O, NO_x, SO_x, O_2) as

* Corresponding author.
E-mail address: hans.sonke@shell.com (J. Sonke).

https://doi.org/10.1016/j.ijggc.2022.103601
Received 1 June 2021; Received in revised form 6 December 2021; Accepted 3 February 2022
Available online 11 February 2022
1750-5836/

BASIC DEFINITIONS – EAC

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

- Stress Corrosion Cracking
- Hydrogen embrittlement
- Corrosion fatigue

Minor players - Corrosion erosion/liquid metal embrittlement/fretting corrosion, etc....

All together sometimes

CO_2 CORROSION – SCC

CO_2 environments – Materials issues

labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

Low temperature fracture that can lead to sudden and catastrophic failures. Joule Thompson effects – low ductility under cryogenic conditions. Besides, supercritical CO_2 can make CCS pipelines more susceptible to cracking

CO_2 corrosion - general aspects

Hydrogen embrittlement

CO_2 Stress Corrosion Cracking – ANP warning issued in Brasil 2017

Labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

CO_2 Corrosion

Starting from CO_2 corrosion basic knowledge (De Waard pioneer model)

↓

Confinement conditions, saturation ratio and precipitation under very low V/S conditions

↓

Loading conditions or loading history – Static/Dynamic/ Mixed

Surface condition as a key factor to be considered. Will depend on time, temperature, iron concentration and CO_2 fugacity – Precipitated iron carbonate film morphology, adhesion, chemical and electrochemical stability. Surface morphology of the metal surface underneath the $FeCO_3$ film. In order to preserve the wire texture, segments of full thickness wires are used as working electrodes on mechanical tests in corrosive environments.

CO_2 SCC

From literature review, specific “knowledge packages” could be identified

1) Old school people from Germany investigated the so called “fire extinguisher steel failure analysis”. Schmitt and others. At least one of the steels tested is comparable to the flexible wire steel (C about 0,3%)

2) Near neutral SCC (NNSCC) – origin in Canada from buried pipeline failures. Investigated for several decades. Based on concepts introduced by Parkins (Newcastle Upon Tyne). Search of similarities between FSCC and cracking produced at the interface coated steel/soil.

3) Side approach considering the contribution of carbon monoxide (CO) to cracking. Not considered into the frame of FSCC investigation. Papers from 1976 to 2023

4) New approach, after 2017, ANP technical note. Conducted by flexibles manufacturers, operators and R&D institutions, going from test of materials to full scale tests.

EAC – FLEXIBLE PIPELINES

Safe conditions limits are pulling down

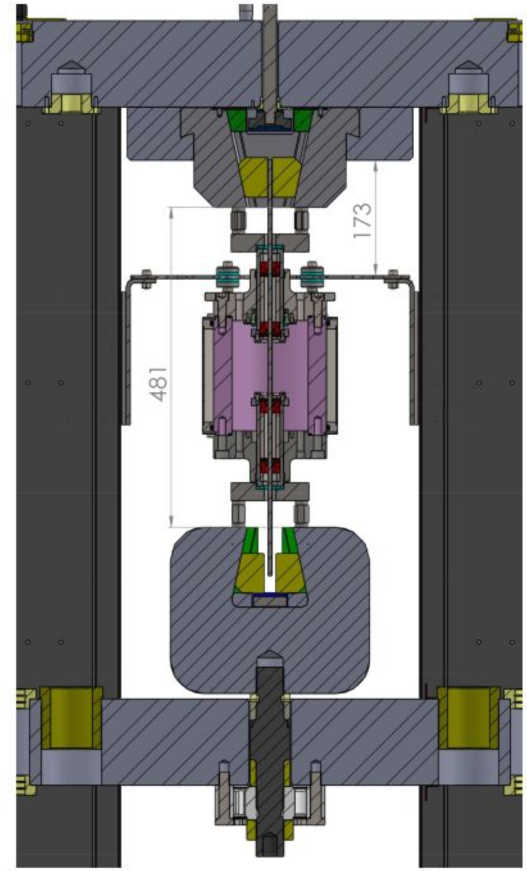
HE embrittlement – expected concentration – diffusion models and others

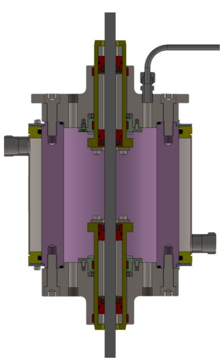
SCC CO_2 – expected concentration – diffusion models and others

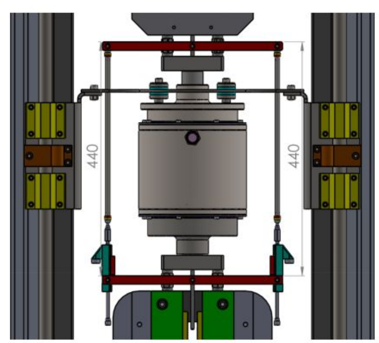
OUR BACKGROUND - LABCORR

labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

HPHT (SSRT)

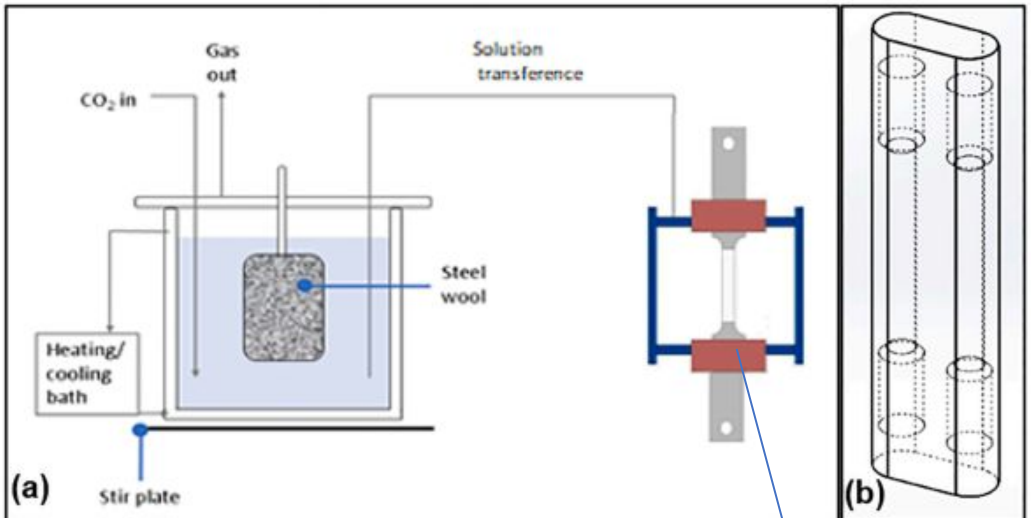


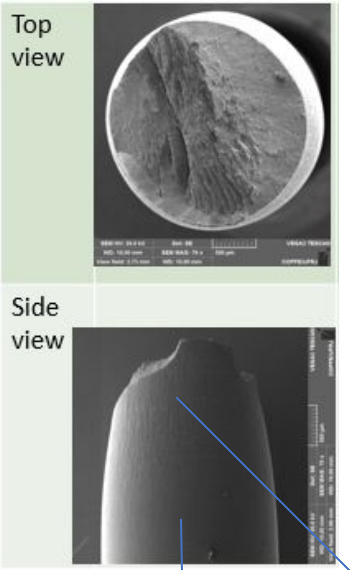




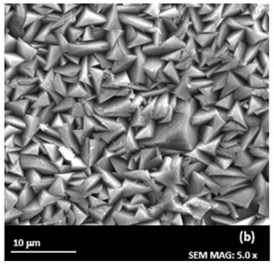
Simulation of annular space of flexible pipes and 4-point bend tests

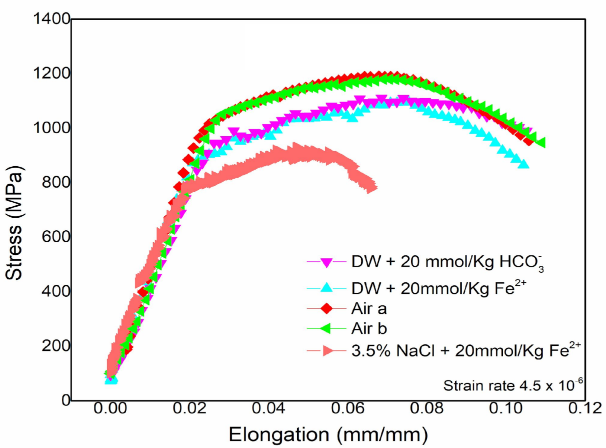
SSRT of machined tensile armor wires in simulated annulus conditions

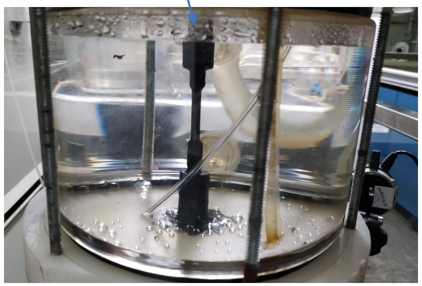


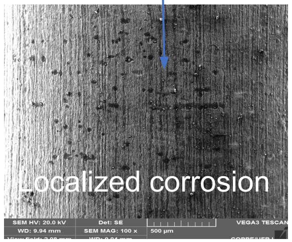


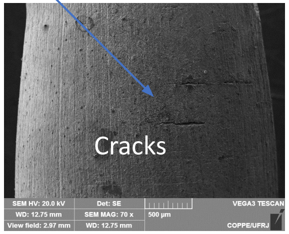
Influence of the filmed surface





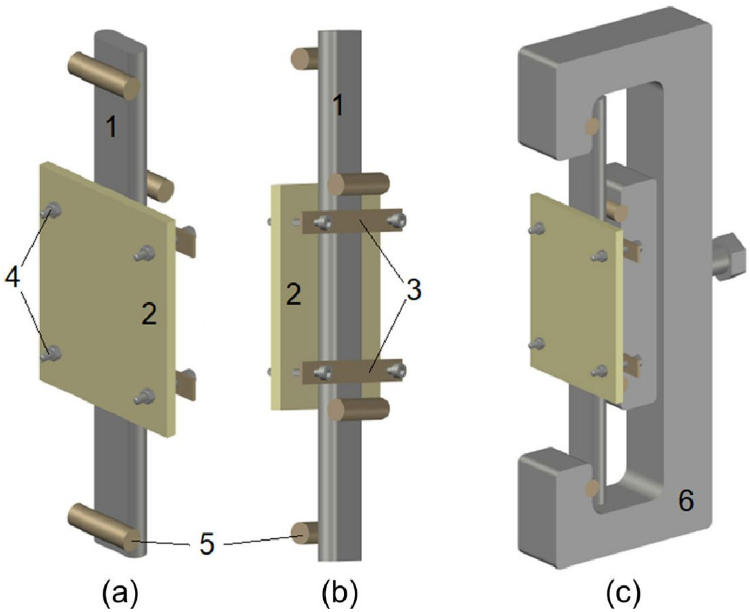


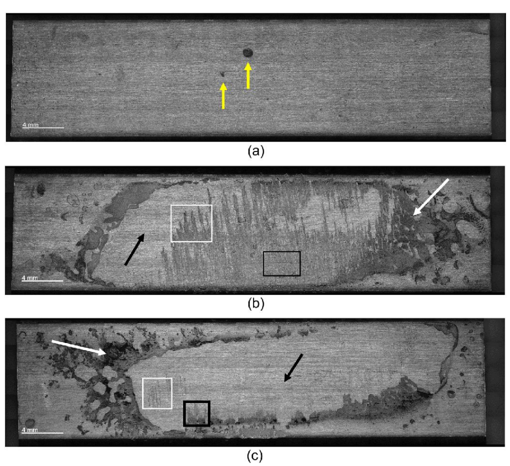


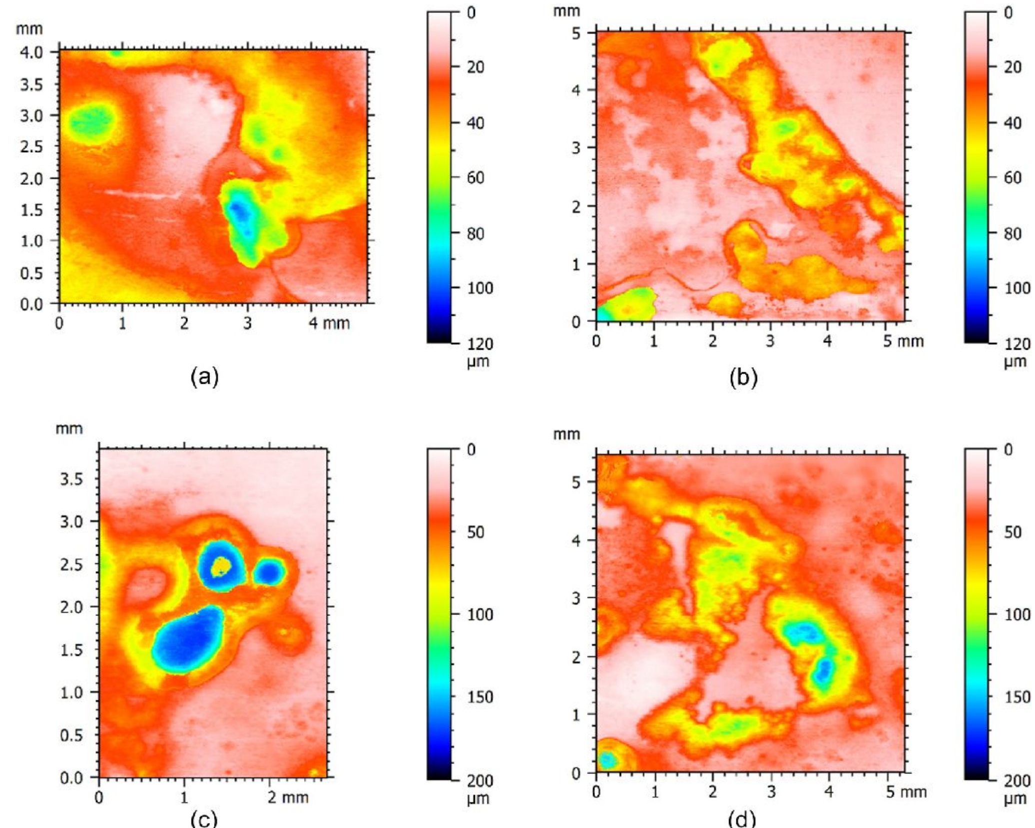


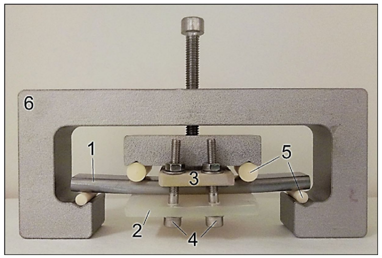
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

CREVICE CORROSION – 4 POINT

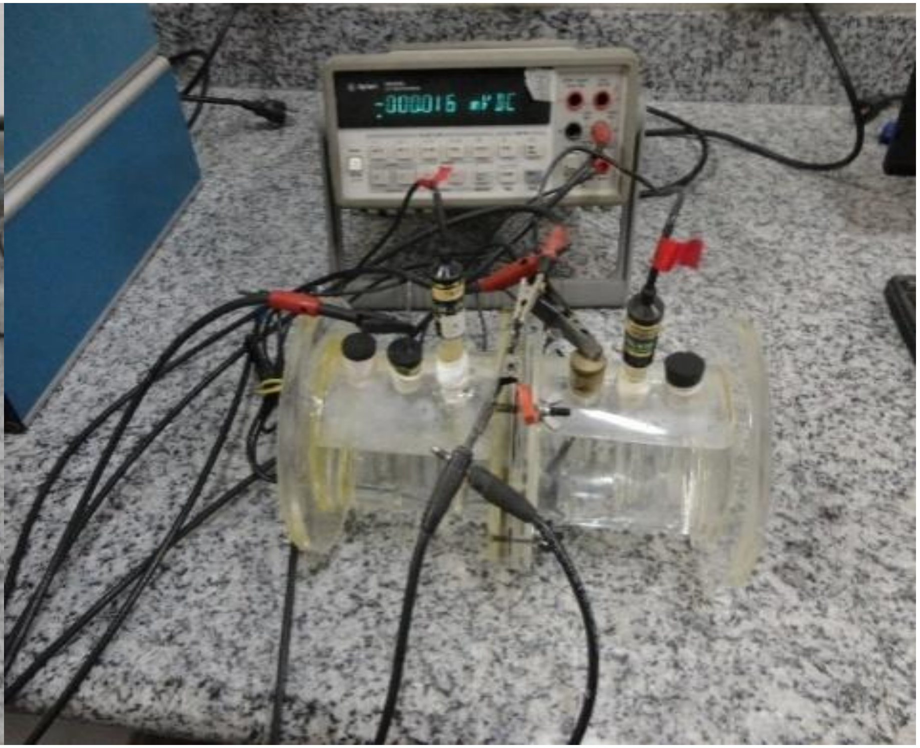






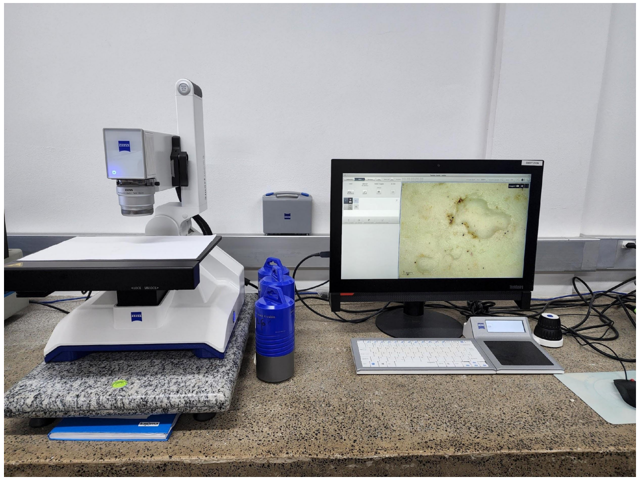


HYDROGEN PERMEATION



SURFACE ANALYSIS

OPTICAL MICROSCOPY



CONFOCAL MICROSCOPY

SEM/EDS

ADDITIONAL TECHNIQUES

A) Tomography

B) Digitalization

C) Electric potential drop

D) Fretting corrosion tests – Zeta wire

E) Phased array US

POTENTIAL DROP - (PD)

Bipolar operational power

Amplifier Lock-in

(a)

(b)

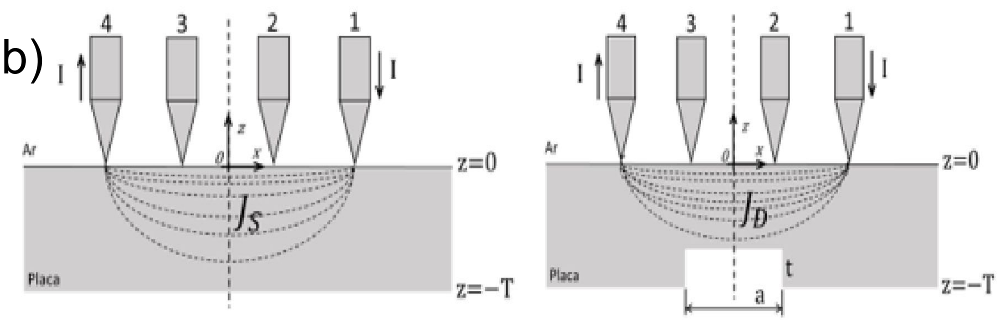


Fig 3 (a) Equipments used for potential drop method.(b) Schematic representation of PD technique.

PD inspection methods:

- ACPD (Alternating current potential drop): Detection of internal and surperficial defects. (e.g. localized corrosion and SCC-CO_2).
- DCPD (Direct current potential drop): Detection of internal defects. (e.g. HIC cracks)

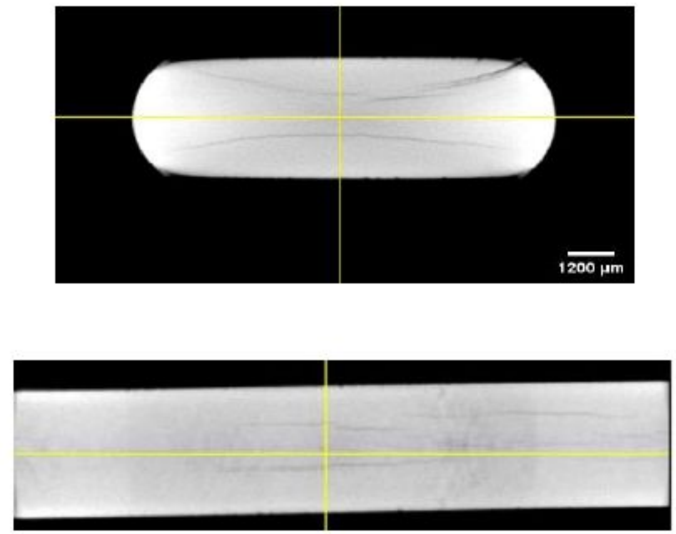
TOMOGRAPHY

- Results

3D tomography image from a tensile wire after being exposed to an H_2S solution.

(a)

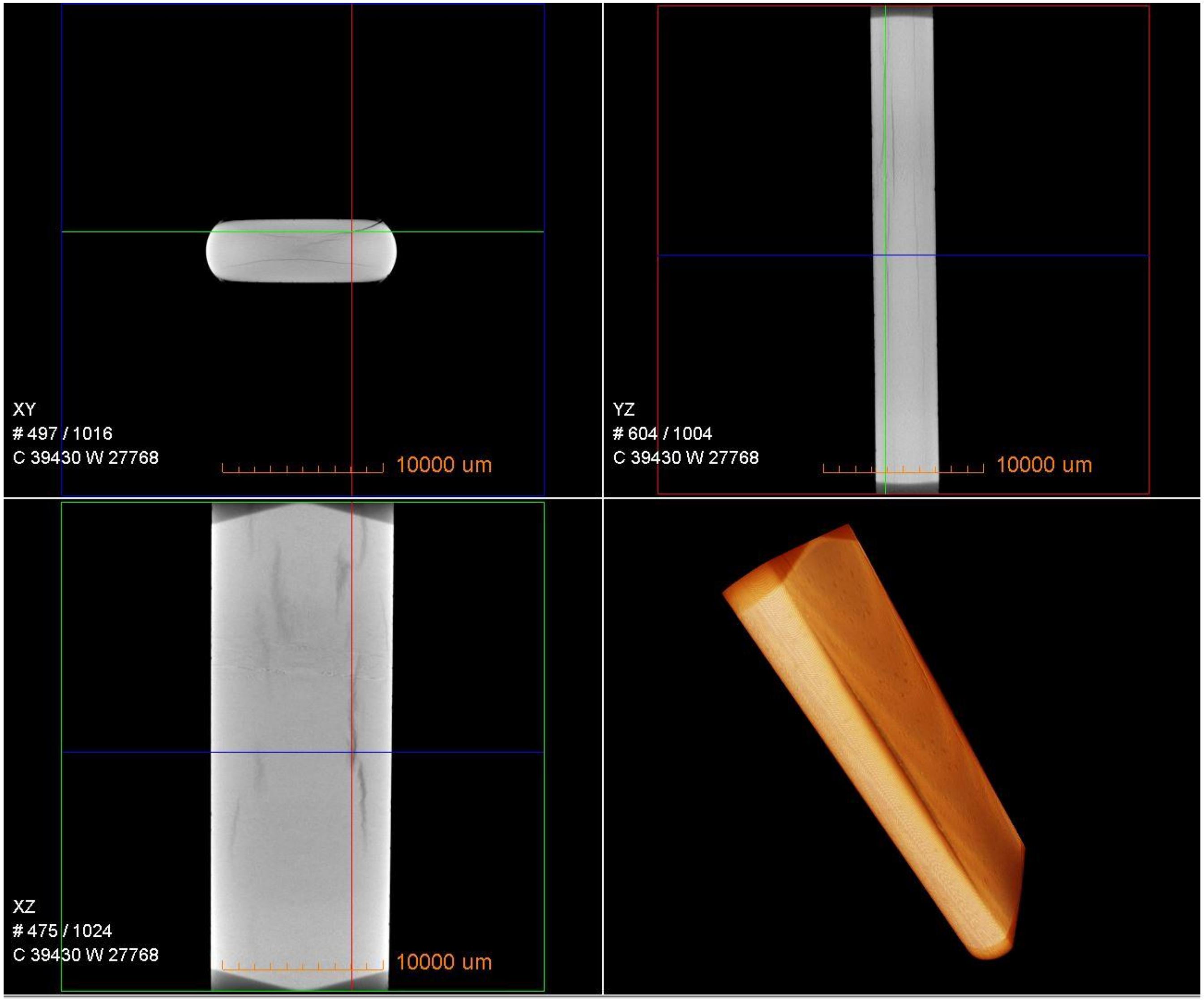
(b)



Tomography images (a) Cross-section. (b) Coronal plane.

- Conclusions → it is possible to use tomography to detect, locate and dimension internal cracks in armor wires that have been exposed to a corrosive environment.

TOMOGRAPHY


XY
497 / 1016
C 39430 W 27768
10000 um
YZ
604 / 1004
C 39430 W 27768
10000 um
XZ
475 / 1024
C 39430 W 27768
10000 um

labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

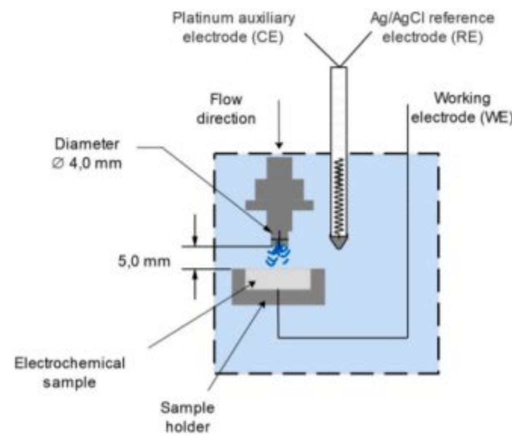
HPHT tests (Static and RCage/RCE)

labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

H_2S test system

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

Erosion-Corrosion System



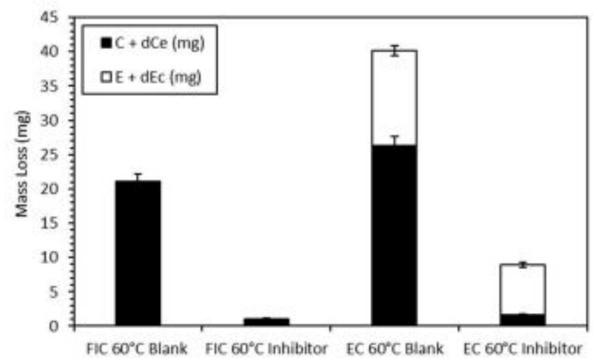
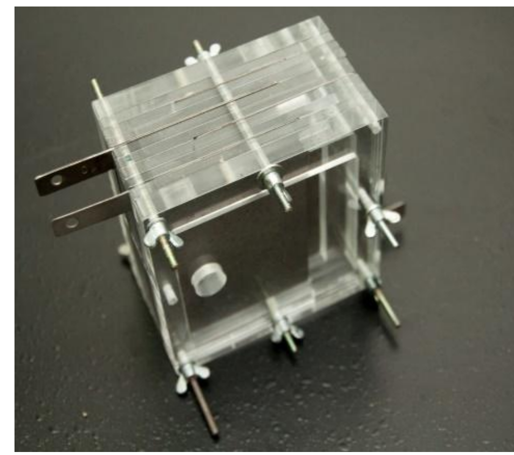


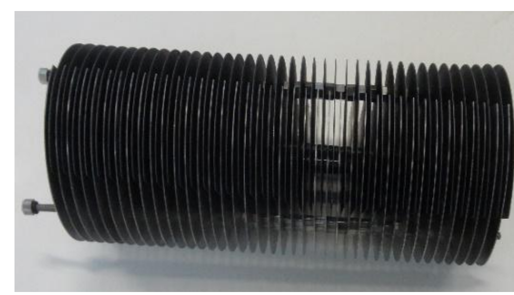
Fig. 5. Contribution of erosion and corrosion components of degradation, drawing attention to the influence of the sand particles on inhibitor performance at 100 ppm.

Contribution of erosion and corrosion components of degradation drawing attention to the influence of the sand particles on inhibitor performance at 100 ppm.

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

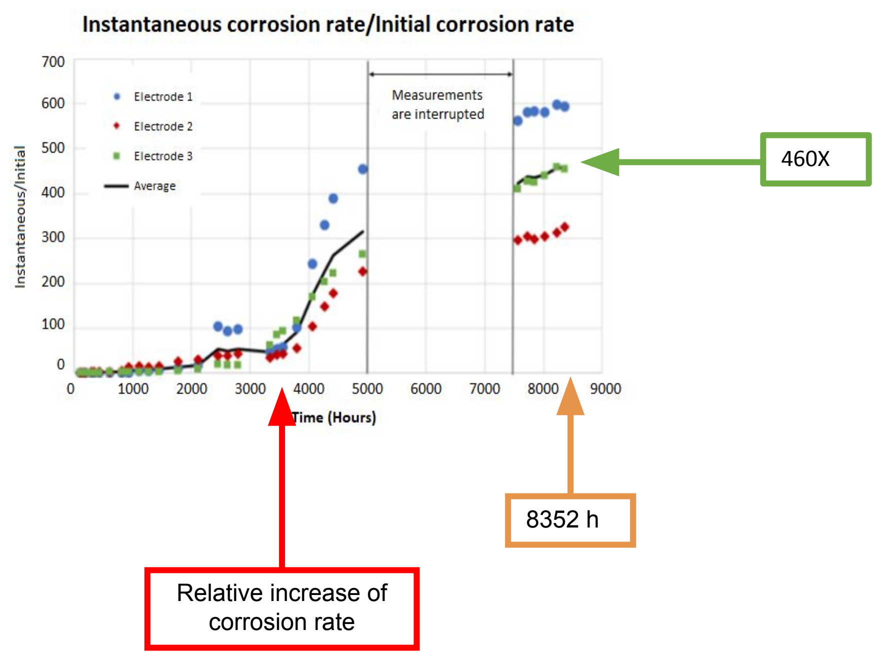
Electrochemical treatment of wastewater





labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

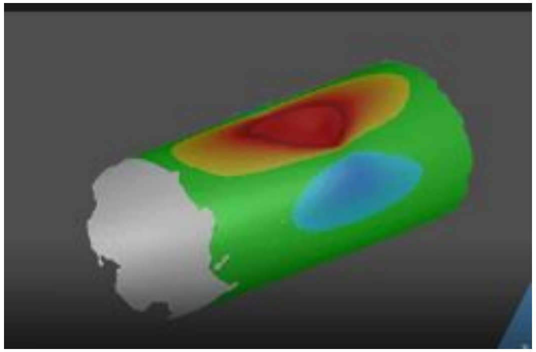
Under deposit Corrosion System

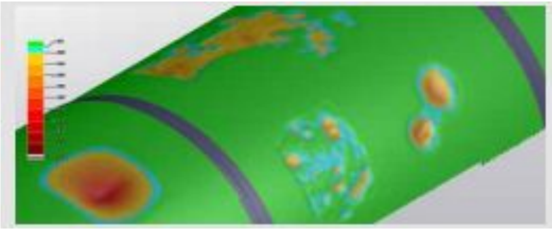


HandyScan – Scanner 3D Pypecheck and PolyWorks Software

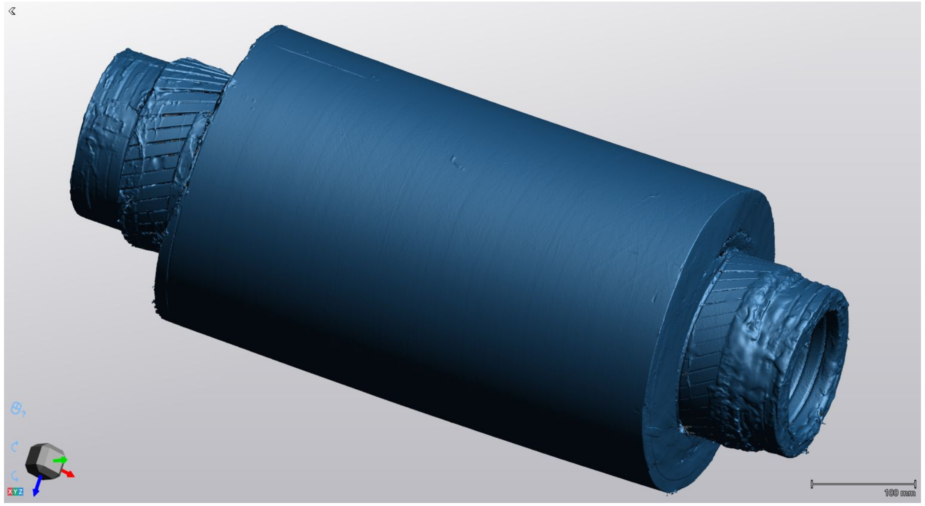
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

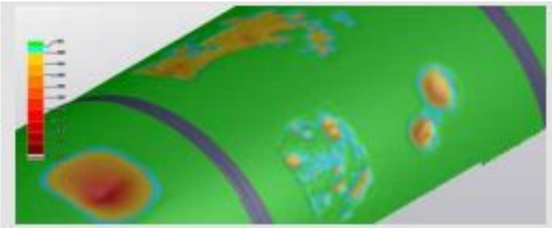
In the acquisition process

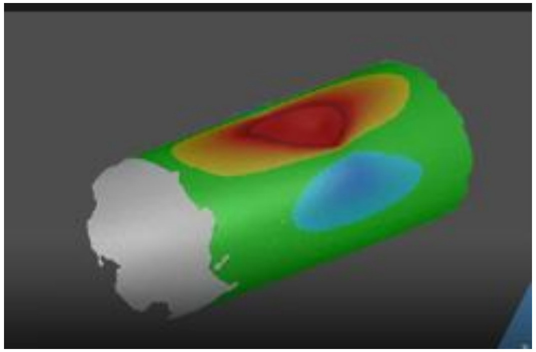


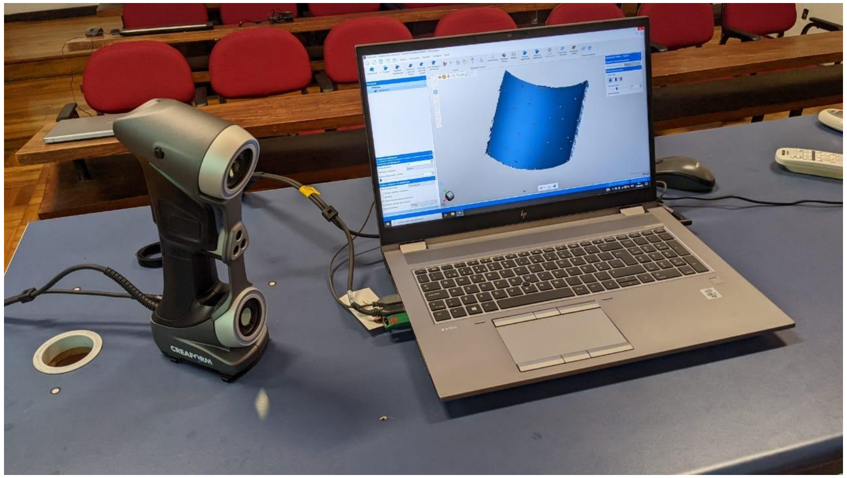


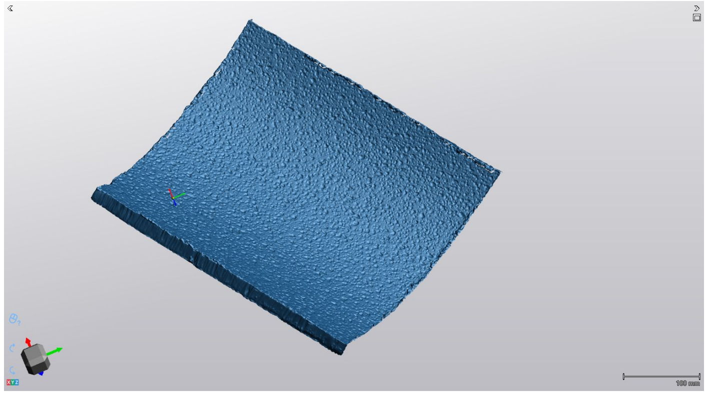
FIELD ACTIVITIES - SCANNER 3D





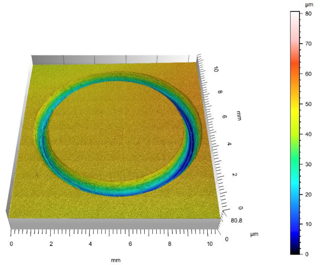


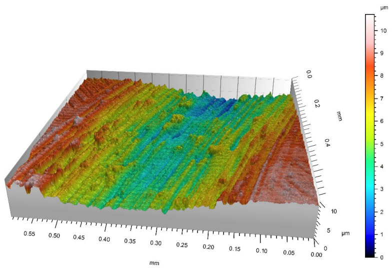




TRIBOCORROSION

The analysis includes tribocorrosion assessments performed in tribometer and characterization of surfaces under wear and corrosion conditions, in relative motion and loading. In this field our main evaluations are in flexible pipes and in the biomedical area such as dental and orthopedic implants.



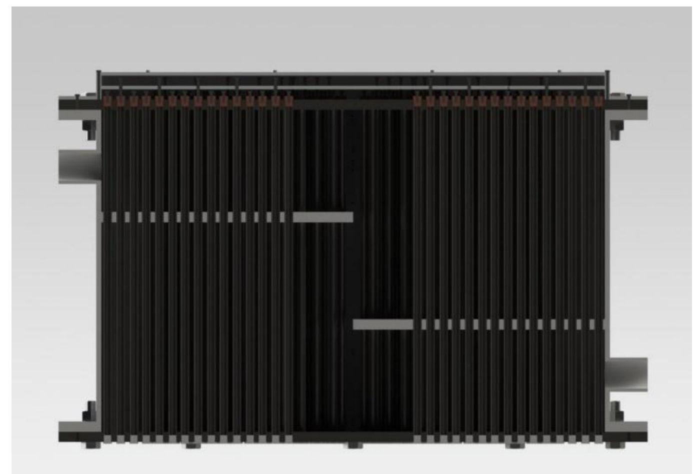


labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

APPLIED ELECTROCHEMISTRY - INTEGRITY MANAGEMENT

Phase 1 - Development of Electrochemical treatment process of refinery sour water with co-product generation

Electrochemical conversion cell for H_2S removal



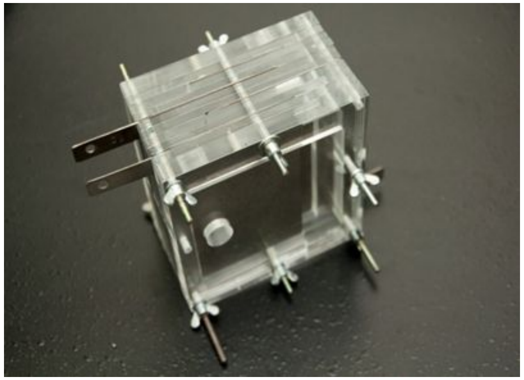
<u>Tested materials:</u>

- Carbon steel
- **Nickel** → high anodic and cathodic current densities
- Titanium
- Graphite
- Platinum

Results: H_2S removal and H_2 generation

APPLIED ELECTROCHEMISTRY - INTEGRITY MANAGEMENT

Phase 2 : Improvement of alternative electrochemical technology for the treatment of sour water generated in refineries



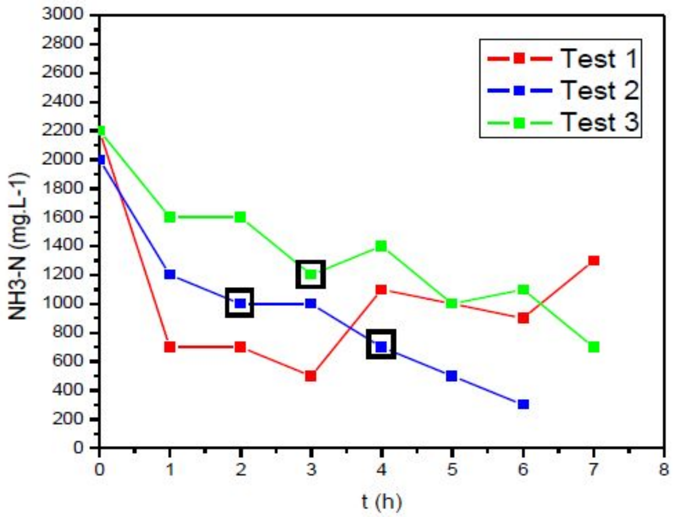
Parallel plate electrochemicalreactor – bench scale

Tested materials for N-NH_3 oxidation:

- Platinum – high electro-activity
- **DSA®** - high electro-activity and higher affinity for ammonia
- Nickel – corrosion
- Anodized Al – no satisfactory corrosion resistance or electrochemical activity
- Graphite – undefined parallel reactions

Tests	Initial COD concentration mg.L^{-1}	Final COD concentration mg.L^{-1}	Removal %
1	6040	380	93.7
2	2170	550	74.6
3	7790	1150	85.2

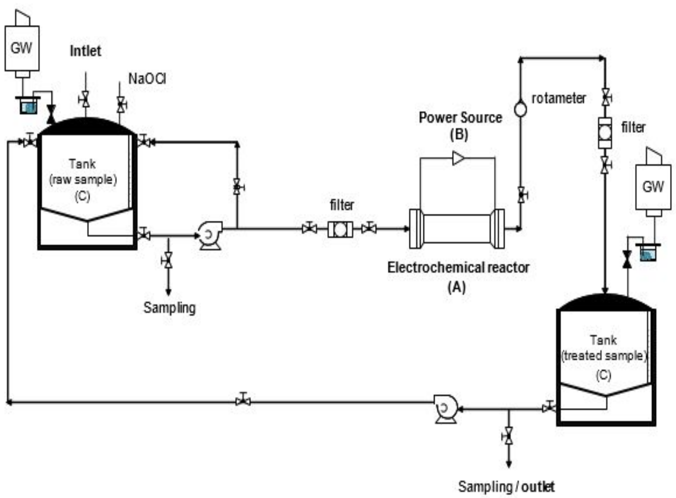
COD removal from the electrochemical treatment.

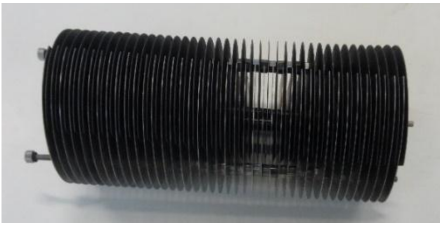


Variations in NH3-N content according to the NaOCl injection system. Test 1: NaOCl added at the beginning of the process; Test 2: NaOCl added at the beginning and at two additional occasions during the process; Test 3: NaOCl added at the beginning and once more during the process. Intermediary NaOCl injections are indicated by the squares.

labcorr
Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

Phase 3 : Improvement of alternative electrochemical technology for the treatment of sour water generated in refineries – Optimization of the Electrochemical Reactor





B)

Main results:

- The electro oxidation of NH_3-N species was found to be reversible, indicating the formation of co-products
- H_2 sensor improvement enabling field use

2022 - Experimental investigation of CO_2 SCC using SSRT as a screening tool to spot the influence of key parameters – pCO_2, T and strain rate.

Engineering Failure Analysis 139 (2022) 106451

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

ELSEVIER

Stress corrosion cracking susceptibility of armour layers in CO_2 annulus environments – SSRT experimental simulation

J.A.C. Ponciano Gomes *, S.C. Silva, T. Campos

Federal University of Rio de Janeiro, Department of Materials and Metallurgical Engineering, Labcorr, Rio de Janeiro, Brazil

ARTICLE INFO

Keywords:
CO_2 Stress Corrosion Cracking
Annular space
Flexible pipes
$FeCO_3$ precipitation

ABSTRACT

Flexible wires present wet occluded spaces where corrosion induces supersaturation of ferrous ions and precipitation of $FeCO_3$. Localized corrosion is possible due to discontinuities of the precipitated $FeCO_3$. This work aims to investigate the Stress Corrosion Cracking susceptibility of armour layer in $FeCO_3$ supersaturated seawater, addressing the influence of CO_2 partial pressure and strain rate, at 25 °C and at 40 °C, using the Slow Strain Rate Test. The results were expressed by ASTM G129 standard parameters. The material showed loss of ductility under all experimental conditions. The most aggressive conditions were at 25 °C, 10 bar, under $10^{-7}\ s^{-1}$ and $10^{-6}\ s^{-1}$ strain rates, respectively. The results showed that fracture mechanism is related to hydrogen embrittlement, suggested by the presence of internal secondary cracks on the fracture surface. These secondary cracks suggest the interference of delamination. From the results it was possible to rank the severity of experimental conditions imposed.

1. Introduction

The flexible pipes have been used by the oil and gas industry for many decades to ensure characteristics that are considered essential to the project, such as easy configuration adjustment, transport and storage conditions [1,2,3].

Corrosion in confined environments of the annulus of flexible pipes, which have a restricted volume of electrolyte in relation to the steel surface, may cause different corrosion morphologies, such as crevices, pits and environment assisted cracks. Different corrosion morphologies are likely to occur, such as crevices, pits and environment assisted cracks. It is estimated that the ratio between the volume of solution and the surface area (V/S) of the metallic wires of carbon steel or high-strength low-alloy steel (HSLA), is lower than 0.1 mL/cm^2 [4,5]. Along with other parameters, such as the composition of the electrolyte (condensed water or sea water, as well as the dissolved gases present), temperature and pressure, it was experimentally evidenced that the V/S ratio is the main factor affecting the corrosion process of armour layers [5].

The confined environment of annulus of flexible pipes can assume different and complex characteristics which can affect the properties of many layers comprised between the inner and outer sheath. These variations of the environment formed in the annulus can occur due to a wide range of events during service, leading to degradation of the internal components, and can jeopardize the integrity of the equipment, with failure of premature replacement.

Damages to the outer sheath of the flexible pipes also frequently occur, allowing seawater to ingress into the annulus, in presence of

* Corresponding author at: Professor at Labcorr, Department of Materials and Metallurgical Engineering, Federal University of Rio de Janeiro, Brazil.
E-mail address: ponciano@metalmat.ufrj.br (J.A.C. Ponciano Gomes).

https://doi.org/10.1016/j.engfailanal.2022.106451
Received 8 February 2022; Received in revised form 25 April 2022; Accepted 17 May 2022
Available online 21 May 2022

Laboratório de Corrosão

SCIENCE SECTION

Effect of Flow Rate on the Corrosion Behavior of API 5L X80 Steel in Water-Saturated Supercritical CO_2 Environments

Jonas da Silva de Sá,[‡,,**] Wenlong Ma,[**,***] Joshua Owen,[**] Yong Hua,[**] Anne Neville,[**] José A.C. Ponciano Gomes,[*] and Richard Barker[**]*

The effect of the water-saturated supercritical carbon dioxide ($scCO_2$) flow rate on the corrosion behavior of API 5L X80 steel at a temperature of 35°C and pressure of 80 bar was investigated. Tests were performed with the samples attached to a rotating shaft inside an autoclave. Results indicate that increasing the $scCO_2$ flow rate had no significant influence on the general/localized corrosion rate under the various dynamic conditions considered. The average general corrosion rate was 0.064 mm/y, while the average measured pitting penetration rates were one order of magnitude higher. The size of the corrosion features on the surface of the samples, which were believed to provide an indication as to the size of the condensed water droplets, was much smaller than the calculated critical droplet size needed to be displaced by the flow, supporting the theory as to why flow rate had little effect on the corrosion response.

KEY WORDS: carbon dioxide, flow effects, steel, supercritical environment

INTRODUCTION

Global warming has become a wide public concern, with CO_2 emission into the atmosphere representing one of the biggest contributors to the rise in the Earth's temperature. Carbon capture and storage (CCS) technology is currently a feasible and economic method for reducing greenhouse gases emissions. It consists of capturing CO_2 from large source points, compressing it into a liquid or supercritical state, and transporting it to a storage site for sequestration or for the purposes of enhanced oil recovery (EOR).[1] Hence, the implementation of CCS technologies has the potential to reduce CO_2 emissions into the atmosphere, while also facilitating the recovery of hydrocarbons through the application.[2] The handling of CO_2 during CCS needs to be conducted in a safe manner; therefore, it is essential to evaluate the corrosion risk in CO_2 transport and injection pipelines.[3-4]

Although dry CO_2 is not corrosive to steels, the presence of free water has been regarded as a particular cause for concern for supercritical CO_2 applications. If water is present, it quickly becomes saturated with CO_2, producing carbonic acid, thus creating a local corrosive environment that may affect the pipeline integrity.[3] Therefore, most applications focus on sufficiently drying the CO_2 before using it. However, in water-alternating-gas (WAG) EOR applications, the well is flooded alternatively with CO_2 and water, and in such applications residual water cannot be avoided and the injection lines would be periodically exposed to CO_2 fluids with different water contents.[1]

The effect of water content, impurities, temperature, and pressure on the corrosion of the steel in static supercritical CO_2 has been extensively studied in recent years.[3,5] However, the effect of flow rate on the supercritical CO_2 corrosion behavior of the steel has rarely been reported. It has been shown that in the specific aqueous phase environments, the corrosion rate of the steel can increase substantially due to the mass-transfer generated by the flow. The increase in local turbulence in aqueous environments can also hinder the formation or damage the protective corrosion products film on the surface.[6-7]

However, in the supercritical CO_2 phase, the corrosion mechanism is substantially different from that encountered in a single-phase flow aqueous environment, and more akin to corrosion in condensate/wet-gas systems. In this scenario, the water can locally exceed the solubility limit and condense via a dropwise or film-wise mechanism onto the steel surface, leading to corrosion of the area in direct contact with the aqueous phase.[8] The corrosion in such systems is expected to be controlled by the electrochemical reaction occurring at the interface between the steel sample and the free water. Consequently, the corrosion rate measured would be influenced by the extent of the wetted area.[1,8-9] Therefore, understanding this initial stage of the condensation process is very important for the prediction of the extent of corrosion in CO_2 injection wells. However, the condensation of water droplets in the supercritical CO_2 phase is still not fully understood. Some authors believe the water droplets condense directly on the steel surface similarly to atmospheric corrosion,[10] while others believe that a variation of temperature or pressure is required for the

Submitted for publication: September 3, 2021. Revised and accepted: November 15, 2021. Preprint available online: November 15, 2021, https://doi.org/10.5006/3939.
‡ Corresponding author. E-mail: jonas.sa@coppe.ufrj.br.
* Metallurgical and Materials Engineering Program, Federal University of Rio de Janeiro, Rio de Janeiro 21941-598, Brazil.
** School of Mechanical Engineering, University of Leeds, Leeds LS2 9JT, United Kingdom.
*** School of Mechanical and Electronic Engineering, China University of Petroleum, Qingdao 266580, People's Republic of China.

ISSN 0010-9312 (print), 1938-159X (online)

2022 – CO_2 corrosion under supercritical conditions. Peculiar corrosion mechanisms in different Supercritical CO_2 phases (aqueous and gas)

Laboratório de Corrosão

2022 - Interaction of polymeric materials and steel leading to localized corrosion and possible evolution to cracking

Received: 1 August 2022 | Accepted: 24 August 2022
DOI: 10.1002/maco.202213468

ARTICLE

Materials and Corrosion

Corrosion of tensile wires covered with PA11 layers in simulated annulus environments at low CO_2 pressure

Pedro N. Silva[1,2] | Erica V. Senatore[2] | Jose A. C. P. Gomes[2]

[1]Corrosion Technology Department, Institute for Energy Technology, Kjeller, Norway
[2]Metallurgical and Materials Engineering Department, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Correspondence
Pedro N. Silva, Corrosion Technology Department, Institute for Energy Technology, PO Box 40, Kjeller NO-2027, Norway.
Email: pedro.netto@ife.no

Funding information
EMBRAPII and Shell Brazil, Grant/Award Number: PEMM20682

Abstract

High-strength carbon steel wires covered with polymer layers were exposed to different test environments simulating the conditions in the annulus of flexible pipes at low CO_2 pressure and flooded with seawater. The polymer layers mimicked the antiwear tapes which are placed in between the steel layers of the tensile armor of the pipes. Specimens without the polymer layer were exposed to the same test environments for comparison and allowed identifying how the presence of the polymer layer influenced the corrosion mechanism. In some of the experiments, oxygen was introduced into the gas mixture to simulate fresh seawater entering the annulus after a breach in the outer sheath. Surface analysis of the corroded specimens after removal of corrosion scales was carried out by scanning electron microscopy, optical profilometry, and confocal microscopy. The polymer layers were observed to have a considerable effect on the corrosion morphology.

KEYWORDS
antiwear tape, carbon steel, CO_2 corrosion, crevice, flexible pipe, oxygen, tensile wire

1 | INTRODUCTION

In flexible pipes used in offshore production systems, the tensile armor consists of high-strength steel wires, which correspond to the outermost metallic layers in the cross-section of the pipe (Figure 1). The antiwear layers are placed between overlaying tensile wires to avoid contact and prevent wear. Polyamide 11 (PA11) is commonly used for this purpose.[1]

If the annulus is filled with water (either condensed water or seawater), an environment that is potentially corrosive to the steel wires is generated. However, because of the annulus configuration, where the ratio of water volume to steel surface area (V/S) is very small, typically below 0.1 ml cm^{-2}, the accumulation of corrosion products is fast, and saturation is quickly achieved. This leads to the formation of corrosion scales on the steel surface, which can give a varying degree of corrosion protection to the steel depending on factors such as temperature, water chemistry, and the steel microstructure.

In the flexibles used in gas injection lines, carbon dioxide (CO_2) diffuses from the bore to the annulus through the inner pressure sheath. In the water-filled annulus, carbonic acid (H_2CO_3) is formed as CO_2 dissolves into water. In the absence of oxygen, the steel wires corrode according to Equation (1), producing ferrous ions (Fe^{2+}) and an equivalent amount of bicarbonate (HCO_3^-). Some of the bicarbonate ions dissociate (Equation 2) until equilibrium is reached, and when the concentration of dissolved Fe^{2+} and CO_3^{2-} is high enough, iron carbonate (siderite, $FeCO_3$) precipitates on the steel surface (Equation 3).

$$Fe + 2H_2CO_3 \rightarrow Fe^{2+} + 2HCO_3^- + 2H \quad (1)$$

labcorr
Laboratório de Corrosão

2021 Physicochemical conditions leading to Near Neutral SCC susceptibility in confined conditions of CO_2 corrosion – assumed to be one basic requirement for SCC CO_2

Corrosion of High-Strength Carbon Steels in Siderite Supersaturated Water at Near Neutral pH

Tatiane Campos,[‡,] Marion Seiersten,[**] Simona Palencsár,[**] Arne Dugstad,[**] and José A. Ponciano Gomes[*]*

When carbon steel corrodes in anaerobic carbonated water, and the steel surface area to liquid volume is high, the concentration of ferrous and bicarbonate ions increases rapidly even though the corrosion rate is low. Such solutions with high bicarbonate concentration and a near neutral pH are believed to induce stress corrosion cracking of high-strength carbon steels. This work was conducted to investigate the solid precipitation in siderite supersaturated solutions. It was also an objective to measure the corrosion rate of high-strength carbon steel in solutions with high bicarbonate concentration at pH close to neutral. Preloading the solutions with ferrous ions and bicarbonate made it possible to measure desupersaturation and corrosion rate as function of time. The initial siderite supersaturation was more than 1,000 in the desupersaturation experiments. Despite this, the nucleation and growth of siderite was so slow that the solutions remained supersaturated for 100 h to 500 h at 10°C to 25°C. The ferrous ion concentration decreased from 1,200 mg/kg to 100 mg/kg in less than 24 h at 40°C, but did not reach equilibrium within 250 h. The precipitate was siderite at 5°C to 25°C. At 40°C, the solid was a mixture of siderite and chuckanovite in low salinity water and siderite with dissolved Ca^{2+} in artificial seawater. The corrosion rate of carbon steel at pH 6.7 to 7.2 at 25°C decreased to less than 0.01 mm/y in 5 h. Siderite precipitated and grew to a thin protective layer at the steel surface. Even though the solutions were highly supersaturated with respect to siderite throughout the experiments, the carbonate layer at the steel surface did not grow to more 5 μm thickness during 250 h to 400 h. The investigated steels were armor wires for flexible pipes. They have an oxide layer at the surface which is an inherent result of the manufacturing process. The presence of these oxides did not impede the formation of protective siderite layer.

KEY WORDS: annulus, CO_2 corrosion, flexible pipe, near neutral pH, siderite, stress corrosion cracking

INTRODUCTION

Various industries use coatings and insulation to minimize corrosion. However, corrosion is seldom eliminated as corrodents may enter manufacturing defects and delamination voids. Corrosion in such occluded spaces is characterized by a limited supply of water and a fast buildup of corrosion products.[1-2]

Flexible pipes are extensively used as risers and flowlines in offshore oil and gas production systems. They have armor wires of high-strength carbon steel in a confined annular space between an inner and outer polymer sheath. During operation, water from the bore may diffuse through the inner sheath while damage to the outer sheath or improper sealing will result in seawater ingress.[3-4] Diffusion of CO_2 and H_2S from the bore through the inner polymer sheath increases the corrosivity of the water in the annulus.

When CO_2 diffuses through the inner sheath it maintains a low, but significant, concentration of CO_2 and carbonic acid in the water phase in the annulus. Although at lower concentration than in the bore, it may cause significant corrosion of the carbon steel wires. The corrosion reactions are probably the same as encountered at higher CO_2 concentrations, but their relative contribution to the corrosion rate can be different. The cathodic and anodic reactions considered are given in Equations (1) through (5).[5-9]

$$2H_2CO_3 + 2e^- \rightleftharpoons 2HCO_3^- + H_2 \quad (1)$$

$$2HCO_3^- + 2e^- \rightleftharpoons 2CO_3^{2-} + H_2 \quad (2)$$

$$2H^+ + 2e^- \rightleftharpoons H_2 \quad (3)$$

$$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^- \quad (4)$$

$$Fe \rightleftharpoons Fe^{2+} + 2e^- \quad (5)$$

The cathodic reactions either consume acid or produce alkali. If the alkaline corrosion products accumulate, the pH of the water in the annulus will increase and reach neutral pH (6.5 to 8.5).[10-16] The V/S ratio (i.e., the relation between the free volume in the annulus [V] and the surface area of the carbon steel wires [S]) is commonly less than 0.1 mL/cm^2. So, even a low corrosion rate will result in a fast increase of Fe^{2+} and HCO_3^-

Submitted for publication: December 2, 2020. Revised and accepted: March 10, 2021. Preprint available online: March 11, 2021, https://doi.org/10.5006/3514.
‡ Corresponding author. E-mail: tcampos@metalmat.ufrj.br.
* LabCorr/PEMM/COPPE, Federal University of Rio de Janeiro-UFRJ, P.O. box 68505, Zip Code 21941-599, Rio de Janeiro/RJ, Brazil.
** Institute for Energy Technology, P.O. Box 40, NO-2027 Kjeller, Norway.

Laboratório de Corrosão

Engineering Failure Analysis 120 (2021) 105081

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

ELSEVIER

Hydrogen embrittlement of API 5L X65 pipeline steel in CO_2 containing low H_2S concentration environment

S.C. Silva *, A.B. Silva, J.A.C. Ponciano Gomes

Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering, Labcorr, Rio de Janeiro, Brazil

ARTICLE INFO

Keywords:
Hydrogen embrittlement
Sweet environment
Sour environment
Cathodic polarisation
Pipeline carbon steel

ABSTRACT

The basic corrosion mechanisms in CO_2 environments are widely investigated and reported by scientific community. However, cracking failure mechanisms in CO_2 environment or in environments where CO_2 coexist with other gases need a better understanding. Cracking susceptibility of API 5L X65 in pure CO_2 was recently reported and the basic mechanism was attributed to hydrogen embrittlement. The influence of hydrogen permeation and the detrimental effect of cathodic polarisation support the assumption of hydrogen embrittlement as the determining factor for the loss of plasticity and strength. The loss of strength of an API 5L X65 steel when CO_2 and H_2S coexist in the same environment is the focus of the present work. Hydrogen embrittlement (HE) and hydrogen induced cracking (HIC) of pipeline steels are failures modes expected to occur in CO_2 with traces of H_2S environments. The present work aims to approach the performance in laboratory of an API 5L X65 steel in CO_2 with traces of H_2S environment (slightly sour), using as baseline the performance of the material in pure CO_2 environment (sweet), already reported. Hydrogen permeation and Slow Strain Rate Tests (SSRT) were carried out in CO_2 environment containing low concentration of H_2S. It was observed that traces of H_2S in CO_2 environment promote much more intense hydrogen permeation, much higher than in purely CO_2 environment. Loss of ductility was also much more severe than in CO_2 environment, with and without the influence of cathodic polarisation. Hydrogen generation enhancement promoted by traces of H_2S in solution, corresponding to an average content of 21 ppm in solution, had a heavy effect on hydrogen embrittlement of the steel, confirmed by the lower ratio of reduction in area (RRA) and time to fracture in comparison with sweet service conditions.

1. Introduction

Carbon pipeline steels are exposed to severe operational conditions and the hydrogen embrittlement susceptibility is a primary concern for the material selection in oil and gas production and transport [1]. The growing demand of oil and gas industry support the search of low-cost and safe transport systems. The development of high-strength carbon steel pipelines is necessary in order to significantly reduce the total cost of long-distance oil and gas pipelines. However, there is a strong concern about the environments in which these pipelines are employed, owing to the presence of aggressive ions, such as Cl^-, and gases as CO_2 and H_2S [2]. CO_2 corrosion (sweet corrosion) and H_2S corrosion (sour corrosion) in aqueous solution are among the most severe problems for oil and gas industry. CO_2 gas present in oil production or transport is used to enhance the oil recovery. Nevertheless, this gas reacts with the brine

* Corresponding author at: Department of Materials and Metallurgical Engineering, Federal University of Rio de Janeiro, Brazil.
E-mail address: maraufrj@hotmail.com (S.C. Silva).

https://doi.org/10.1016/j.engfailanal.2020.105081
Received 8 June 2020; Received in revised form 4 November 2020; Accepted 5 November 2020
Available online 9 November 2020

2021 - EAC results in mixed H_2S/CO_2 environments, showing different hydrogen embrittlement mechanisms. Potential control within immunity corrosion domain

labcorr
Laboratório de Corrosão

Engineering Failure Analysis 111 (2020) 104380

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Assessment of hydrogen embrittlement severity of an API 5LX80 steel in H_2S environments by integrated methodologies

Mariana Costa Folena*, Jose Antonio da Cunha Ponciano

Department of Metallurgical and Materials Engineering (COPPE/UFRJ) – Labcorr, Federal University of Rio de Janeiro, Centro de Tecnologia, Bloco I, Cidade Universitária, Rio de Janeiro, Brazil
LabCorr – Centro de Tecnologia, Bloco I – Cidade Universitária, Rio de Janeiro, RJ 21941-972, Brazil

A R T I C L E I N F O

Keywords:
Hydrogen embrittlement
Surface layers
Pipeline failure

A B S T R A C T

High strength steel, as API 5L grade X80 and above, have been applied in pipelines for sour service in oil and gas industry. Hence, comes the concern about the risks comprising hydrogen diffusion and embrittlement due to combined effect of operational conditions and corrosive environment containing hydrogen sulphide (H_2S). Many efforts have been made to predict and understand the mechanisms involving hydrogen embrittlement under applied strain, nonetheless they are still not entirely understood. Furthermore, the growth of iron sulphide scales can influence on the diffusion process. This study investigates the behaviour of the API X80 steel concerning hydrogen absorption in solutions with different concentrations of H_2S, by integrating different test methodologies at static and tensile conditions. It aims to evaluate hydrogen embrittlement susceptibility of the steel by means of hydrogen permeation and slow strain rate tests and a new complementary image processing methodology. Particularly, the embrittlement phenomenon is studied alongside with iron sulphide film influence as a protective barrier to hydrogen entry in sodium thiosulphate brines containing up to 10 ppm of H_2S. Investigations by means of electrochemical impedance spectroscopy and surface analysis indicated that exists a relationship between different concentrations of H_2S, scale precipitation and its barrier protectiveness to hydrogen uptake. It was observed a diminution of hydrogen permeation through the steel due to formation of mackinawite, however under tensile stress the film breakage may allow not only hydrogen diffusion into the steel, but also the occurrence of hydrogen embrittlement.

1. Introduction

H_2S present in oil and gas sour fields can affect the metallurgical properties of structural steels, such as its ductility, which results in loss of mechanical properties. Hydrogen embrittlement is a relevant process that can lead to catastrophic pipeline failures. Operational conditions of the pipelines, such as high temperature, high pressure and flow conditions, together with the presence of hydrogen, results in the scenario required for the occurrence hydrogen embrittlement (HE) and hydrogen induced cracking (HIC). Each year, tens of millions of dollars are expended to replace or repair pipelines and vessels that suffer excessive localized corrosion, stress corrosion cracking (SCC) or hydrogen embrittlement (HE) degradation processes [1].

During the past decades much effort has been made in order to achieve a better understanding of the embrittlement phenomena, and how to prevent it [2,3]. Still, up to now these mechanisms are not fully understood due to the high number of driving variables

* Corresponding author.
E-mail address: marianafolena@metalmat.ufrj.br (M.C. Folena).

https://doi.org/10.1016/j.engfailanal.2020.104380
Received 20 August 2019; Received in revised form 25 November 2019; Accepted 6 January 2020
Available online 19 February 2020

2020 – Several integrated techniques to assess hydrogen embrittlement susceptibility – mechanical tests in corrosive environments, hydrogen diffusion, including image processing tools.

Laboratório de Corrosão

2020 – Similar experimental approach in pure CO_2 environment carried out under cathodic polarization using mechanical tests, hydrogen diffusion to confirm the influence of hydrogen

Engineering Failure Analysis 113 (2020) 104550

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

ELSEVIER

Cracking mechanism in API 5L X65 steel in a CO_2-saturated environment – Part II: A study under cathodic polarisation

S.C. Silva[a], A.B. Silva[a], M.C. Folena[a], R. Barker[b], A. Neville[b], J.A.C. Ponciano Gomes[a,*]

[a] Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering, Labcorr, Rio de Janeiro, Brazil
[b] Institute of Functional Surfaces, Faculty of Mechanical Engineering, University of Leeds, Leeds LS2 9JT, United Kingdom

ARTICLE INFO

Keywords:
Hydrogen embrittlement
Cathodic polarisation
CO_2 corrosion
Surface layers
Pipeline steel failures

ABSTRACT

The aim of this work is to achieve a better understanding of hydrogen effect in CO_2 environments, isolating its contribution by imposing cathodic polarisation on Hydrogen Permeation (HP) and Slow Strain Rate Tests (SSRTs). The influence of Fe_3C and $FeCO_3$ layers on hydrogen embrittlement (HE) susceptibility was a specific focus of this study. The results indicate that CO_2 environment generates hydrogen, which permeates through steel, although in lower amount compared to H_2S environments. Moreover, in Fe_3C-rich surface, the HP current achieves values higher than in wet-ground surface. Furthermore, in $FeCO_3$-filmed surface HP current is higher at the beginning of the test but decreases over time. The results of SSRT show the loss of ductility of the steel under cathodic polarisation that was driven by hydrogen and the embrittlement effect magnitude depends on the surface condition, indicating that a pre-corroded steel surface can raise the HE susceptibility in a CO_2 environment.

1. Introduction

Carbon steel pipelines are widely used due to their high yield strength while maintaining enough ductility as required by structural materials [1]. Pipeline steels must have high strength and fracture toughness as well as provide an economical and safe option to transport oil and natural gas along far distances [2–4]. However, carbon steels are susceptible to uniform corrosion in aqueous environments [1] being CO_2 corrosion one of the major integrity issues for the oil and gas industry. Also known as "sweet corrosion", this particular degradation mechanism has been reported to cause 25% of safety incidents. It has been associated with damage by both general and localised corrosion. Furthermore, the presence of corrosion products/films has been shown to have a significant effect on the corrosion mechanism [5,6]. Transgranular Stress Corrosion Cracking (TGSCC) has been studied and related to environments with CO_2 as a main contaminant [5]. Among the determining factors of TGSCC is hydrogen embrittlement. It is known that the application of a cathodic potential below the thermodynamic equilibrium potential H/H^+ ensures the hydrogen generation in metallic interface. Based on this, Asher [7] examined the effect of hydrogen on mechanical properties of pipeline steels by using slow strain rate tests. Initial tests were conducted in the standard TGSCC environment with the application of cathodic polarisation to ensure that hydrogen would be generated at the steel surface and then would permeate into the steel test specimens. Increased hydrogen generation on the steel surface by cathodic polarisation resulted in a reduction of deformation to failure, thereby indicating loss of ductility. As previously mentioned, further important aspect to be understood in CO_2 corrosion is the influence of corrosion products formed on the carbon steel surface. In CO_2-saturated aqueous environment, the formation and precipitation of iron carbonate ($FeCO_3$) and iron carbide (Fe_3C) enrichment can occur [8] and these layers can be protective or harmful for the pipeline steel.

* Corresponding author.
E-mail address: ponciano@metalmat.ufrj.br (J.A.C. Ponciano Gomes).

https://doi.org/10.1016/j.engfailanal.2020.104550
Received 5 September 2019; Received in revised form 6 March 2020; Accepted 13 April 2020
Available online 17 April 2020

Laboratório de Corrosão

Received: 9 July 2018 | Accepted: 15 August 2018
DOI: 10.1002/maco.201810407

ARTICLE

Materials and Corrosion

Analysis of the use of environmentally friendly corrosion inhibitors for mild steel in a carbon dioxide saturated chloride solution via experimental design

Mariana Vieira Casanova Monteiro[1] | Frederick Pessu[2] | Richard Barker[2] | José Antônio da Cunha Ponciano Gomes[1] | Anne Neville[2]

[1] LabCorr, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil
[2] Institute of Functional Surfaces, School of Mechanical Engineering, University of Leeds, Leeds, United Kingdom

Correspondence
Mariana Vieira Casanova Monteiro, LabCorr, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil.
Email: marianavcmonteiro@gmail.com

Funding information
CNPq (National Council for Scientific and Technological Development/Conselho Nacional de Desenvolvimento Científico e Tecnológico); ANP (Brazilian National Agency of Petroleum, Natural Gas and Biofuels/Agência Nacional do Petróleo, Gás Natural e Biocombustíveis); Shell

In the oil and gas industry, carbon dioxide (CO_2) gas dissolved in produced fluids can cause both general and localized corrosion of carbon steel pipelines due to the speciation of carbonic acid. To mitigate corrosion, the injection of inhibitors into the production fluid is one of the most commonly used methods. However, recent changes in regulations has resulted in a requirement for the development of new corrosion inhibitors that conform to European regulations. This paper presents a full two-level factorial experimental design approach to study individual effects of environmentally friendly classed inhibitor components (phosphate ester, imidazoline, and quaternary amine derivatives) as combined inhibitors and their interactive effects on carbon steel corrosion processes in CO_2-saturated 3.5 wt.% NaCl brine. Through the application of in situ electrochemical monitoring, post-test interferometry, and scanning electron microscopy (SEM) it was possible to determine the influence of each component within the blends and their effect on both general and localized corrosion. Based on 24 h experiments, the phosphate ester derivative reduced general corrosion rate in all blends; imidazoline derivatives reduced the uniform corrosion rate only when it was at the high level in the blend; and the quaternary amine derivative promoted pitting on the surface.

KEYWORDS
carbon dioxide corrosion, corrosion inhibitors, environmentally friendly chemicals, imidazoline, mild steel, phosphate ester, quaternary ammonium salt

1 | INTRODUCTION

Internal carbon dioxide (CO_2) corrosion of carbon steel pipelines is a serious and costly problem in the oil and gas industry.[1] Carbon steels are extensively used in this industry, despite being highly susceptible to corrosion under these conditions.[2] This is a result of their low cost and high level of availability. CO_2, generally present in the fluid produced in the form of dissolved gas, is an influential component in oil field production fluids and its presence permits the formation of carbonic acid, a weak acid which can result in significant levels of corrosion, unless appropriately mitigated.[3–5]

Among the different forms of corrosion control, the application of inhibitors is one of the most common methods, being widely used in oil and gas production systems in order to control internal corrosion of carbon steel structures.[6–7] Such chemicals can be administered through continuous injection, batch treatment, or squeeze treatment. Traditional inhibitors tend to consist predominantly of nitrogen-containing compounds (imidazolines, amines,

2019 – Corrosion inhibitor (green) as mitigation technology in CO_2 environments.

Laboratório de Corrosão

2019 - Cracking in pure CO_2 environments is possible even with low carbon steels (API X65) and hydrogen is part of the cracking mechanism behind.

Engineering Failure Analysis 99 (2019) 273–291

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Cracking mechanism in API 5L X65 steel in a CO_2-saturated environment

Samara Cruz da Silva[a,*], Eduardo Alencar de Souza[a], Frederick Pessu[b], Yong Hua[b], Richard Barker[b], Anne Neville[b], José Antônio da Cunha Ponciano Gomes[a]

[a] Department of Metallurgical and Materials Engineering (COPPE/UFRJ)-Labcorr, Federal University of Rio de Janeiro, Centro de Tecnologia, Bloco I, Cidade Universitária, Rio de Janeiro, Brazil
[b] Institute of Functional Surfaces, Faculty of Mechanical Engineering, University of Leeds, Leeds, United Kingdom

ARTICLE INFO

Keywords:
Hydrogen embrittlement
Surface layers
Corrosion
Pipeline failures

ABSTRACT

Hydrogen charging in low alloy steels poses a significant problem in the oil and gas industry. Detrimental hydrogen effects are not commonly expected in CO_2 aqueous environments. However, the acid nature of these environments and the high corrosion rates expected justify the assessment of cracking susceptibility of carbon steel in a CO_2-saturated environment as presented in this work. The focus of this investigation is to understand how different surface films/corrosion products influence the hydrogen permeation and cracking mechanism of an API 5L X65 carbon steel in a saturated CO_2 environment. The experiments were carried out to assess hydrogen permeation at open circuit potential on steel samples which were either wet-ground, or pre-filmed with iron carbide (Fe_3C) rich or iron carbonate ($FeCO_3$) layers. Tafel measurements were also performed to determine the effect of the surface composition on the cathodic reactions. Slow strain rate tests (SSRT) were conducted in order to evaluate the effects of hydrogen on the cracking mechanisms of the steel in this sweet environment. Results indicated that at open circuit conditions, Fe_3C was able to increase the steady state hydrogen permeation current due to accentuation of the cathodic hydrogen-evolution reaction. Although $FeCO_3$ suppressed the cathodic reaction at the steel surface, the development of the protective and densely packed crystalline layer increased hydrogen uptake marginally from that of the ground steel reduced. SSRT indicated a very moderate loss of ductility in wet-ground and $FeCO_3$ steel surface conditions. However, a more significant reduction in area was observed in the tests carried out on Fe_3C rich samples. These results imply that a corroded API 5L X65 steel surface in a CO_2 rich environment can enhance the hydrogen embrittlement (HE) susceptibility and as such, hydrogen permeation susceptibility needs to be considered in material selection.

1. Introduction

Carbon steel pipelines play an extremely important role throughout the world as a transporting system of oil and gas over long distances from their sources to ultimate consumers. Under specific operating conditions, the risk of hydrogen embrittlement of steels can be one of the primary concerns. CO_2 is known for its strong impact on corrosion. Besides its impact on global electrochemical kinetics, CO_2 might also have a direct contribution to the hydrogen charging mechanism [1], seeing that is well-known that in

* Corresponding author.
E-mail address: maraufrj@hotmail.com (S.C.d. Silva).

https://doi.org/10.1016/j.engfailanal.2019.02.031
Received 20 August 2018; Received in revised form 29 January 2019; Accepted 14 February 2019
Available online 15 February 2019
1350-6307/

Int. J. Electrochem. Sci., 8 **(2013)** 9187 - 9200

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Electrochemical Treatment of Oil Refinery Wastewater for NH_3-N And COD Removal

Laisa Candido[1,*], *José Antonio C. Ponciano Gomes*[1], *Hermano Cezar Medaber Jambo*[2]

[1]Corrosion Laboratory – COPPE; Federal University of Rio de Janeiro; Cid. Universitária - Centro de Tecnologia-Bloco I; Ilha do Fundão - POBOX 68505; Rio de Janeiro, RJ – ZIP CODE 21941-972 – BRAZIL
[2] PETROBRAS S.A; Avenida Chile, 65; Rio de Janeiro, RJ – ZIP CODE 20031-912 – BRAZIL
[*]E-mail: laisa@metalmat.ufrj.br

Received: 24 April 2013 / *Accepted:* 9 June 2013 / *Published:* 1 July 2013

760 Jambo, Freitas and Ponciano Materials and Corrosion *52*, 760–765 (2001)

Assessment of hydrogen permeation on steels by a simplified device using two electrode configuration based on passive interfaces

Beurteilung der Wasserstoffpermeation an Stahl mit Hilfe einer vereinfachten Zwei-Elektroden-Anordnung mit passiven Grenzflächen

**H. C. M. Jambo, D. S. de Freitas*
and J. A. C. Ponciano**

PERGAMON

Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
Corrosion Science 45 (2003) 2129–2142

CORROSION SCIENCE
www.elsevier.com/locate/corsci

Scanning photoelectrochemical analysis of hydrogen permeation on ASTM A516 grade60 steel welded joints in a H_2S containing solution

F.M.F. Guedes [a], S. Maffi [b], G. Razzini [b], L. Peraldo Bicelli [b,*], J.A.C. Ponciano [a]

[a] *Departamento de Eng Metalúrgica e de Materiais-COPPE/UFRJ, Rio de Janeiro, 21949-970, Brazil*
[b] *Dipartimento di Chimica Fisica Applicata del Politecnico-CNR-CESPEL, Via Mancinelli, 7, 20131 Milano, Italy*

Received 27 March 2001; accepted 5 February 2003

Materials Chemistry and Physics 129 (2011) 1146–1151

Contents lists available at ScienceDirect

Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys

ELSEVIER

Evaluation of anode materials for the electro-oxidation of ammonia and ammonium ions

Laisa Candido*, José Antonio C. Ponciano Gomes

Corrosion Laboratory – COPPE, Federal University of Rio de Janeiro, Cid. Universitária-Centro de Tecnologia-Bloco I, Ilha do Fundão, Caixa Postal 68505, Rio de Janeiro, RJ, CEP 21941-972, Brazil

revista Matéria

ISSN 1517-7076

Revista Matéria, v. X, n. Y, pp. PP – PP, 200x
http://www.materia.coppe.ufrj.br/sarra/artigos/artigo10XXX

Preparação e uso de polímeros sólidos como eletrólito em sensores de hidrogênio

Otávio Carneiro Corrêa[I], José A.C.Ponciano Gomes[II]

[I] Laboratório de Corrosão – PEMM/COPPE/UFRJ – Rio de Janeiro - RJ

occorrea@metalmat.ufrj.br

[II] Laboratório de Corrosão – PEMM/COPPE/UFRJ – Rio de Janeiro - RJ

ponciano@metalmat.ufrj.br

US005858204A

United States Patent [19]
Jambo et al.

[11] **Patent Number:** **5,858,204**
[45] **Date of Patent:** **Jan. 12, 1999**

[54] **ELECTROCHEMICAL SENSOR AND PROCESS FOR ASSESSING HYDROGEN PERMEATION**

[75] Inventors: **Hermano Cezar Medaber Jambo; José Antônio da Cunha Ponciano Gomes**, both of Rio de Janeiro, Brazil

[73] Assignee: **Petroleo Brasileiro S.A.:Petrobras**, Rio de Janeiro, Brazil

[21] Appl. No.: **615,885**

[22] Filed: **Mar. 14, 1996**

[30] **Foreign Application Priority Data**

Mar. 14, 1995 [BR] Brazil .... PI 9501061-0

[51] **Int. Cl.**[6] **G01N 27/26**
[52] **U.S. Cl.** **205/775**; 204/400; 205/790.5
[58] **Field of Search** 204/400, 404; 205/775, 775.5, 776, 776.5, 777, 790.5

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,886,497	5/1959	Butler	205/790.5
3,629,090	12/1971	Ghormley	204/404
3,798,755	3/1974	Sandstrom	204/272
4,065,373	12/1977	Martin et al.	204/195

FOREIGN PATENT DOCUMENTS

2218520 of 1989 United Kingdom .
WO8303007 9/1983 WIPO .

OTHER PUBLICATIONS

Corrosion 84, Paper No. 237, "Corrosion Monitoring with Hydrogen Probes in the Oil Field" by William H. Thomason, 13 pages.

Corrosion 91, Paper No. 444, "Electrochemical Noise for Detection of Susceptibility to Stress Corrosion Cracking" by E.A. Eden, et al., 13 pages.

Primary Examiner—T. Tung
Attorney, Agent, or Firm—Sughrue, Mion, Zinn, Macpeak & Seas, PLLC

[57] **ABSTRACT**

An electrochemical sensor designed to be employed in equipment of petrochemical plants made of an electrochemical cell without polarization which includes an outer tube or first electrode and an internal rod or second electrode. Both first and second electrodes being provided with wires for external electrical contact. The first and second electrodes being separated by a standard electrolytic solution for the oxidation of the nascent hydrogen which is generated by the corrosion reactions caused by sulfur compounds in contact with the hydrogen-permeable metal which constitutes the equipment of petrochemical plants. The sensor is coupled to a zero resistance ammeter which assesses the electrical current generated by the oxidation of the nascent hydrogen and provides a plot of electrochemical noise.

14 Claims, 3 Drawing Sheets

República Federativa do Brasil
Ministério da Indústria, Comércio Exterior e Serviços
Instituto Nacional da Propriedade Industrial

(21) **BR 102014002289-9 A2**

(22) **Data do Depósito:** 30/01/2014

(43) **Data da Publicação:** 01/11/2016

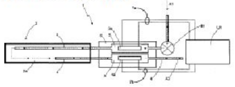
(54) Título: SISTEMA PARA DETECÇÃO E MEDIÇÃO DE FLUXO DIFUSIVO DE HIDROGÊNIO PERMEADO E DISPOSITIVO DETECTOR DE HIDROGÊNIO PERMEADO

(51) Int. Cl.: G01N 17/02; G01N 27/00

(73) Titular(es): PETROLEO BRASILEIRO S. A. - PETROBRAS

(72) Inventor(es): GIL ROBERTO VIEIRA PINHEIRO, Engenheiro(a). CGC/CPF: 77967445791, HERMANO CEZAR MEDABER JAMBO, Engenheiro(a), JOSÉ ANTÔNIO DA CUNHA PONCIANO GOMES, Engenheiro(a). CGC/CPF: 37844156600

(57) Resumo: SISTEMA PARA DETECÇÃO E MEDIÇÃO DE FLUXO DIFUSIVO DE HIDROGÊNIO PERMEADO E DISPOSITIVO DETECTOR DE HIDROGÊNIO PERMEADO, mais precisamente, trata-se de um sistema (1) que permite monitorar a deterioração de equipamentos (E1) através da detecção da difusão do hidrogênio oriundo das reações de corrosão do aço. O sistema (1) é formado num circuito fechado composto por uma sonda (2), a ser montada na parte interna ou na superfície externa do equipamento (E1); a sonda (2) mantém uma entrada de ar (A1) atmosférico, proveniente de bomba de ar (B1) e uma saída de mistura de ar com arraste de hidrogênio (A2); tubos capilares (3) e (4) associados à entrada de ar (A1) e saída de mistura de ar/hidrogênio (A2) são interligados a correspondentes termorresistores (3a) e (4a), cada qual disposto em uma cavidade independente (5) prevista em um bloco de posicionamento (6); a mistura de ar/hidrogênio (A2) é conduzida a um termorresistor especialmente montado com conexões elétricas formando um circuito eletrônico em ponte de Wheaststone; o sistema (1) possui uma unidade eletrônica (U1) capaz de efetuar o processamento do sinal dos termorresistores, a c(...)



IMPACTS

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

- Materials in ageing systems – compliance with new demands - asset integrity, EAC stability.
- Impact of materials on ongoing projects – asset integrity, EAC stability and safe conditions. New materials (qualification, NDT tools, repair)
- Alternative electrochemical process – including the use of depolarizers and alternative energy sources.
- Alternative (tailored) materials for hydrogen production, separation and storage.
- Follow-up the Green Energy Era – just in case

Laboratório de Corrosão
COPPE|UFRJ
DMM . PEMM . Poli

KNOWLEDGE INTEGRATION

- ELECTROCHEMISTRY
- MATERIALS SCIENCE
- NUMERICAL MODELLING
- NDT
- SIGNAL PROCESSING - DIGITALIZATION
- ARTIFICIAL INTELIGENCE – DATA AND TEXT MINING
- OTHERS

Thanks for your time and atention!!