



Congresso Internacional de  
Corrosão, Integridade,  
Pintura e Revestimentos  
Anticorrosivos



# New coatings: opportunities and challenges

Israel Gonçalves, D.Sc.

Pesquisador em corrosão

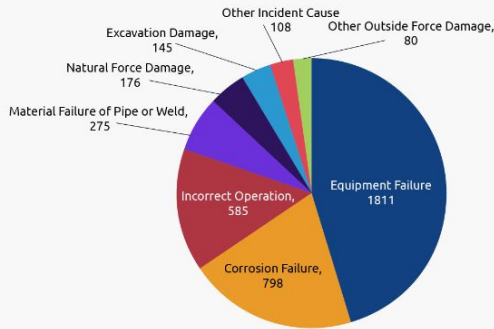
INSTITUTO  
NACIONAL DE  
TECNOLOGIA **IINTE**

MINISTÉRIO DA  
CIÊNCIA, TECNOLOGIA  
E INOVAÇÃO

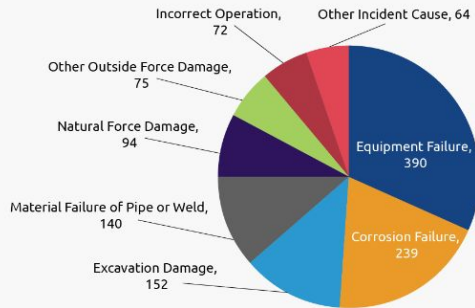


# Contextualization - corrosion failure

**Cause of Hazardous Line Liquid Incidents  
2010 - 2019**



**Cause of Gas Transmission and Gathering  
Line Incidents: 2010 - 2019**



Data from

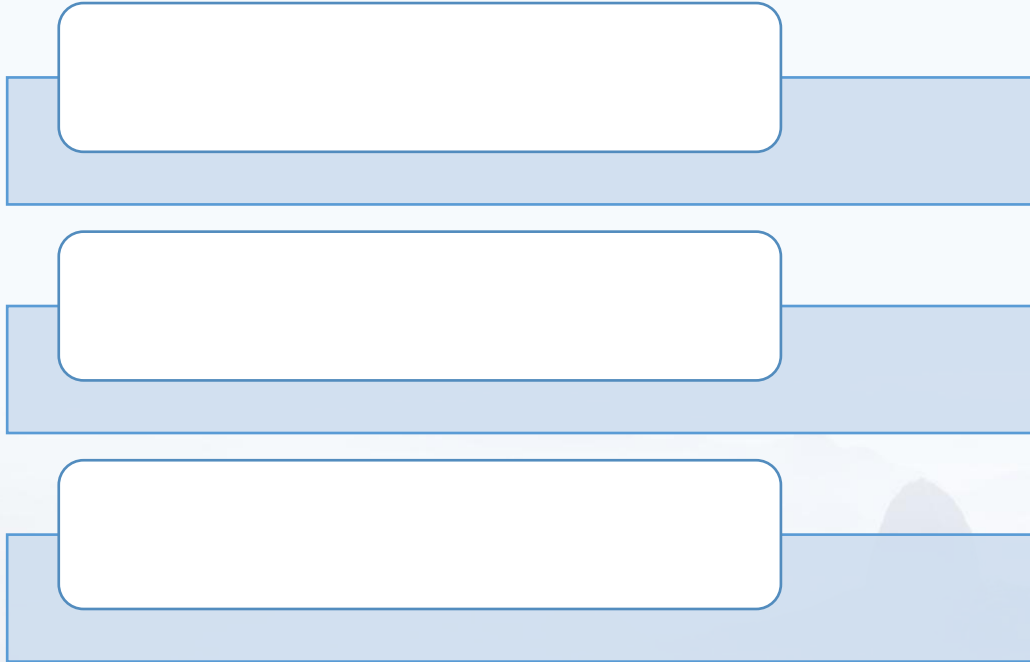
Pipeline and  
Hazardous  
Materials Safety  
Administration

Summary of pipeline incidents 2010–19 (Kelso, 2020).

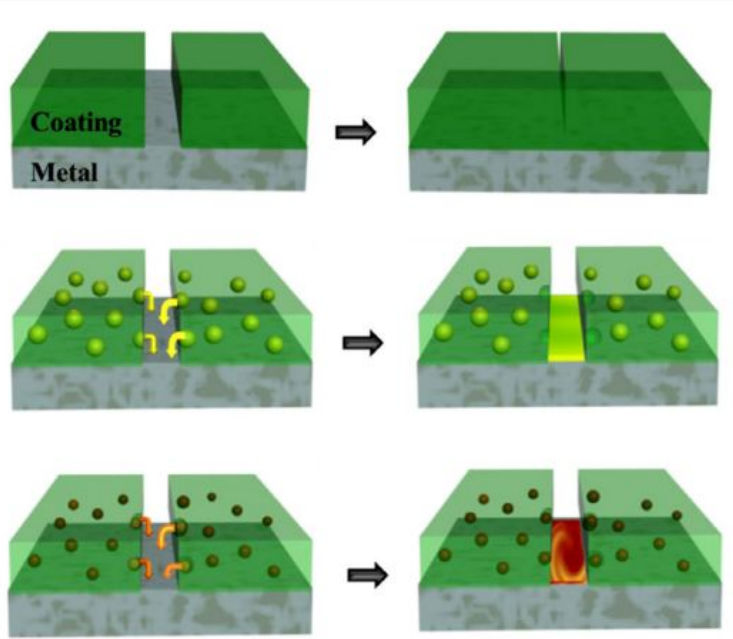
Report	Incidents	Fatalities	Injuries	Evacuees	Damages (\$)	Fires	Explosions
Hazardous Liquid Lines	3978	10	26	2482	2,812,391,218	130	15
Gas Transmission & Gathering Lines	1226	25	108	12,984	1,315,162,976	133	57
Gas Distribution	1094	105	522	20,526	1,229,189,997	659	257
<b>Totals</b>	<b>6298</b>	<b>140</b>	<b>656</b>	<b>35,992</b>	<b>5,356,744,191</b>	<b>922</b>	<b>329</b>

Kelso, M., 2020. Pipelines Continue to Catch Fire and Explode.

# Some examples of new anticorrosive coatings

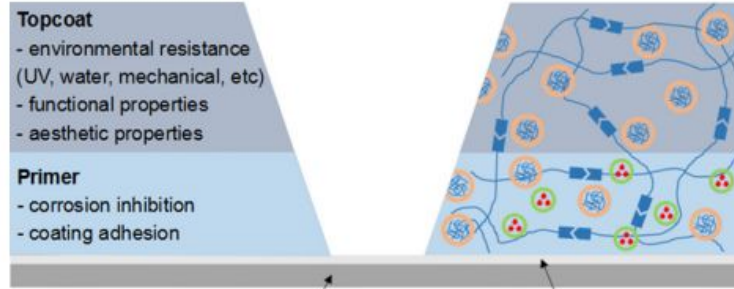


# Self-healing







**Topcoat**  
- environmental resistance (UV, water, mechanical, etc)  
- functional properties  
- aesthetic properties

**Primer**  
- corrosion inhibition  
- coating adhesion

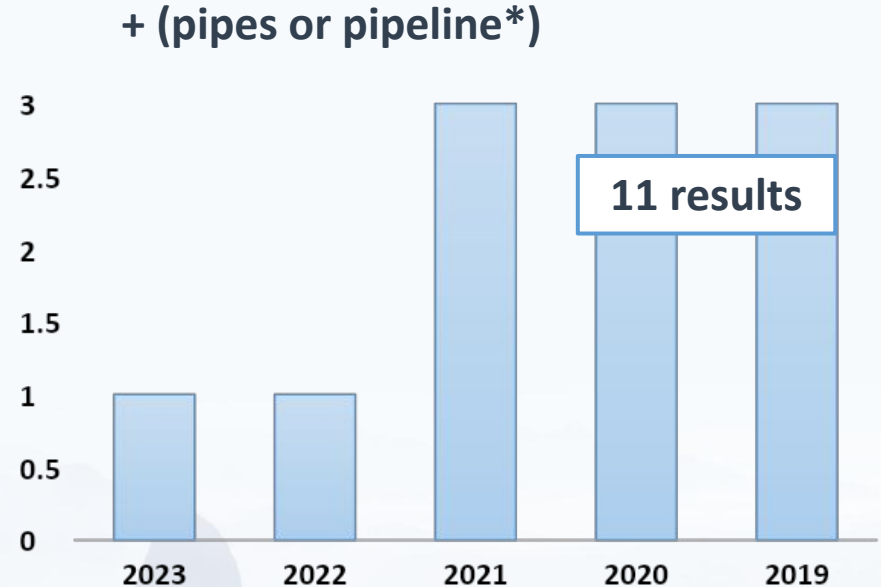
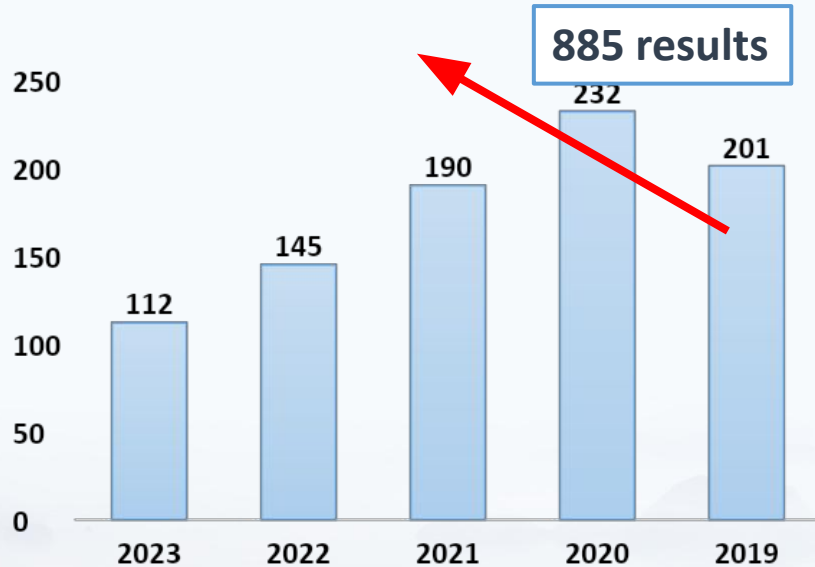


Metal substrate

Pre-treatment

-  Polymerizable healant
-  Corrosion inhibitor
-  Reversible bond
-  Reversible chain conformation

# Self-healing - Research and development



corrosion (Abstract) and surface OR film\* OR coating OR deposit\* (Abstract) and self healing (Abstract)

# Self-healing - Patent

CAS SciFinder<sup>®</sup> Task History

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Initiating Search December 11, 2023, 11:34AM

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**References: Corrosion**

Advanced Search:

**AND** Abstract/Keywords: surface OR film\* OR coating OR deposit\*  
**AND** Abstract/Keywords: self-repair\* OR "self healing" OR "self- healing"  
**AND** Abstract/Keywords: pipes OR pipeline\*

Filtered By:

Document Type: **Patent**  
Publication Year: **2019 to 2023**

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Search Tasks

Task	Search Type	View
Exported: Returned Reference Results + Filters (121)	<b>References</b>	<a href="#">View Results</a>

121

## Document Type

- Journal (70)
- Patent (121)
- Review (5)
- Conference (1)

## Language

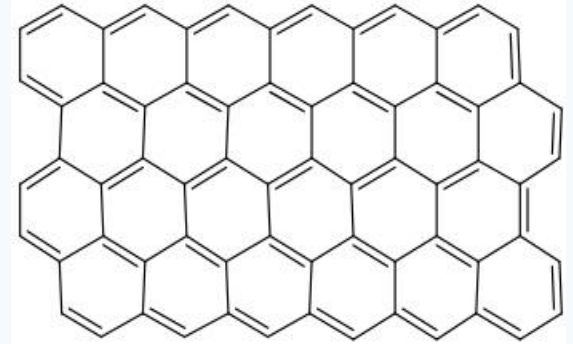
- Chinese (115)
- Russian (2)
- Japanese (1)
- Korean (1)
- Romanian (1)
- Spanish (1)

# Graphene

Production of epoxy-based electrically conductive coatings with the addition of graphene (Ep/Gph)

## Objectives:

- Development of an **electrically conductive coating** for applications in cathodic protection systems under seawater.
- **Achieve an enhancement of the corrosion protection's performance** in these systems by:
  - Barrier effect enhancement
  - Reduction of cathodic disbondment occurrence
  - Reduction of blistering occurrence



Graphene  
Structure

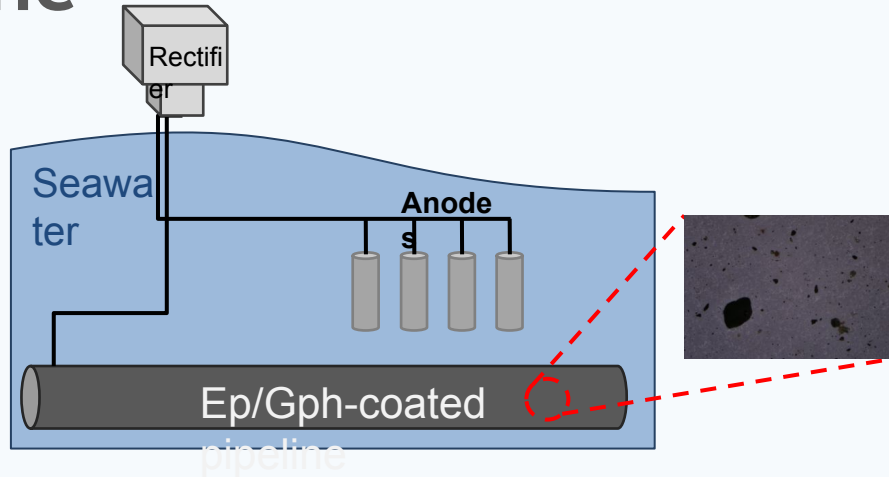
Discovered in 2004

Sp<sup>2</sup> carbon's planar structure

Properties of interest:

- High electrical conductivity
- High Area/Volume ratio

# Graphene

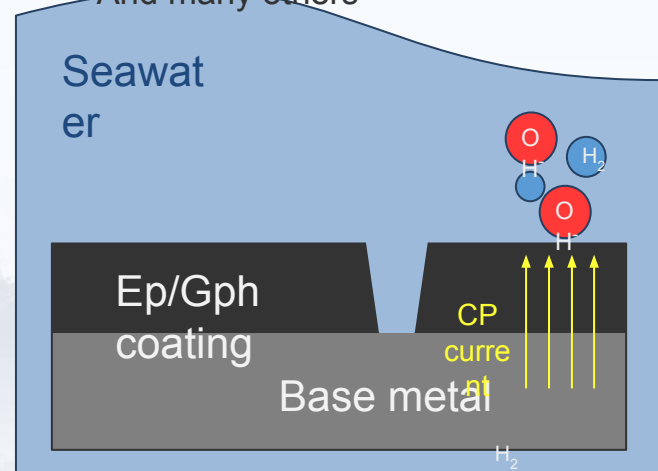


## Important Parameters:

- The effective formation of a **conductive graphene network** depends on factors such as:
  - Average particle size
  - Dispersion's method and time
  - And many others

## Graphene addition benefits:

- **Graphene's high surface area** reduces the formation of **preferential pathways** for water permeation, reducing the occurrence of blistering.
- **The coating's conductivity** allows the reduction reactions to occur on its surface, **reducing the cathodic disbondment** in case of coating failure.



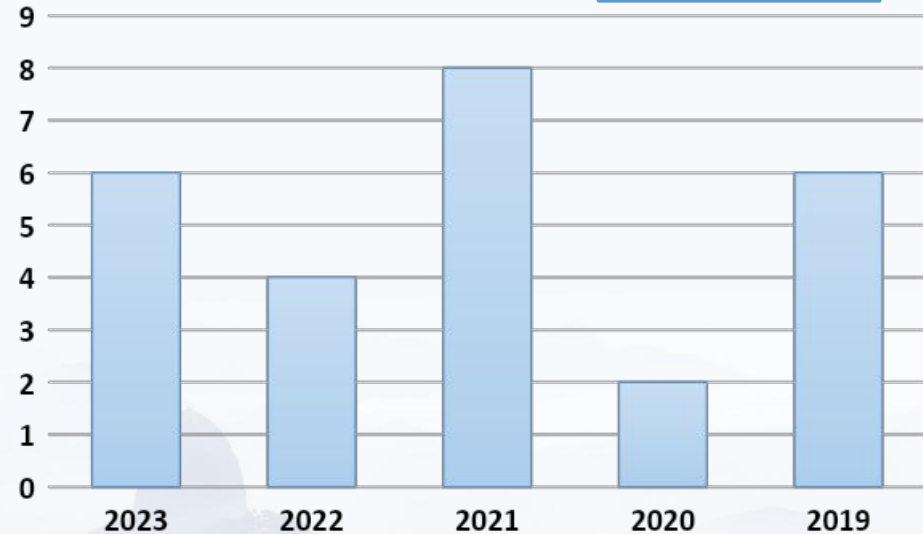
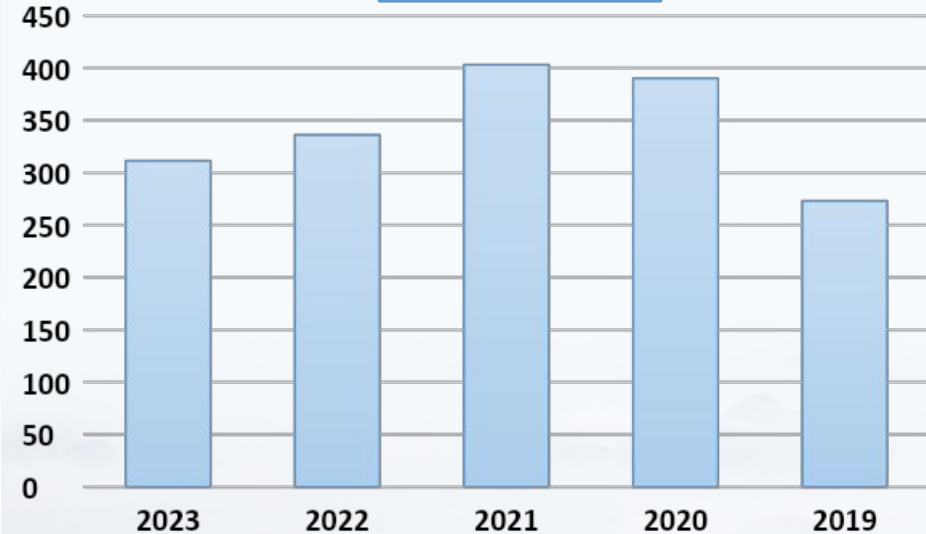


# Graphene - Research and development

1715 results

+ (pipes or pipeline\*)

26 results



corrosion (Abstract) and surface OR film\* OR coating OR deposit\* (Abstract) and graphene (Abstract)



# Graphene - Patent

## Initiating Search

December 11, 2023, 11:52AM

References: Corrosion

Advanced Search:

AND Abstract/Keywords: surface OR film\* OR coating OR deposit\*

AND Abstract/Keywords: graphene

AND Abstract/Keywords: pipes OR pipeline\*

Filtered By:

Document Type: Patent

Publication Year: 2019 to 2023

87

## Search Tasks

Task	Search Type	View
Exported: Returned Reference Results + Filters (87)	References	<a href="#">View Results</a>

### Document Type

Journal (31)

Patent (87)

Review (3)

Conference (1)

### Language

Chinese (83)

English (3)

Korean (1)

# Hydrophobic coatings

## Definition

The degree of hydrophobicity of a solid depends on two factors: its roughness and its surface energy.

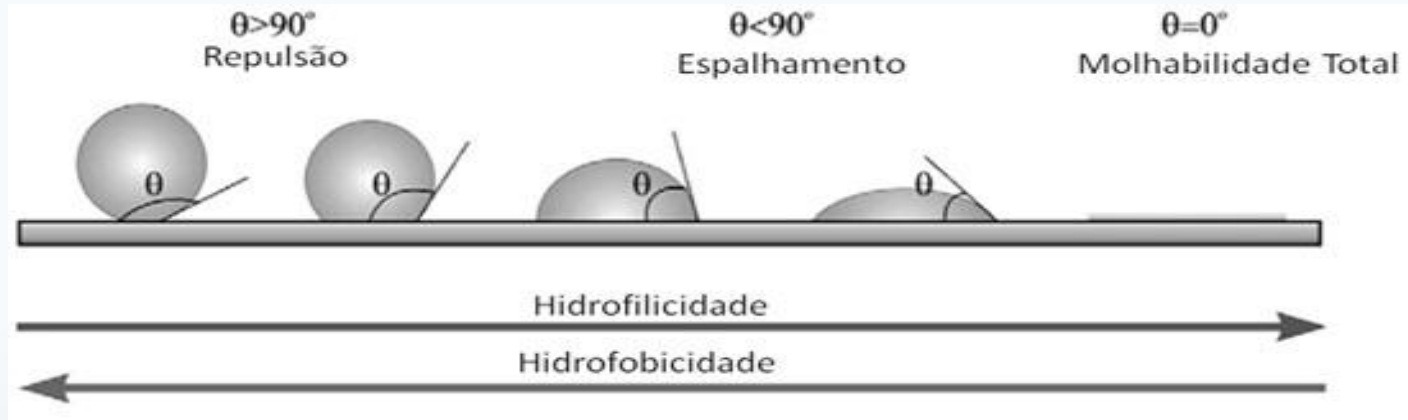


Woodward et al., 2000

The adhesion of one material to another will be greater the greater the energies of the surfaces involved.

# Hydrophobic coatings

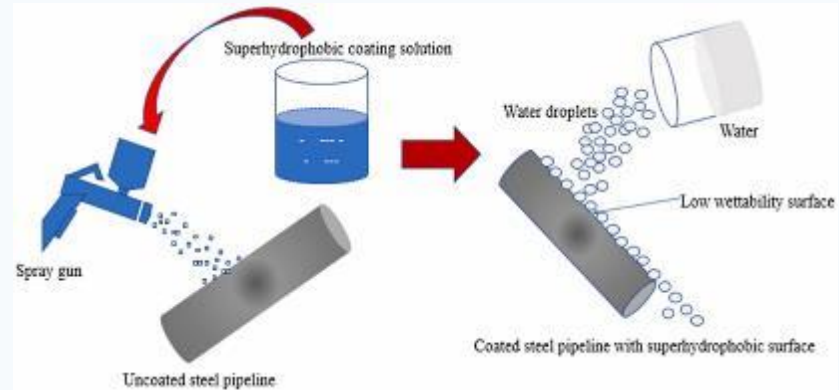
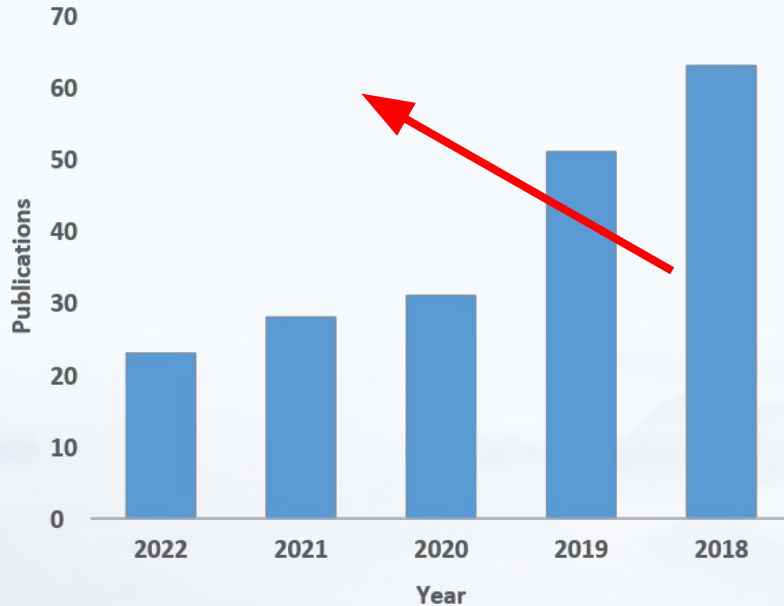
## Water contact angle



Source: Adaptada de Mohamed, Abdulla & Younan, 2014.

# Hydrophobic coatings for pipeline protection

## Research and development

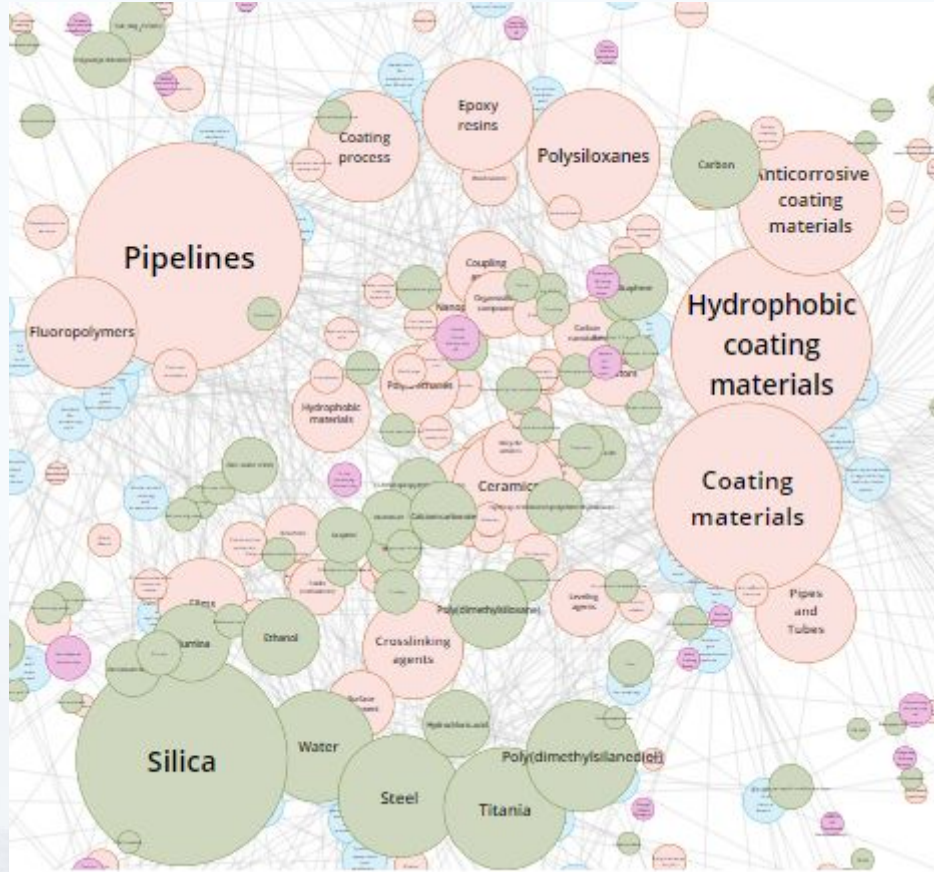
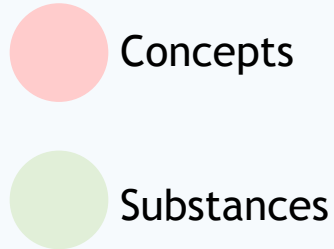


## Title or abstract

(hydrophobic\* OR superhydrophobic\*) AND (pipes OR pipeline\*) AND (surface OR film\* OR coating OR deposit\*)

Source: Web of Science (Jul/2023)

# Hydrophobic coatings for pipeline protection



131 patents

What motivates these tendencies?

# Hydrophobic coatings for pipeline protection

## Anti-icing



### Trans-Alaska Pipeline System

Ice buildup in frigid climates and freeze critical components.

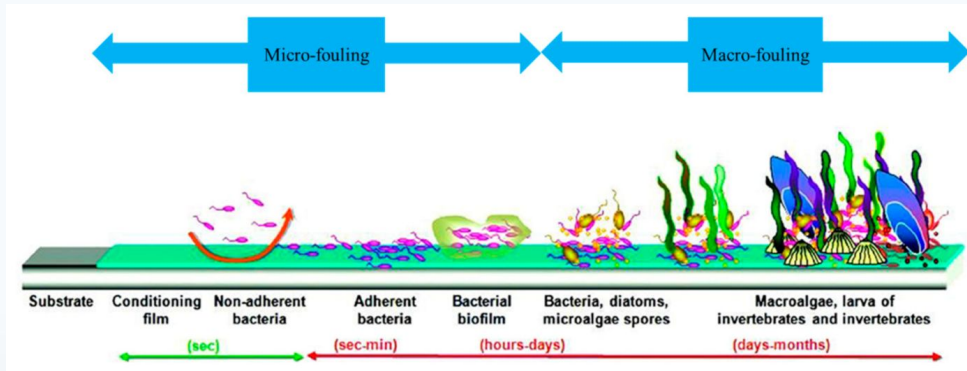
Girgin and Krausmann (2016) looked at 6982 incidents involving onshore pipelines and 72% were caused by freezing

The total cost of 11.1 million USD and the release of 17,400 barrels of oil occurred due to pipeline freezing

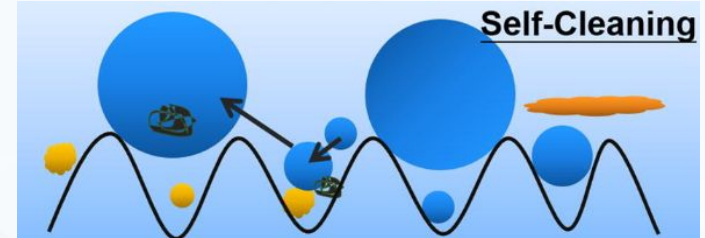
Girgin, S., Krausmann, E., 2016. Historical analysis of U.S. onshore hazardous liquid pipeline accidents triggered by natural hazards. J. Loss Prev. Process. Ind. 40, 578-590.

# Hydrophobic coatings for pipeline protection

## Anti-biofouling



Self-cleaning ability enables the substrate to effectively reduce surface contamination

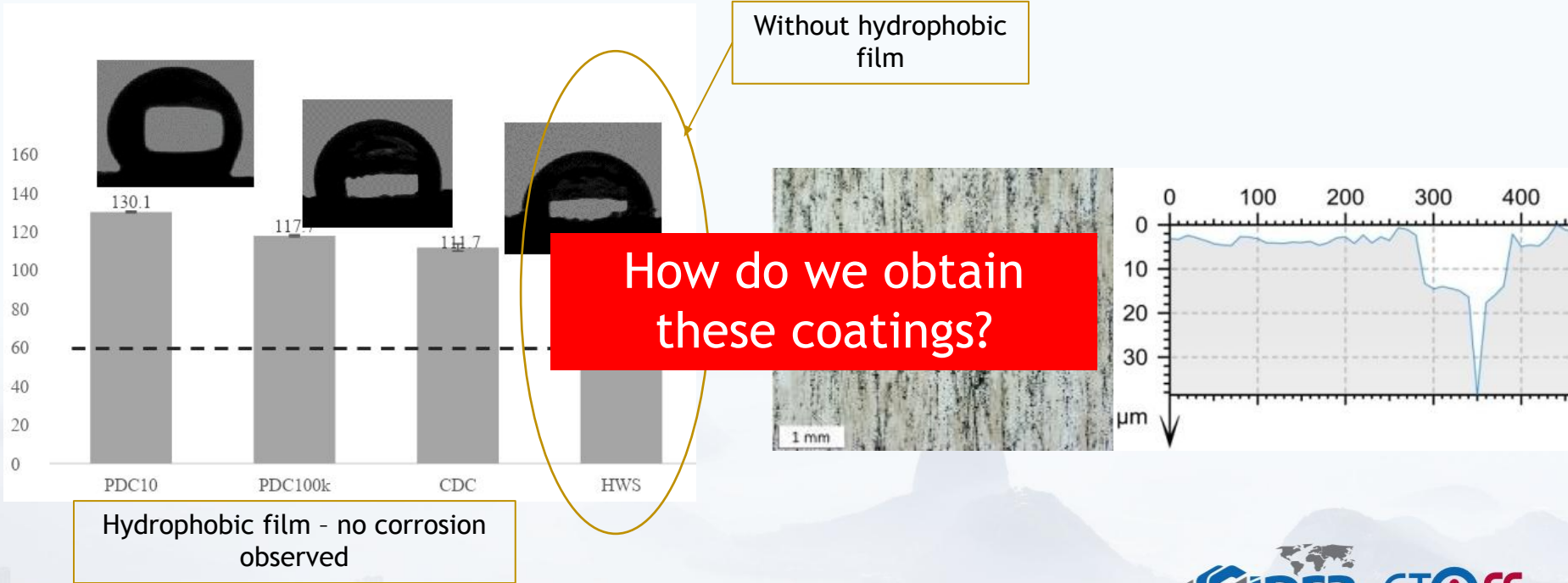


Materials based on hydrophobicity are an effective strategy to reduce the adhesion force between bacteria and a solid surface



# Hydrophobic coatings for pipeline protection

## Anti-corrosion



# Hydrophobic coatings for pipeline protection

## Fabrication strategies for hydrophobic coatings

- Thermal spraying
- Sol-gel
- Dip-coating
- Electrochemical deposition

# Hydrophobic coatings for pipeline protection

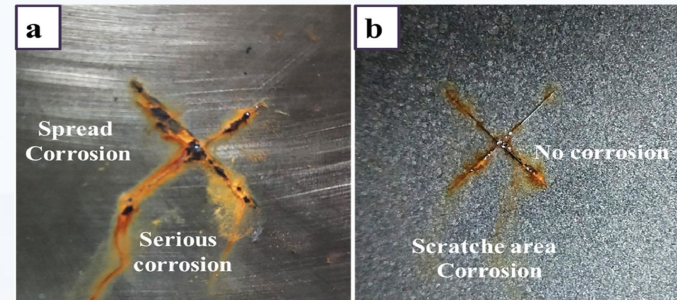
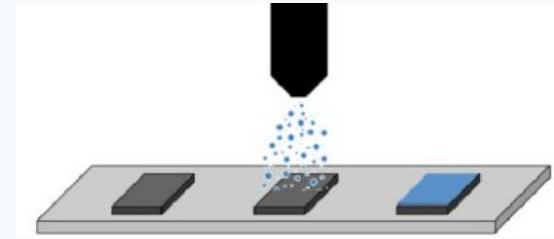
## Fabrication strategies for hydrophobic coatings

- Thermal spraying: hydrophobicity and anti-scaling

1. Epoxy resin
2. Filler: modified carbon nanotubes (iDCNTs), zinc (Zn), polyvinylidene fluoride (PVDF)
3. Xylene and ethyl acetate as solvents
4. Carbon steel

### Results

1. Distinctive **anti-scaling properties** when compared with other epoxy coatings since the deposition of **calcium carbonate was reduced by 81.6%**
2. PTFE NP-filled coating presented **higher hydrophobicity**



(a) EP coating, (b) EP/iDCNTs/Zn/PVDF composite coating.

# Hydrophobic coatings for pipeline protection

## Fabrication strategies for hydrophobic coatings

- Sol-gel

Duas etapas:

1 - Hidrólise dos precursores

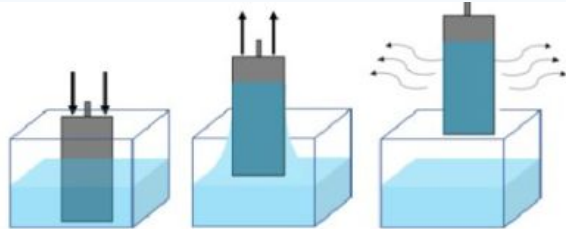
2 - Condensação e formação do filme  
(favorecida em meio alcalino)

# Hydrophobic coatings for pipeline protection

## Fabrication strategies for hydrophobic coatings

- Sol-gel

Dip-coating



Spin-coating



Electrochemical Deposition

# Hydrophobic coatings for pipeline protection

Anti-corrosion

Low conductivity





Application of cathodic potential

Electrophoretic


Pulsed-CEPD x

Application of cathodic potential in a pulsed mode aiming at the reduction of the pH and controlled evolution of  $H_2(g)$ .

Contents lists available at [ScienceDirect](#)

 **Progress in Organic Coatings** 

journal homepage: [www.elsevier.com/locate/porgcoat](http://www.elsevier.com/locate/porgcoat)



Pulsed electrophoretic deposition of hybrid coatings from aqueous suspensions as surface functionalization and sealing technique of anodized AA2024. Part I: Morphological characterization, analysis of the interfacial interactions, and evaluation of pore impregnation of the anodic layer

Israel L.M. Gonçalves<sup>a,b,\*</sup>, Rafael A. Vinhosa<sup>a</sup>, Denise S. de Freitas<sup>a</sup>, Simone L.D.C. Brasil<sup>b</sup>

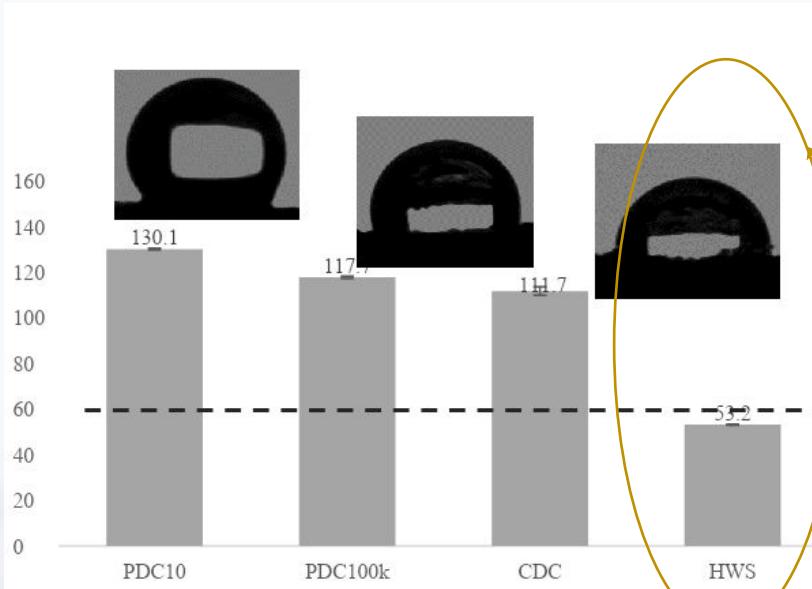
<sup>a</sup> Corrosion Division, National Institute of Technology, Av. Venezuela, 82, Saúde, CEP 22081-312 Rio de Janeiro, RJ, Brazil  
<sup>b</sup> Corrosion and Protection Laboratory, School of Chemistry, Federal University of Rio de Janeiro, Av. Athos da Silveira Ramos 149, Bl. E., CEP 21941-909 Rio de Janeiro, RJ, Brazil

Pulso longo

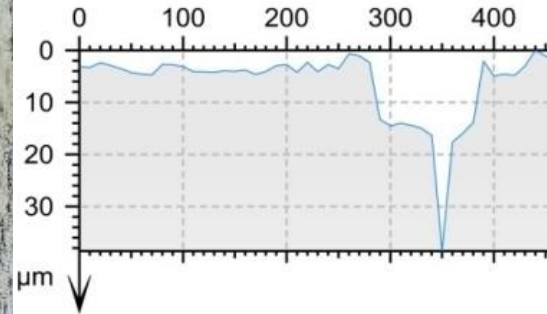
Pulso curto

# Hydrophobic coatings for pipeline protection

## Anti-corrosion



Without hydrophobic film



Hydrophobic film - no corrosion observed

# Hydrophobic coatings for pipeline protection

- **Spraying** is the most **versatile** and widely used technique for the application of coatings, based on the literature
- Shape-memory polymers are recently being incorporated for the **fabrication of superhydrophobic surfaces for self-healing functionality**
- Large-scale is still a challenge
- The **anti-corrosion** performance of various developed superhydrophobic coatings has only been assessed for a **short period of time**
- **Tribological** studies regarding the use of superhydrophobic coatings should also be explored in the future
- Novel **superamphiphobic** coatings should be developed





# Hydrophobic coatings for pipeline protection

*“Future research should focus on developing novel and smart superhydrophobic coatings that incorporate **corrosion inhibitors** and **self-healing** capabilities in order to repair their anticorrosive, anti-biofouling, and self-healing functionalities independently.”*

*Ijaola et al. 2020.*

# Thank you!



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