NSF CAREER: Corrosion resistance of Nano-meter Graphene Coatings in Aggressive Microbial Environment

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Abstract

The microbially induced corrosion (MIC) problem spans a range of multibillion-dollar industries including oil and energy, power plants, wastewater infrastructure, shipping, and aviation. Here, we report the first demonstration of graphene as a superior anti-MIC coating compared to two commercial coatings, i.e. Parylene and Polyurethane. A series of laboratory corrosion cells were used to investigate the effectiveness of graphene coating in preventing MIC of Nickel (Ni) foam under galvanic conditions. The 'Ni' dissolution in the graphene-coated Ni anode was at least an order of magnitude lower than that of Parylene and Polyurethane coating. Detailed electrochemical impedance spectroscopy characterization revealed that graphene offered 10-fold improved microbial corrosion resistance compared to that of polyurethane and 100-fold compared to that of Parylene.

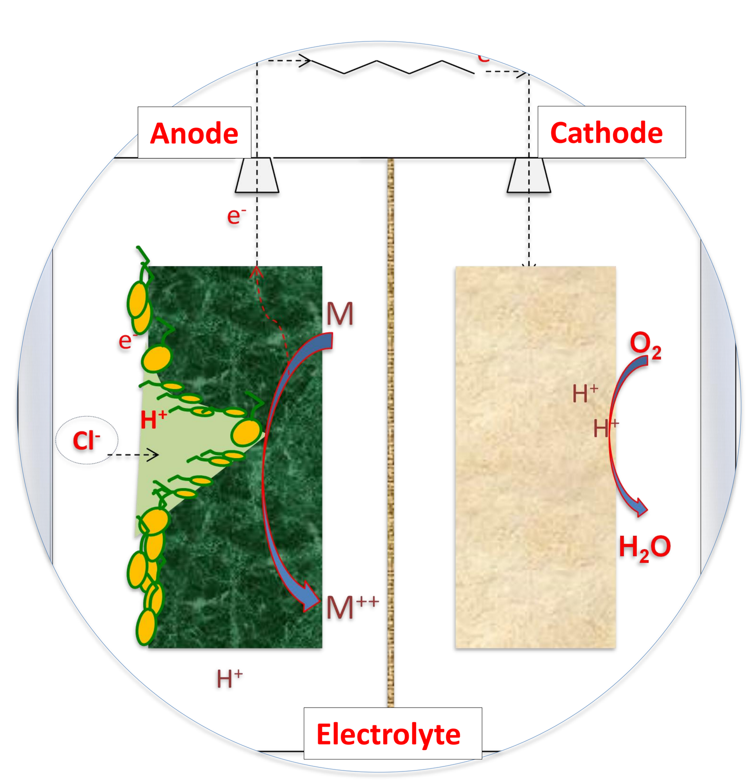
Objectives

The major objective of this research is to evaluate the superiority of graphene coatings compared to two polymer coatings (Parylene C and Polyurethane) for controlling the microbial-induced corrosion (MIC).

Background

- The national expenditure for metallic corrosion has been estimated to be ~276 billion
- The annual costs for corrosion, including direct and indirect costs, is approaching $1 trillion
- Microbe-induced corrosion (MIC) problems account for ~50% of the total corrosion costs

Microbial Corrosion



- Metallic corrosion occurs at the interface of the metal and the surrounding solution
- Corrosion is due to galvanic coupling between electrochemical reactions at the anode and cathode respectively
- Metal corrode due to anodic oxidation of metal into metallic ions and electrons
- Cathodic reaction provides a sink for electric current from anode
- Free energy due to galvanic coupling between anodic and cathodic reactions is used by microbes to meet their metabolic needs
- Microbes accelerate metallic corrosion

Anode : $Ni^{2+} + 2e^- \longrightarrow Ni$; $E_A = -0.25$ V

Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$; $E_C = 1.23$ V

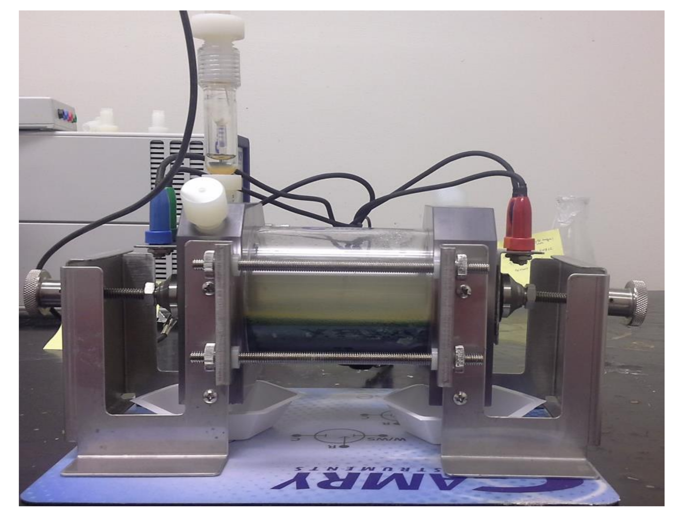
Experimental Design

Corrosion Cells

- Test Cell1: Graphene-coated Nickel anode (Gr/Ni)
- Test Cell2: Parylene-coated Nickel anode (Pa/Ni)
- Test Cell3: Polyurethane-coated Nickel anode (Pu/Ni)

Experimental Conditions

- H-Type MFC; 4 cm^2 of nickel foam as anode
- Mixed microbial population in the anode
- Nafion117 separator
- Graphite brush as cathode [Φ=2.5 cm; L=~2.5 cm]
- Batch-fed mode at external resistance of 1000 ohms
- Glucose-supplemented minimal media as anolyte
- Ferricyanide catholyte in 100 mM PBS buffer



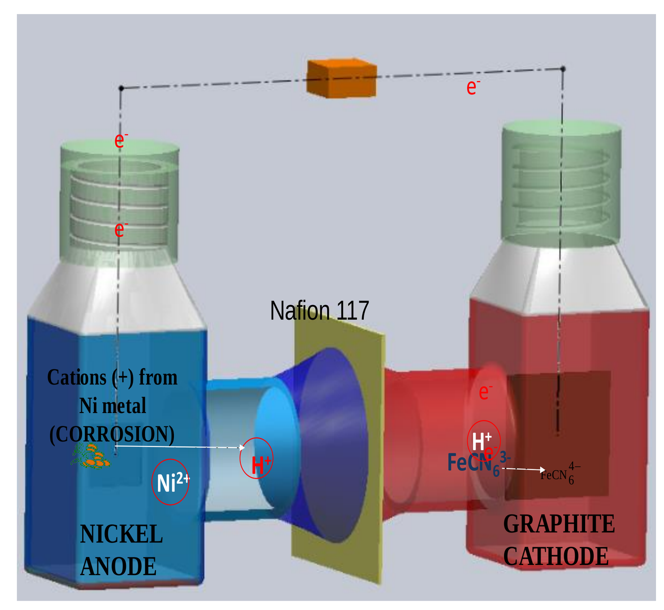
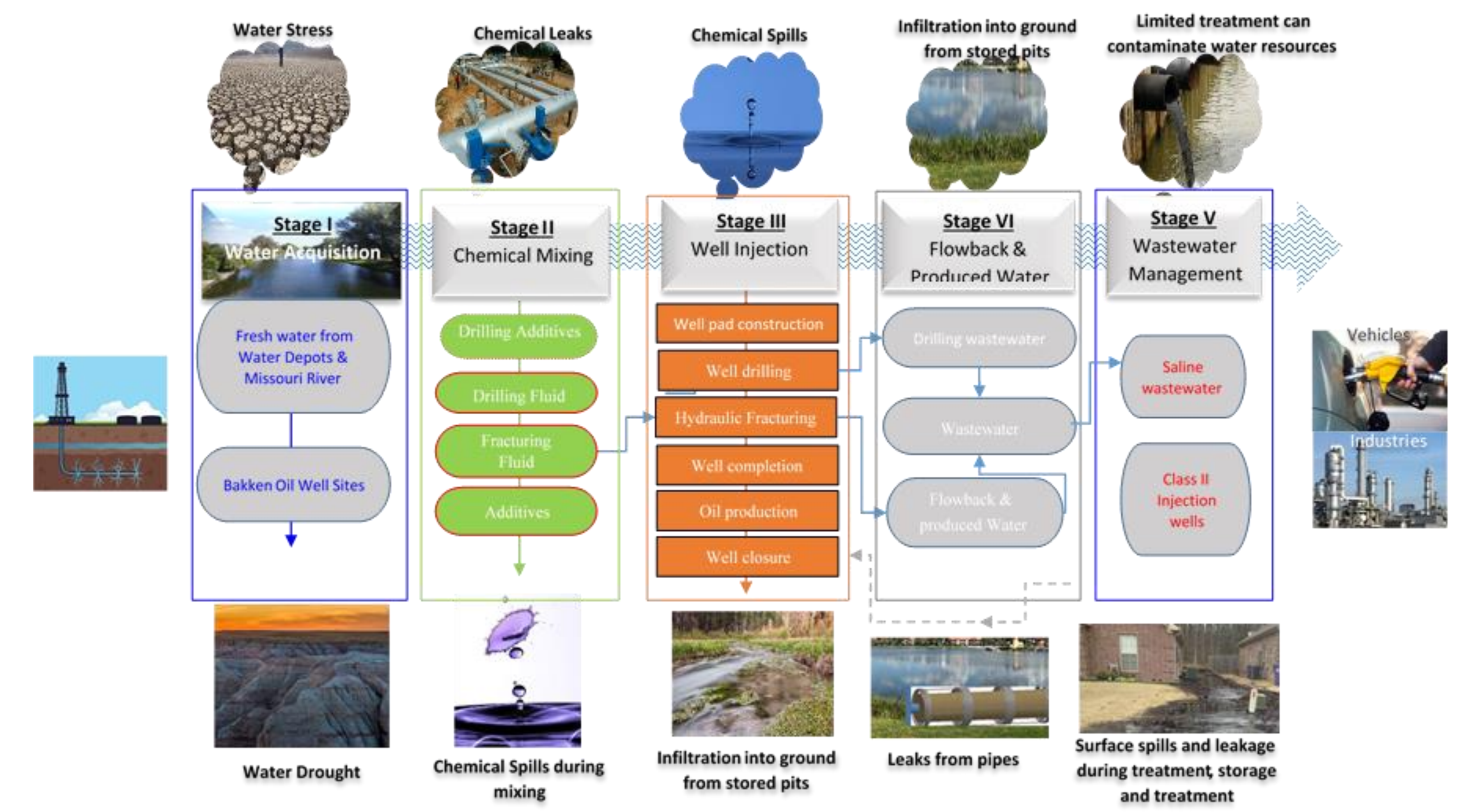


Figure: Schematic of corrosion cell

Graphene coatings for Food-Energy-Water (FEW) nexus challenges in upper Great Plains



- Produced water from fractured oil fields (e.g., Bakken shale) has exceptional levels of total dissolved solids and chemical oxygen demand.
- Metal infrastructure used to transport produced water is prone to corrosion
- We are evaluating the feasibility of graphene and graphene composite coatings for the metal infrastructure in the oil fields

Results

- The results demonstrated the superiority of graphene coating over both parylene and polyurethane coatings.
- The 'Ni' dissolution in the graphene-coated Ni anode was an order of magnitude lower than that of Parylene and Polyurethane coating.
- Detailed electrochemical impedance spectroscopy characterization revealed that graphene offered 10-fold improved microbial corrosion resistance compared to that of polyurethane and 100-fold compared to that of Parylene.

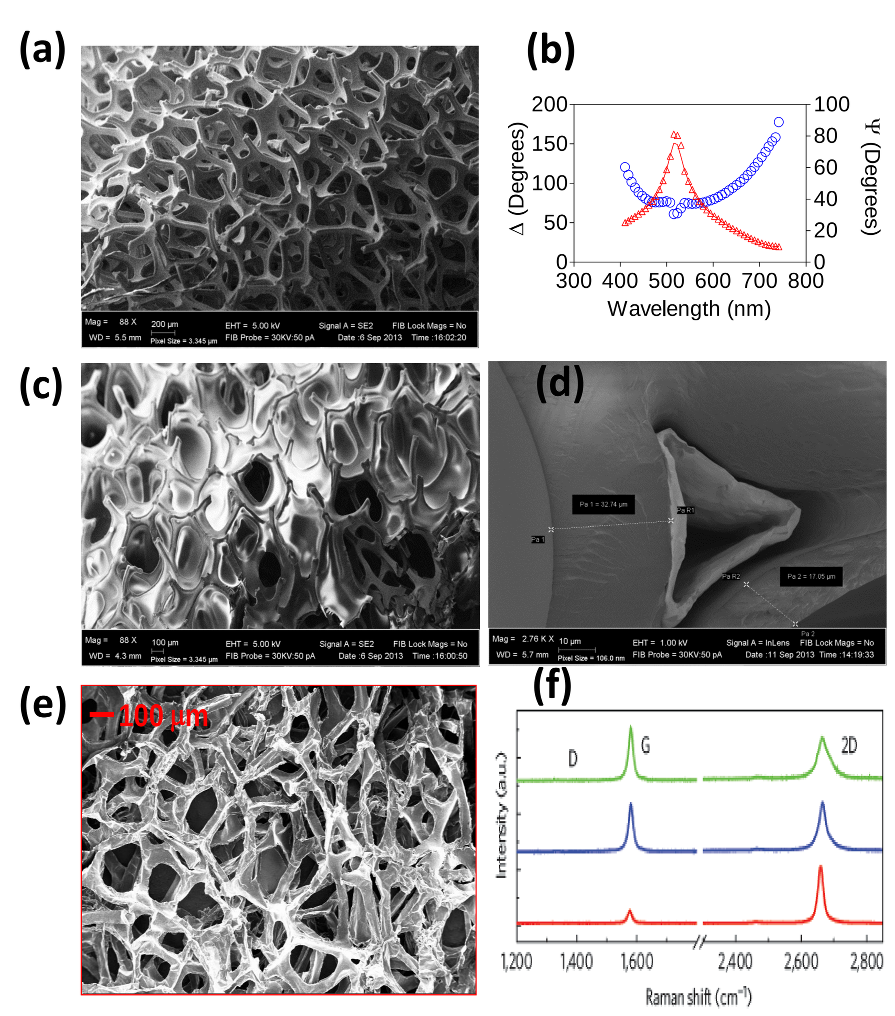


Figure (a) Parylene coated Nickel (b) Ellipsometry data shows 461 μm PA coating (c) Polyurethane coated Nickel (d) SEM image showing thickness of PU coating (e) Conformal coating of few-layer graphene film on a Ni foam (f) Raman spectra of Gr/Ni foam showing monolayer (red), bi-layer (blue), and tri-layer (green)

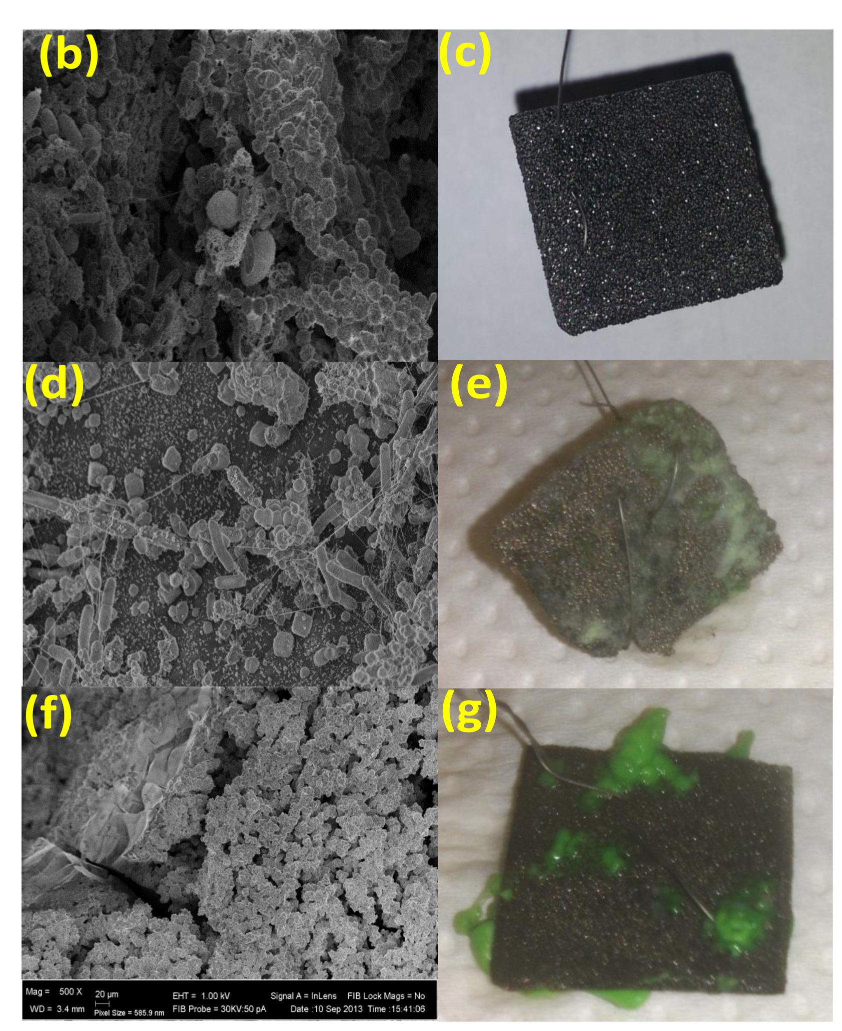
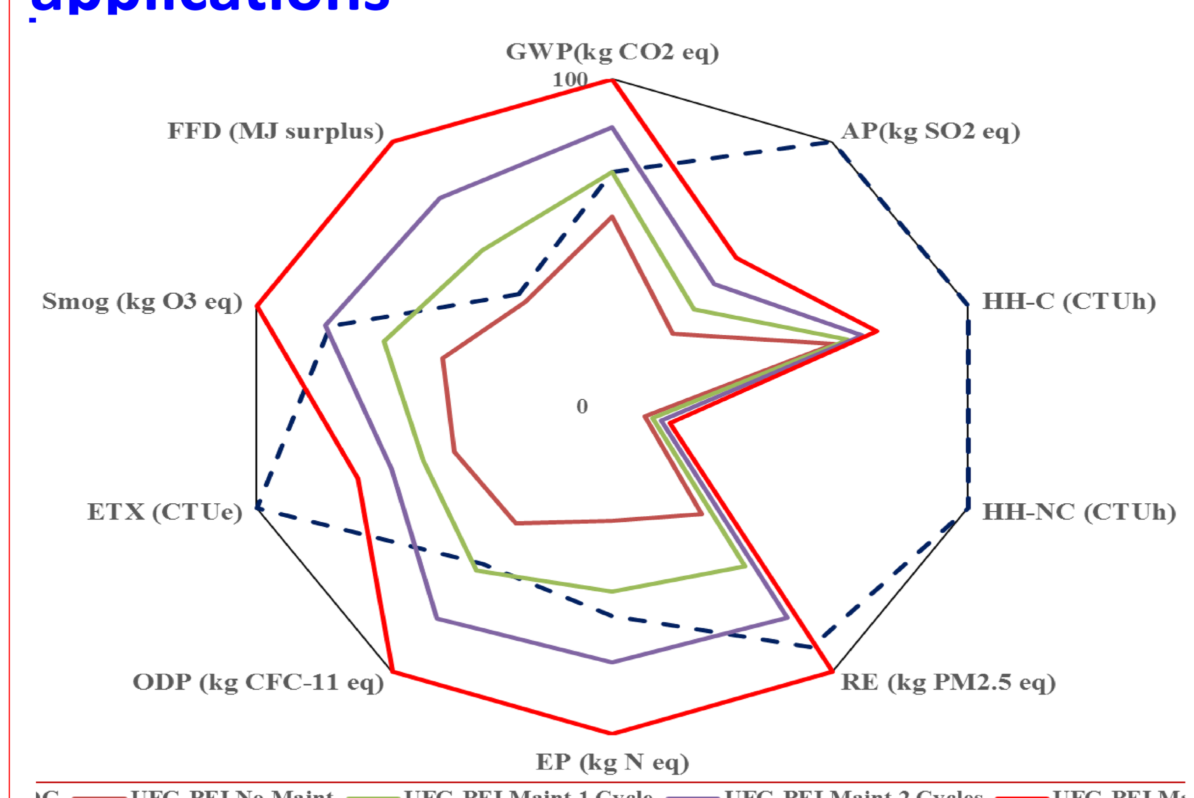


Figure: (b) SEM image of biofilm on Gr/Ni (c) MIC-resistant Gr/Ni anode (d) Biofilm on Parylene coating (e) Corroded Ni/Pa anode after 30 days of MIC experiment (f) Biofilm on PU/Ni (g) Corroded Ni/PU anode after 30 days of MIC experiment

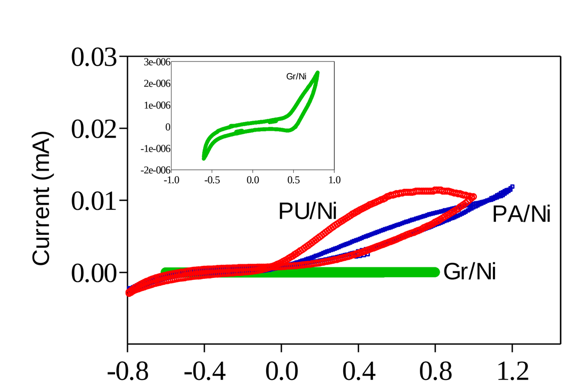
Life-Cycle Analysis of Graphene coatings for atmospheric corrosion applications



- Cradle-to-grave LCA analysis indicated superiority of graphene-polyetherimide coatings compared to zinc coatings

Cyclic Voltammetry

- The PU/Ni and PA/Ni registered a higher range of electrochemical current compared to that of Gr/Ni
- The corrosion rates are 6.708 and ~5.229 mg/L/d in PA/Ni and PU/Ni respectively



Conclusions

- Preliminary studies demonstrated the utility of Graphene coatings in microbial corrosion applications. We found graphene coatings to outperform polymer coatings
- Further studies to develop graphene coatings for large scale applications

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