Characterization of Encapsulated Corrosion Inhibitors for Environmentally Friendly Smart Coatings

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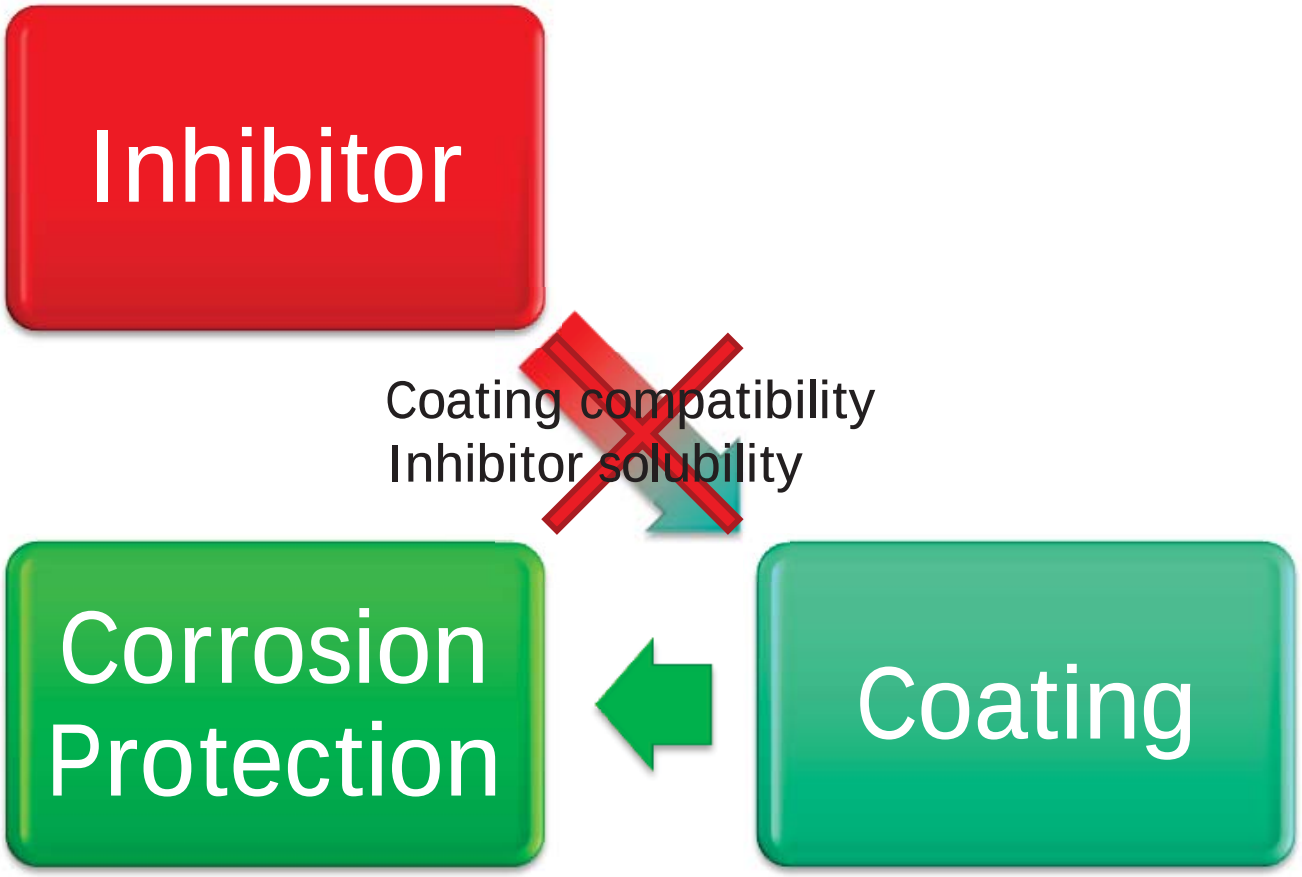
Corrosion

- Worldwide corrosion cost: $2.2 trillion (2010)
- US cost: ~$1 trillion (2013)
- Replace current corrosion inhibitors with environmentally friendly alternatives
  - Coating compatibility issues
  - Solubility issues

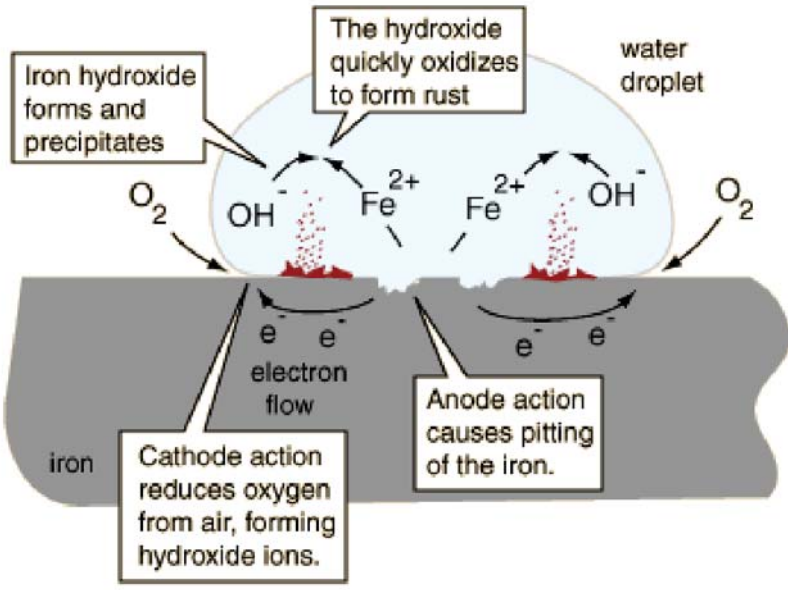
http://philipmarshall.net/Images/corrosion_hyperphysics.gif

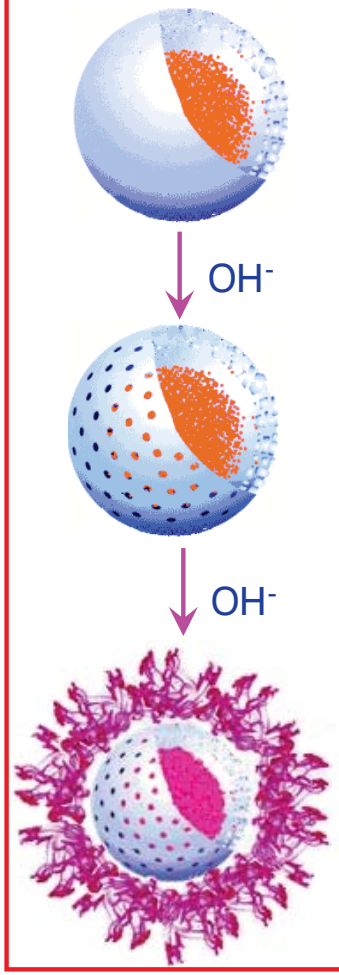
Delivery System



KSC Approach

- "Smart coating" for corrosion sensing and control
  - Autonomous
  - pH controlled
  - Universal



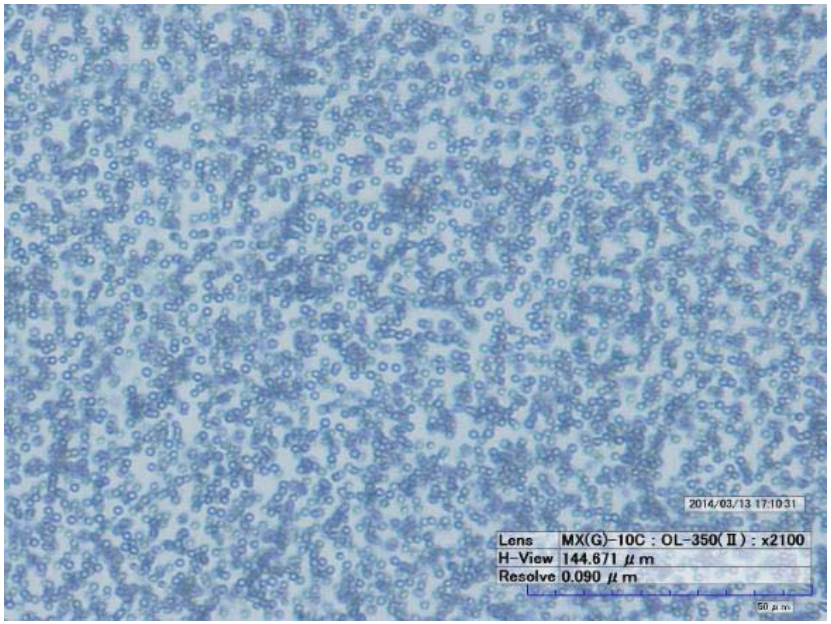


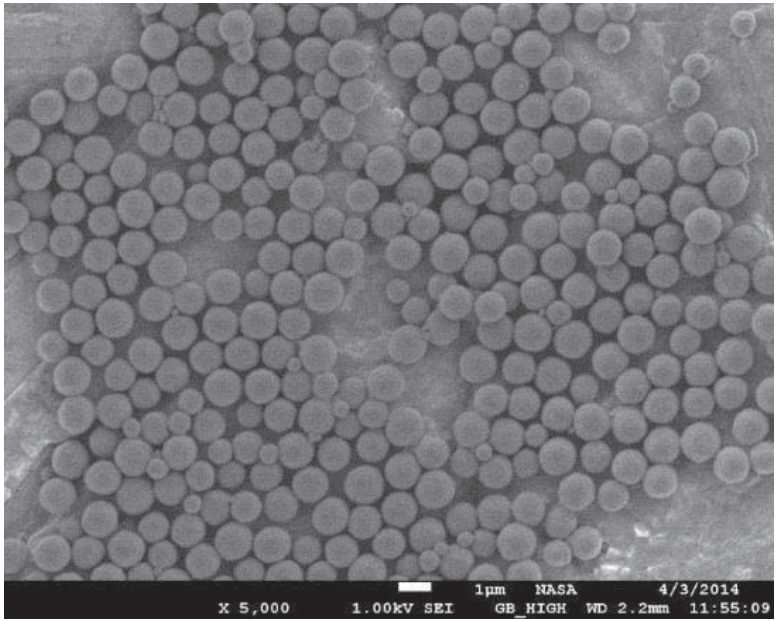
Microcapsule containing pH indicator (inhibitor, self healing agents)

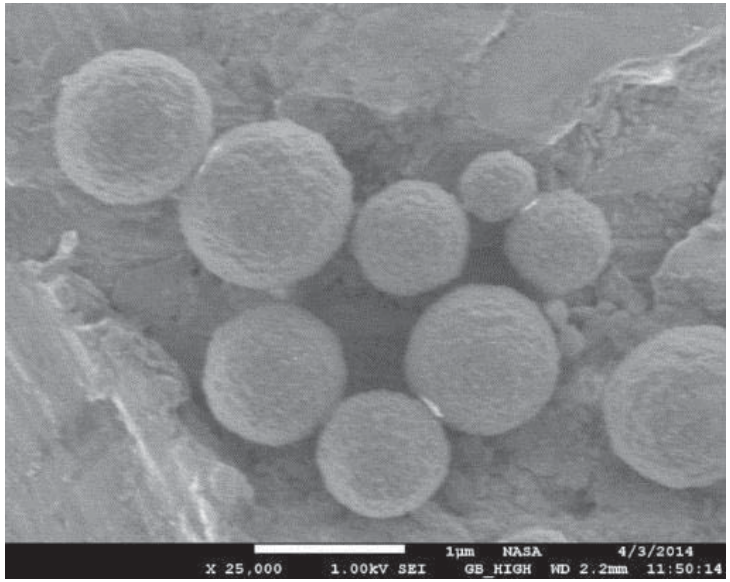
The shell of the microcapsule breaks down under basic pH (corrosion) conditions

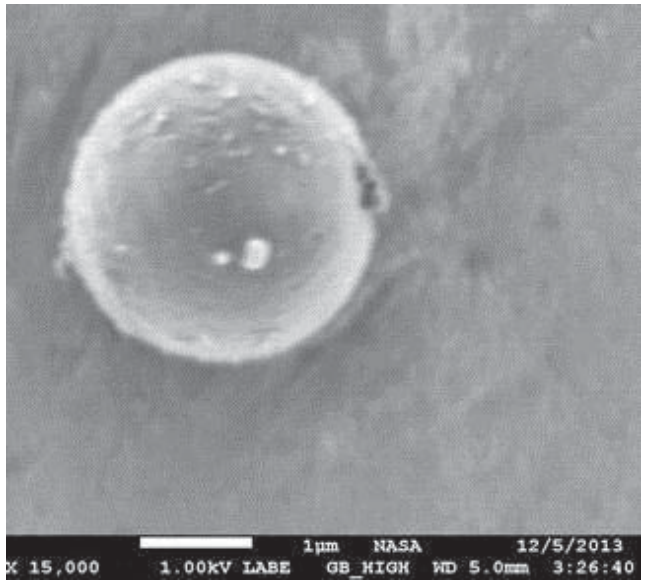
pH indicator changes color and is released from the microcapsule when corrosion starts

Emulsion Polymerization

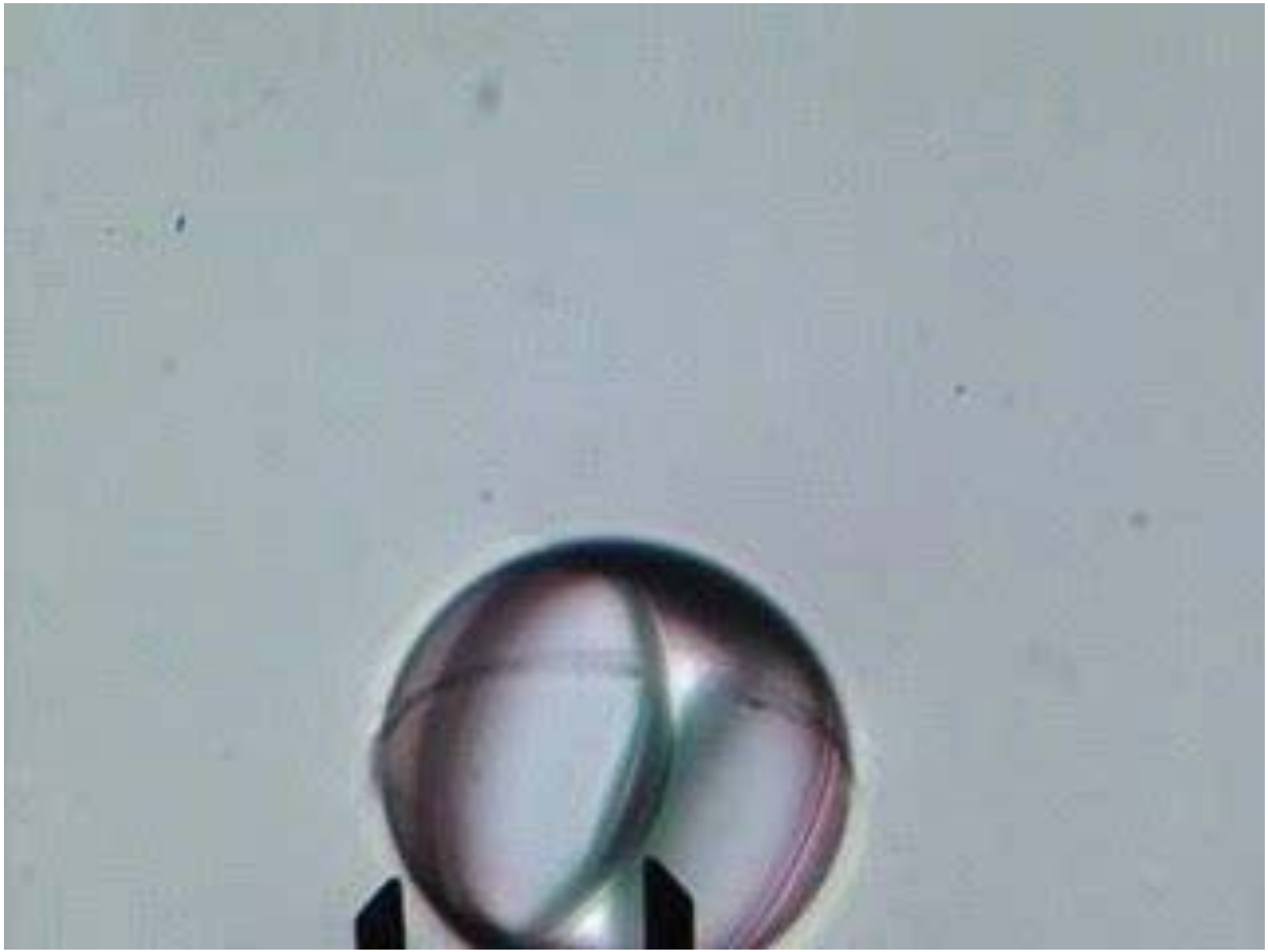








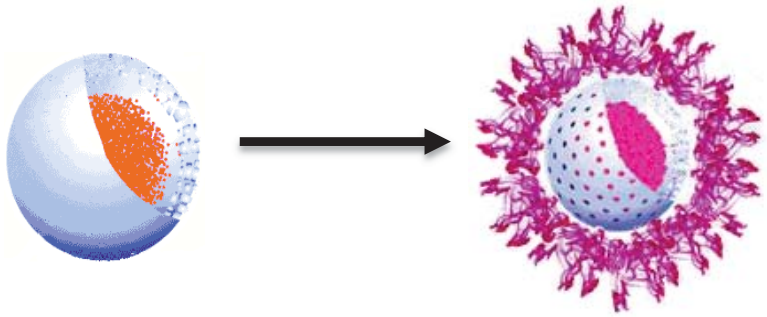
Release Video



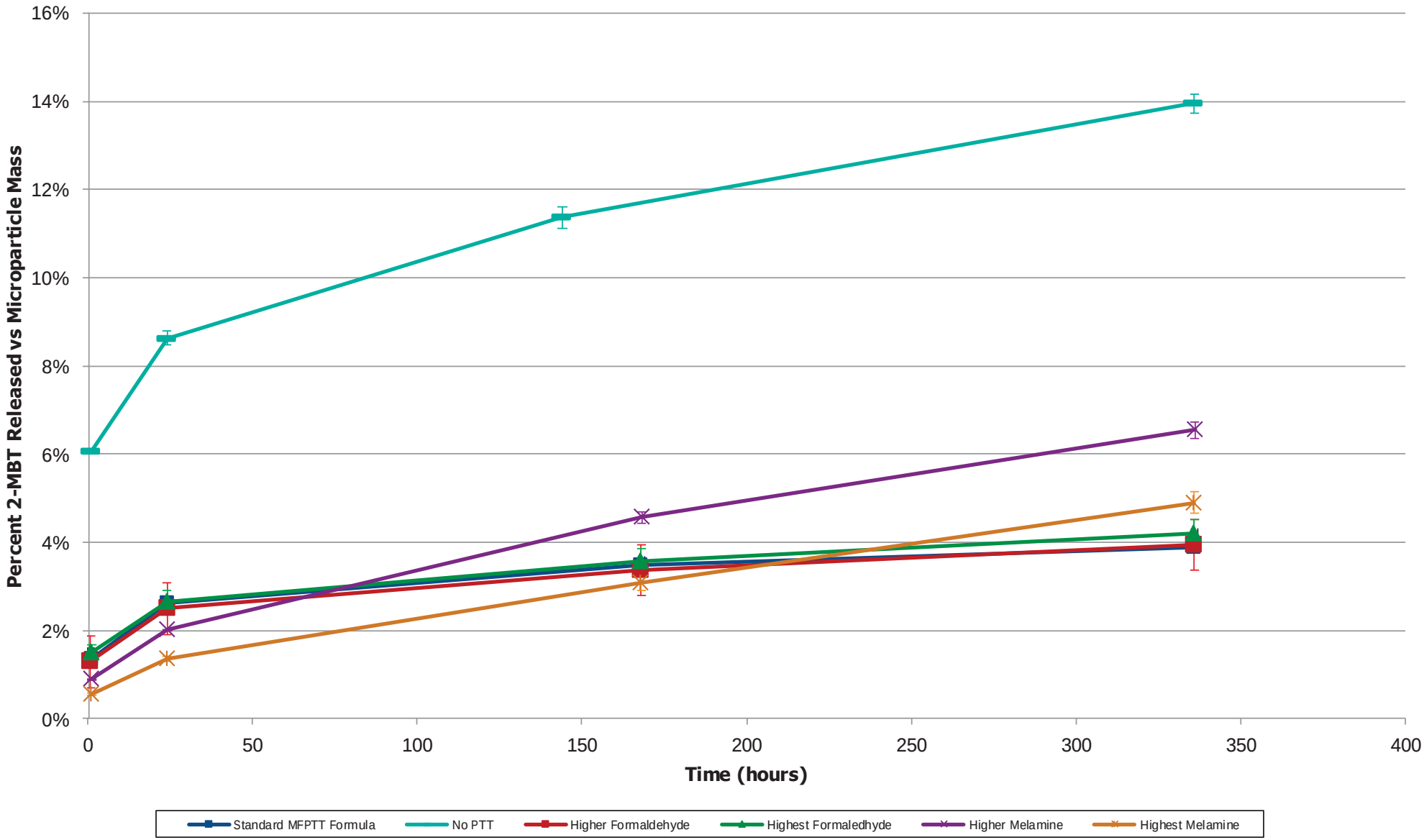
RELEASE STUDIES

Inhibitor Release

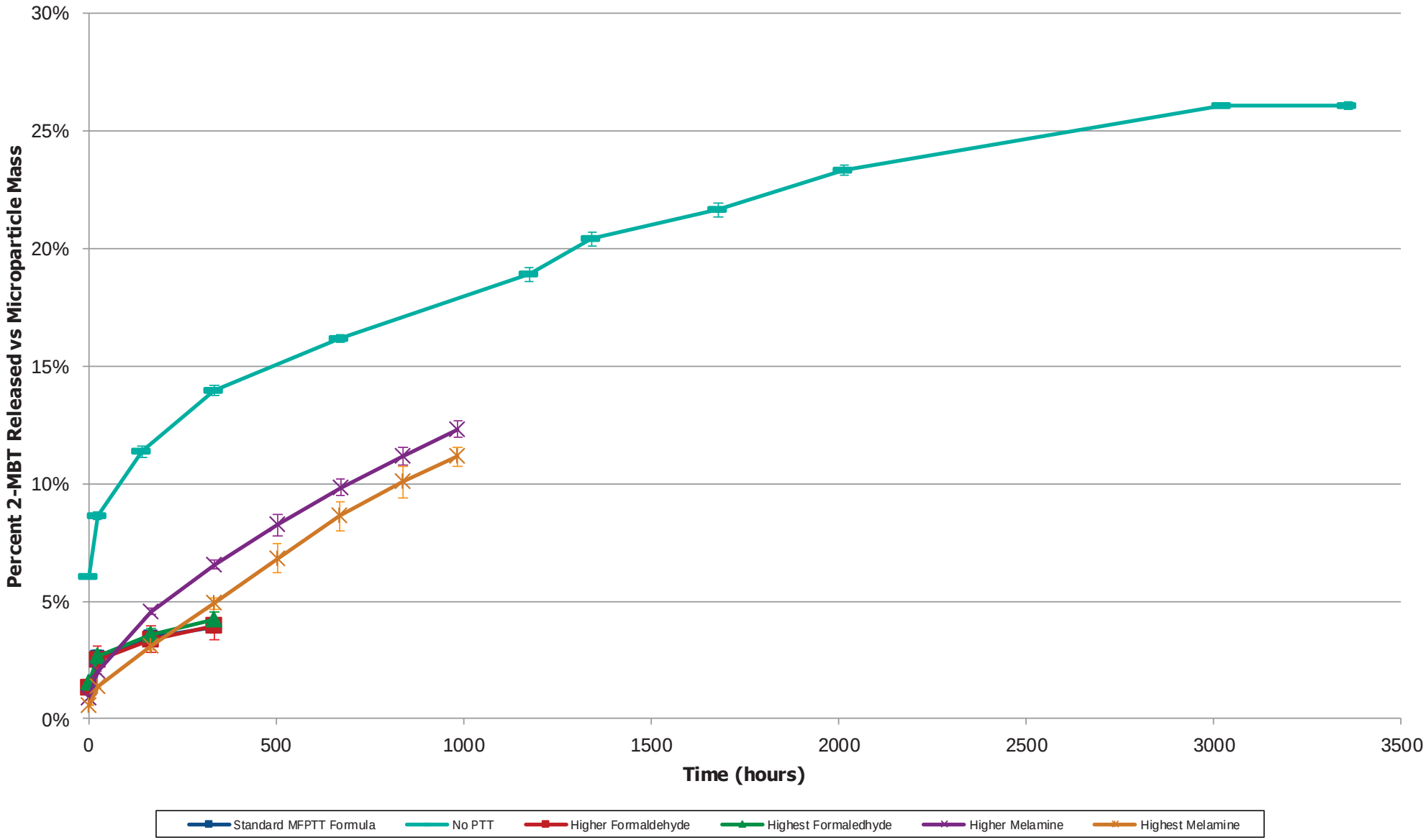
- Determine release of inhibitor with time
  - 2-Mercaptobenzothiazole (2-MBT)
  - Nitrite
  - Molybdate
- Method
  - Immersion of particles into 0.01 M base
  - Sampling at regular intervals



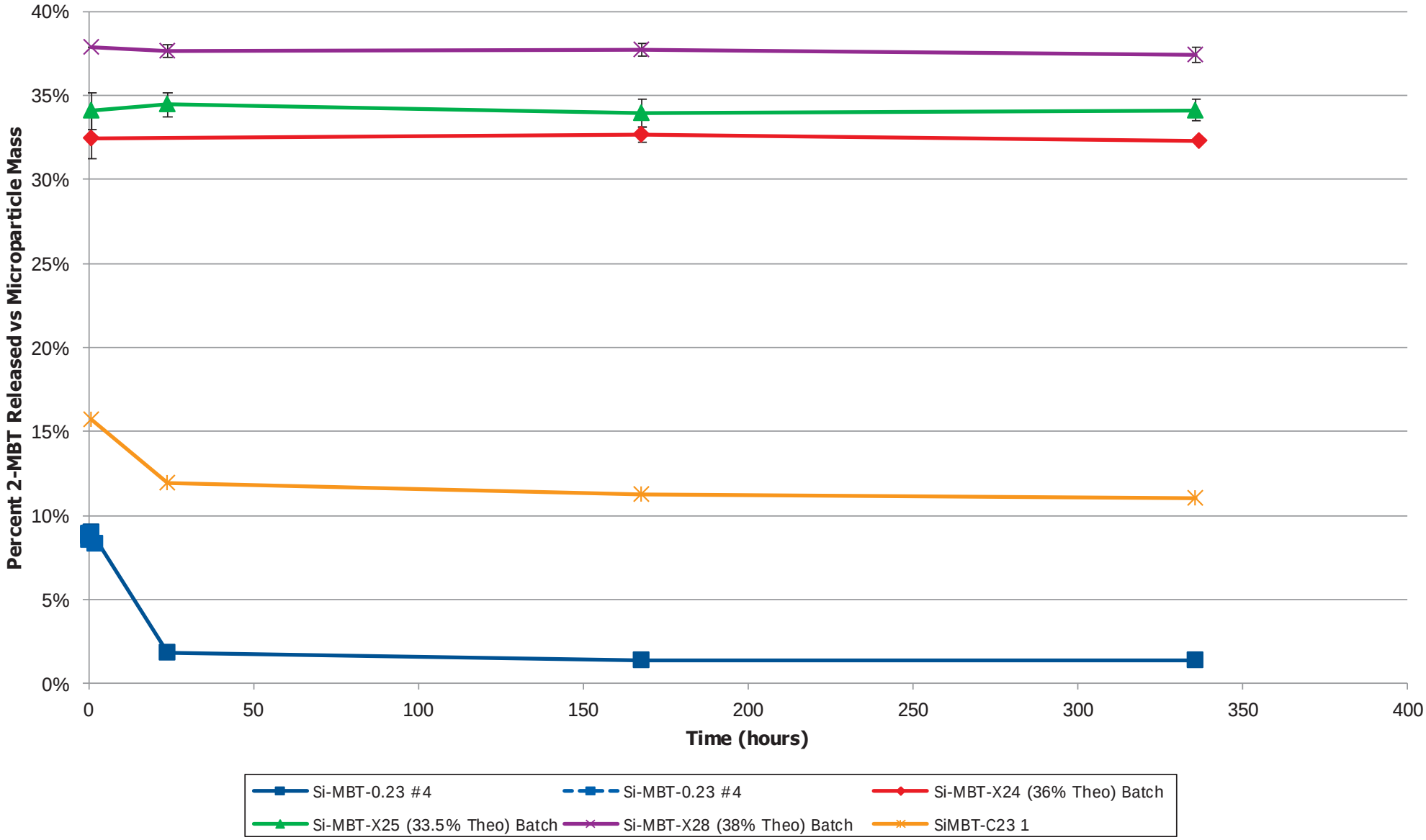
MF: 2-MBT Short-term Release



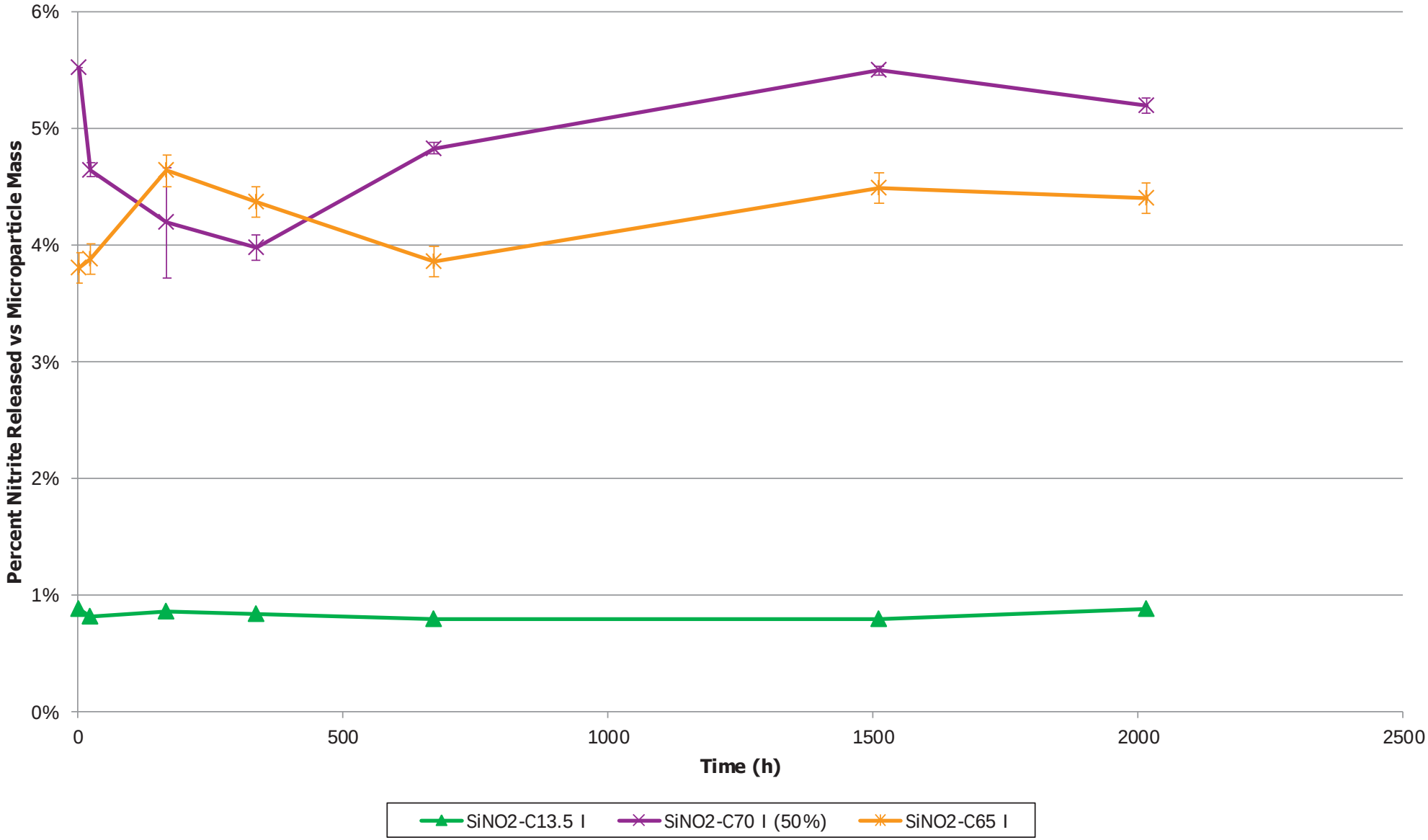
MF: 2-MBT Long-term Release



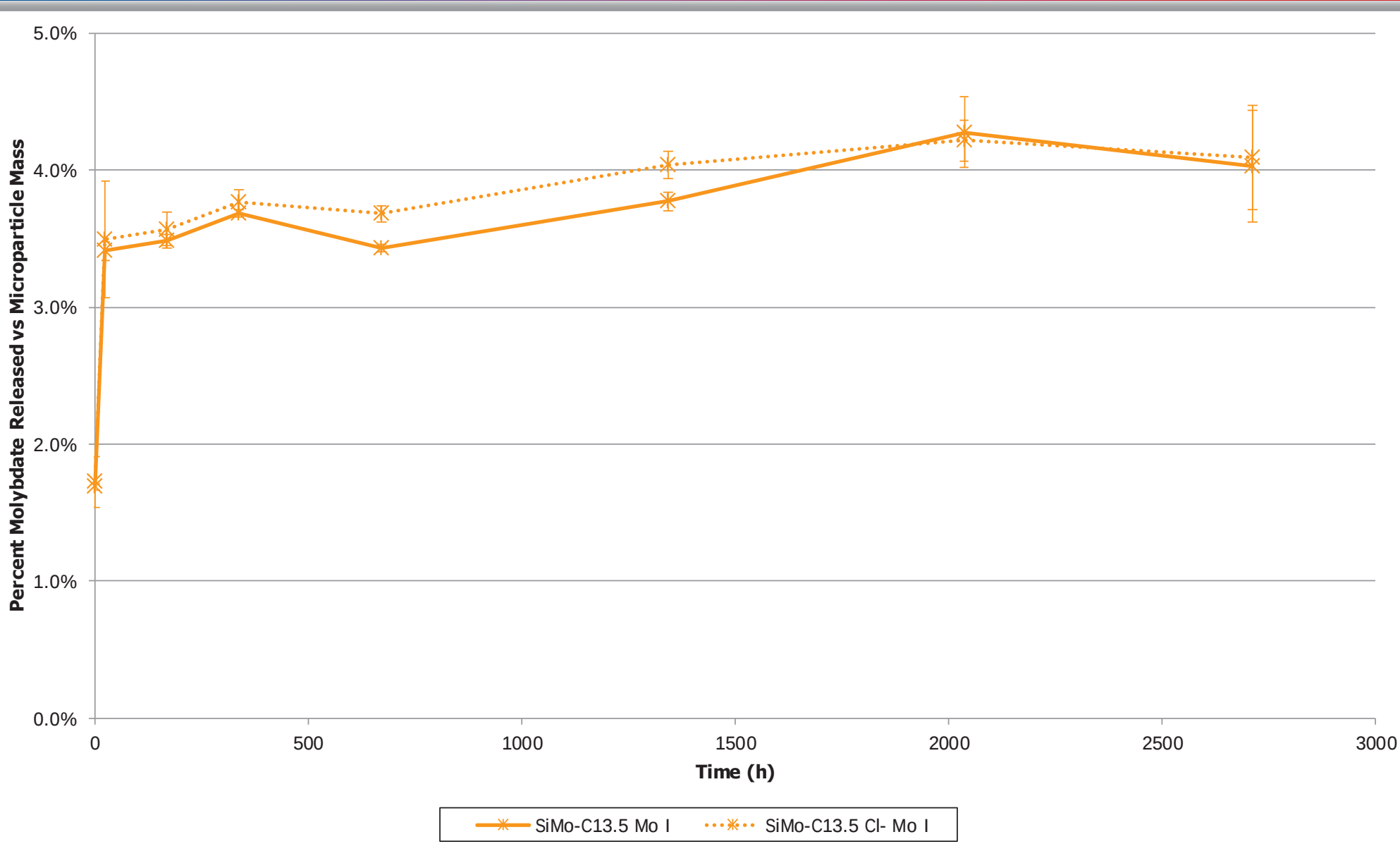
Inorganic: 2-MBT



Inorganic: Nitrite



Inorganic: Molybdate



Release Studies

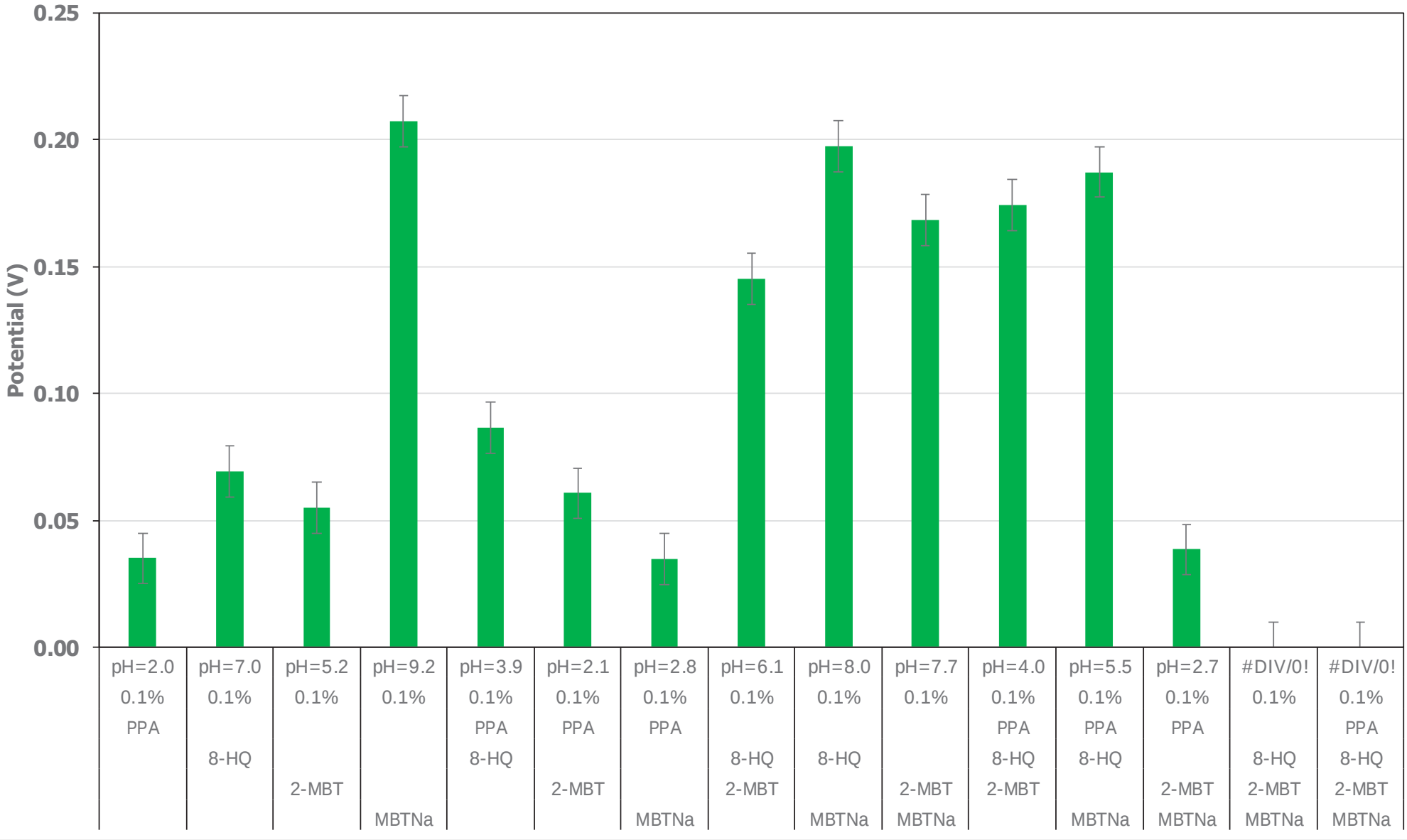
- Successful encapsulation and release of inhibitor
- Organic particles
  - Inhibitors can react with particle material
  - Slower, longer-term release
- Inorganic particles
  - Can incorporate a variety of inhibitors, including highly water soluble ionic compounds
  - Quicker, higher amount release

ELECTROCHEMICAL CORROSION TESTING

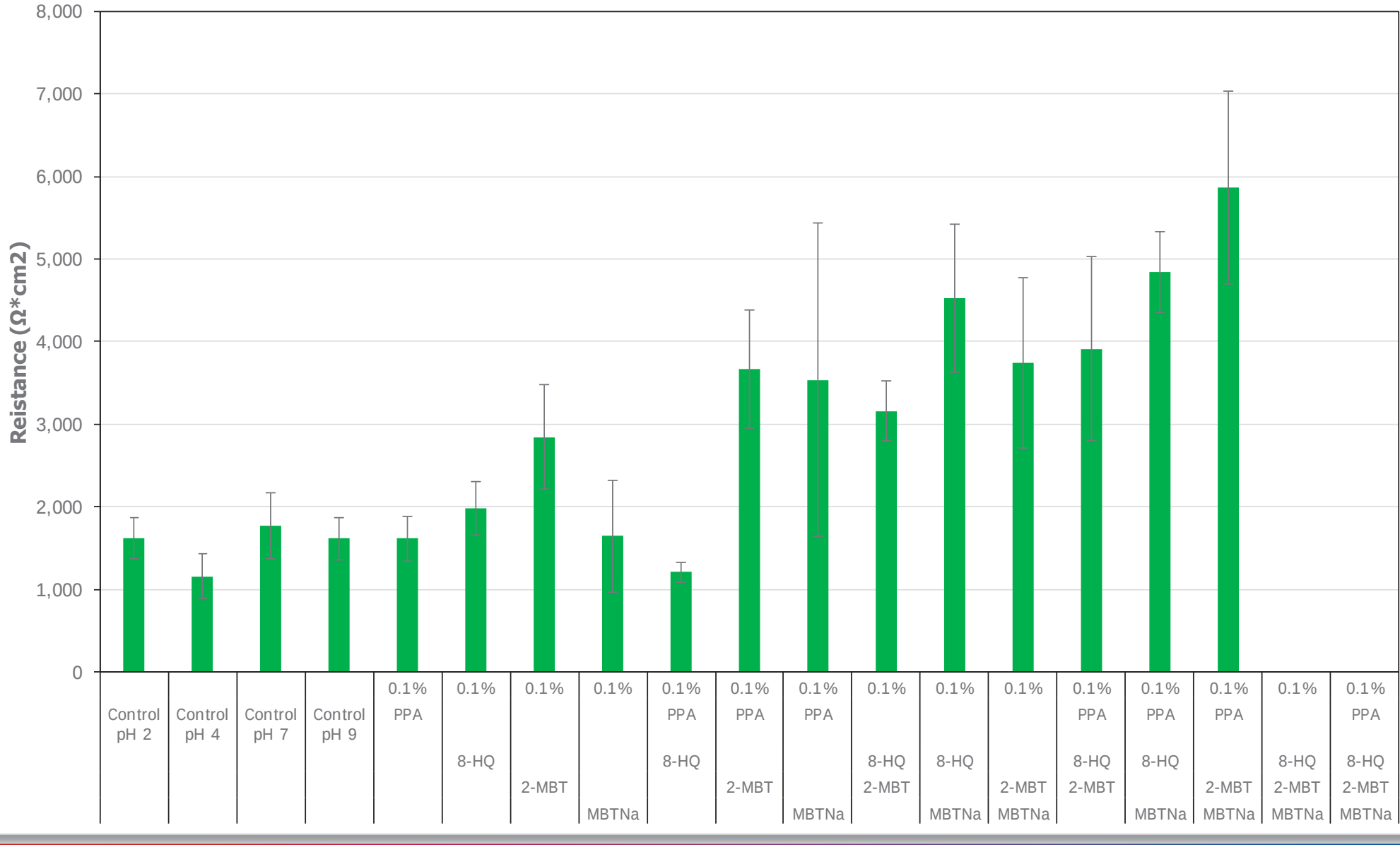
Accelerated Corrosion Testing

- Carbon steel in 3.5% NaCl solution
- Electrochemical measurements
- Salt immersion
  - Phenylphosphonic acid (PPA)
  - 8-Hydroxyquinoline (8-HQ)
  - 2-MBT & Sodium 2-Mercaptobenzothiazole (2-MBTNa)

Corrosion Potential Increase

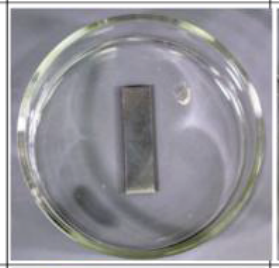
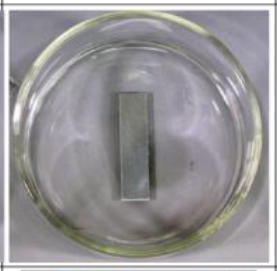
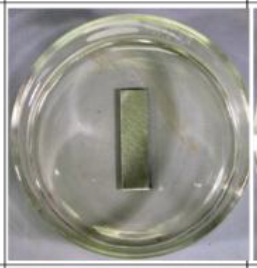
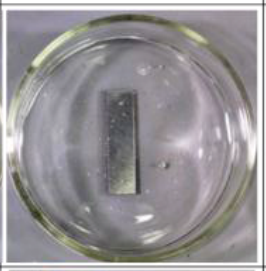
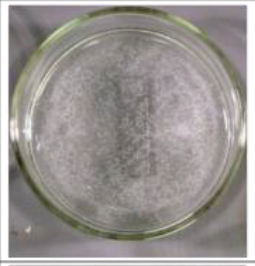
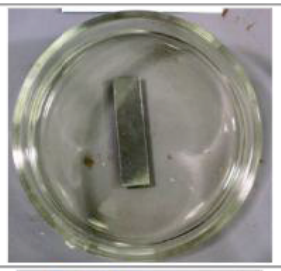
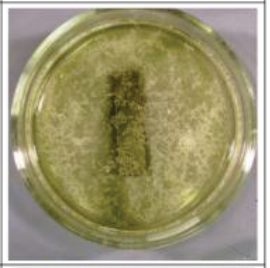
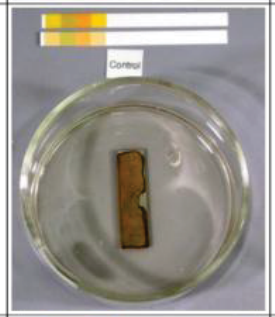
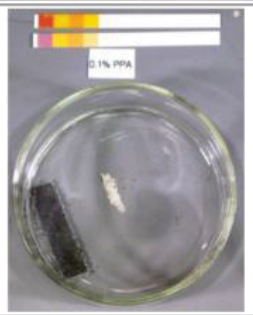
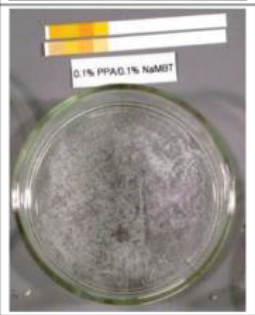
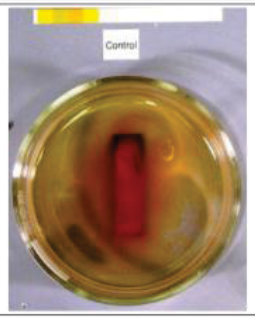
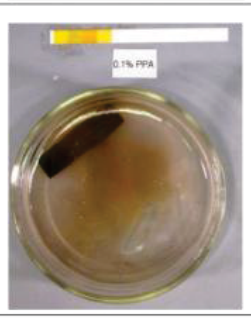
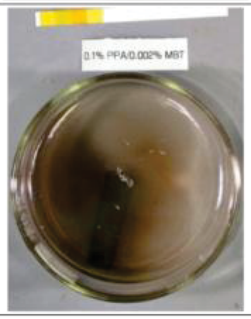
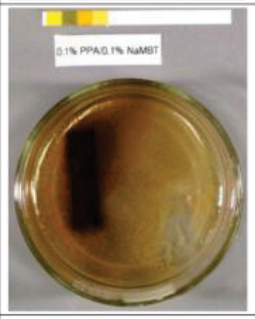
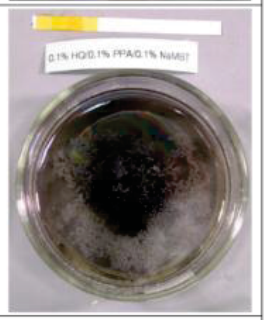


Polarization Resistance

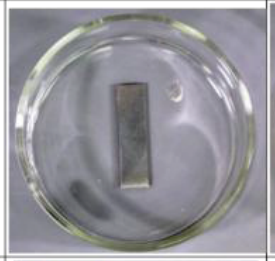
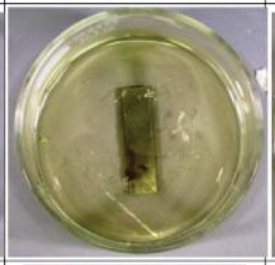
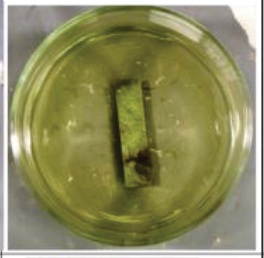
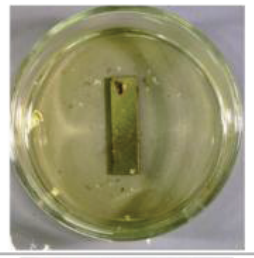
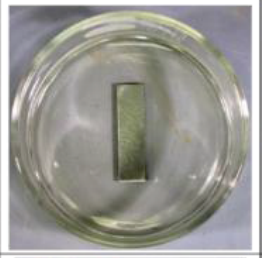
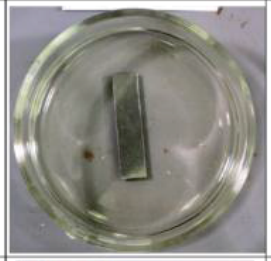
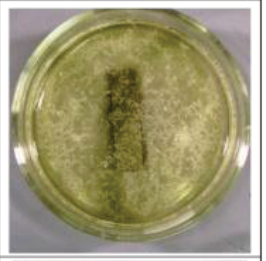
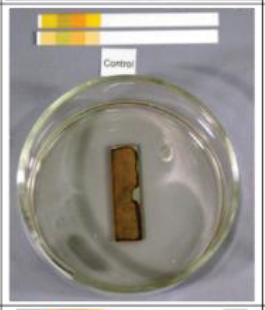
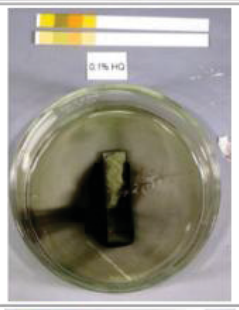
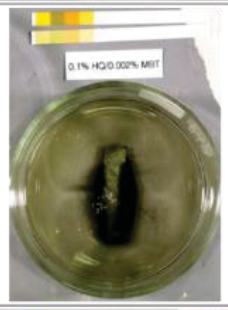
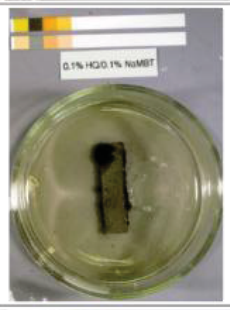
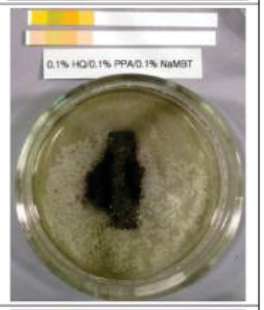
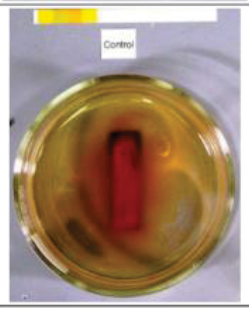


SALT IMMERSION TESTING

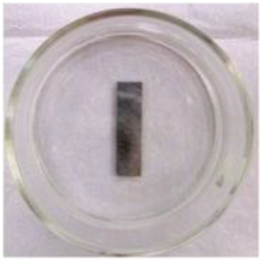
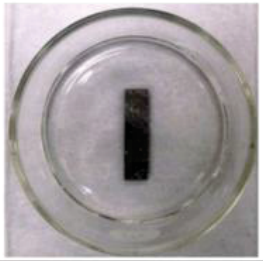
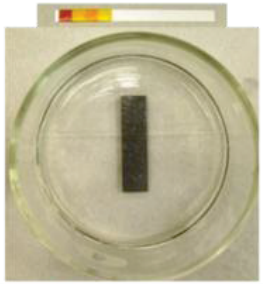
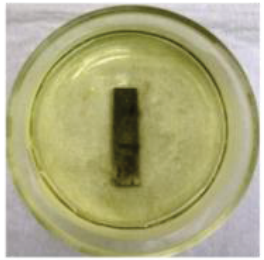
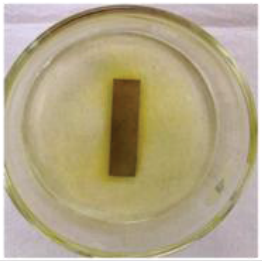
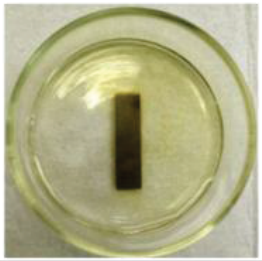
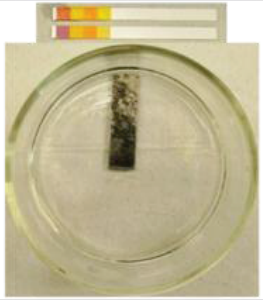
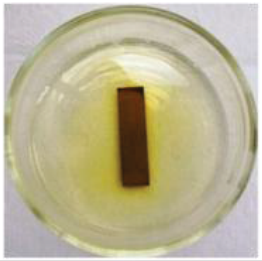
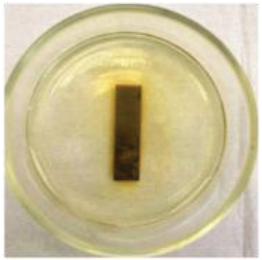
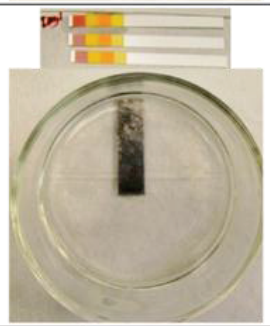
Pure Inhibitor: PPA

Time	Control	0.1% PPA	0.1% PPA and 0.1% 8-HQ	0.1% PPA and 0.002% 2-MBT	0.1% PPA and 0.1% NaMBT	0.1% PPA, 0.1% 8-HQ and 0.002% 2-MBT	0.1% PPA, 0.1% 8-HQ and 0.1% NaMBT
Initial							
5 hour							
6 day							
After Wash							

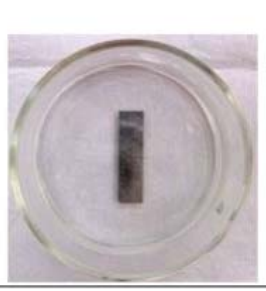
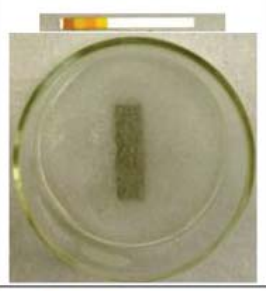
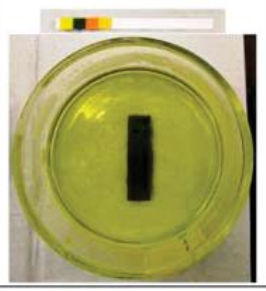
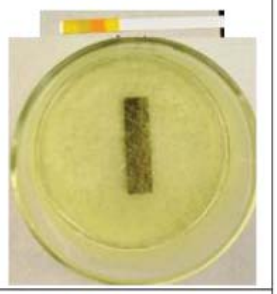
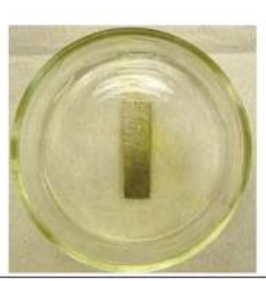
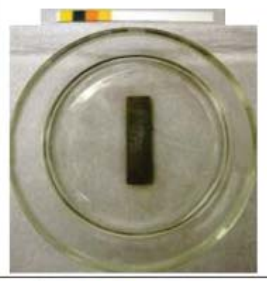
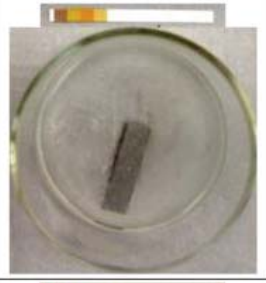
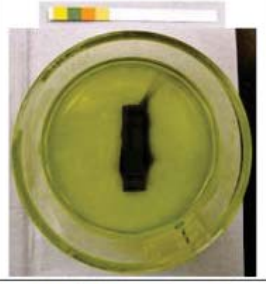
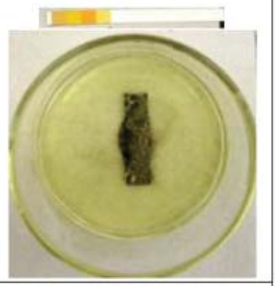
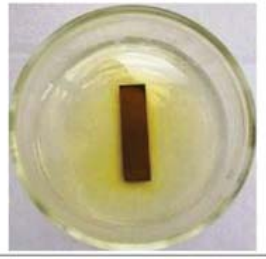
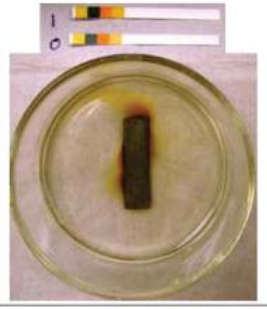
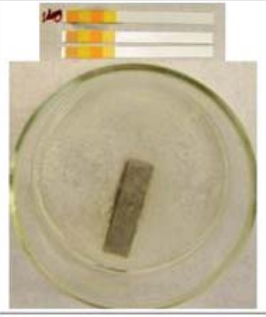
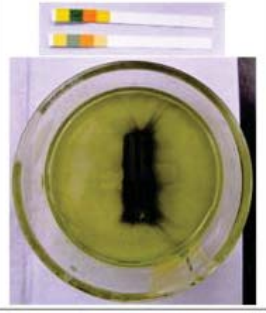
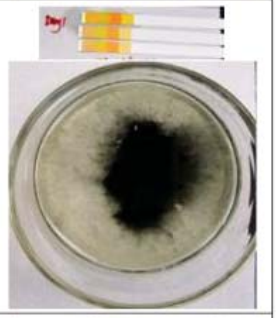
Pure Inhibitor: 8-HQ

Time	Control	0.1% 8-HQ	0.1% 8-HQ and 0.002% 2-MBT	0.1% 8-HQ and 0.1% NaMBT	0.1% PPA and 0.1% 8-HQ	0.1% PPA, 0.1% 8-HQ and 0.002% 2-MBT	0.1% PPA, 0.1% 8-HQ and 0.002% NaMBT
Initial							
5 hour							
6 day							
After Wash							

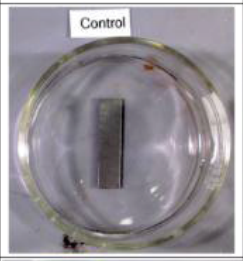
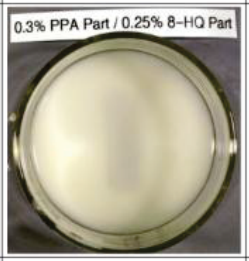
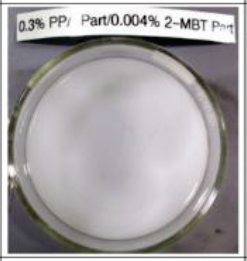
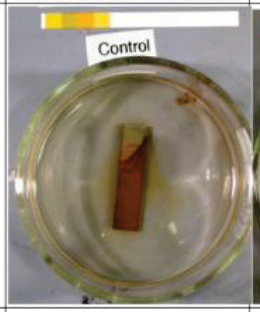
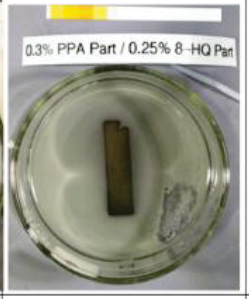
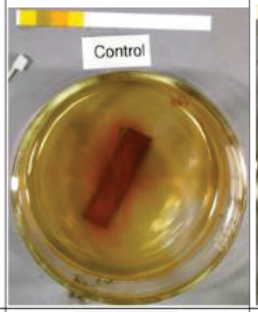
Pure Inhibitor: 2-MBT

Time	Control	0.002% 2-MBT	0.1% PPA and 0.002% 2-MBT	0.1% 8-HQ and 0.002% 2-MBT	0.1% PPA,0.1% 8-HQ and 0.002% 2-MBT
Initial					
4/5 hour					
1 day					
Steel Piece					

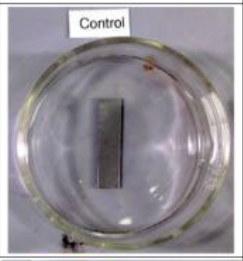
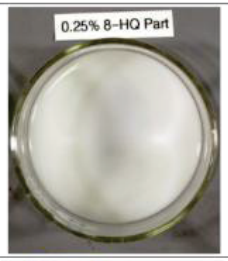
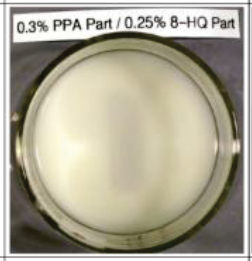
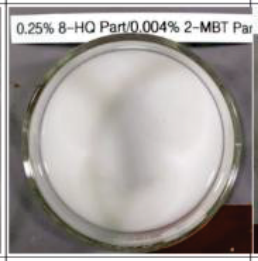
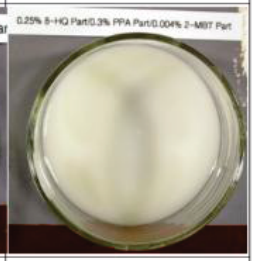
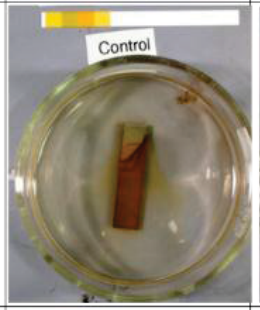
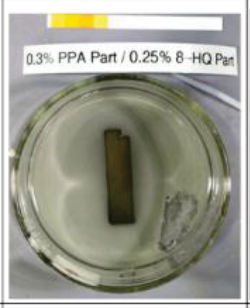
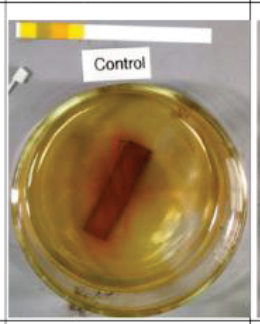
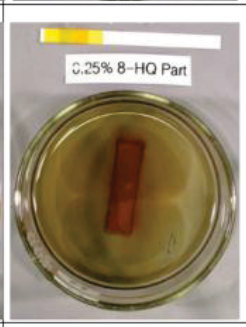
Pure Inhibitor: 2-MBTNa

Time	Control	0.1% NaMBT	0.1% PPA and 0.1% NaMBT	0.1% 8-HQ and 0.1% NaMBT	0.1% PPA, 0.1% 8-HQ and 0.1% NaMBT
Initial					
1 hour					
1 day					
Steel Piece					

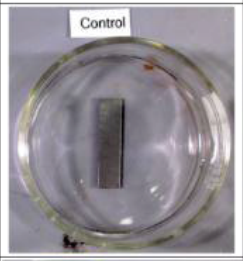
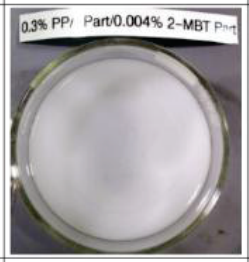
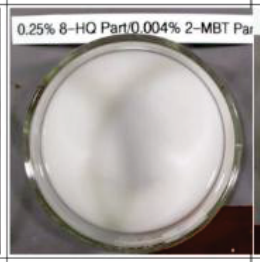
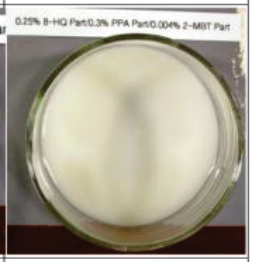
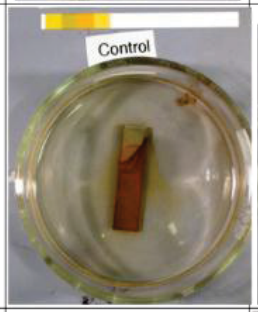
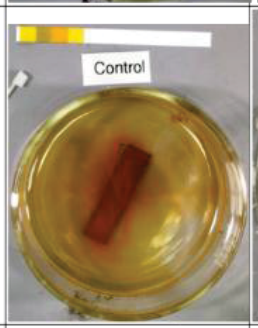
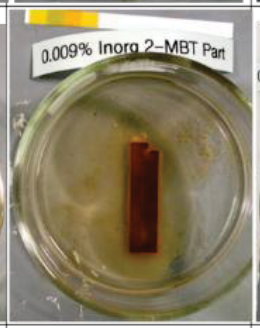
Particles: PPA

Time	Control	0.3% PPA Particles	0.3% PPA Particles 0.25% 8-HQ Particles	0.3% PPA Particles 0.004% 2-MBT Particles	0.3% PPA Particles 0.25% 8-HQ Particles 0.004% 2-MBT Particles
Initial					
1 day					
6 day					
Before Wash					

Particles: 8-HQ

Time	Control	0.25% 8-HQ Particles	0.3% PPA Particles 0.25% 8-HQ Particles	0.25% 8-HQ Particles 0.004% 2-MBT Particles	0.3% PPA Particles 0.25% 8-HQ Particles 0.004% 2-MBT Particles
Initial					
1 day					
6 day					
Before Wash					

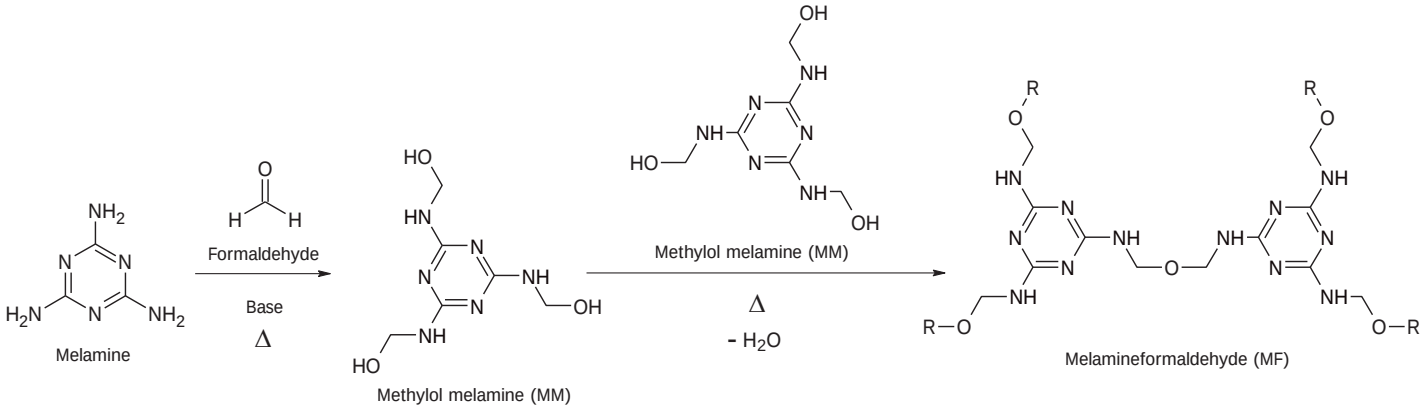
Particles: 2-MBT

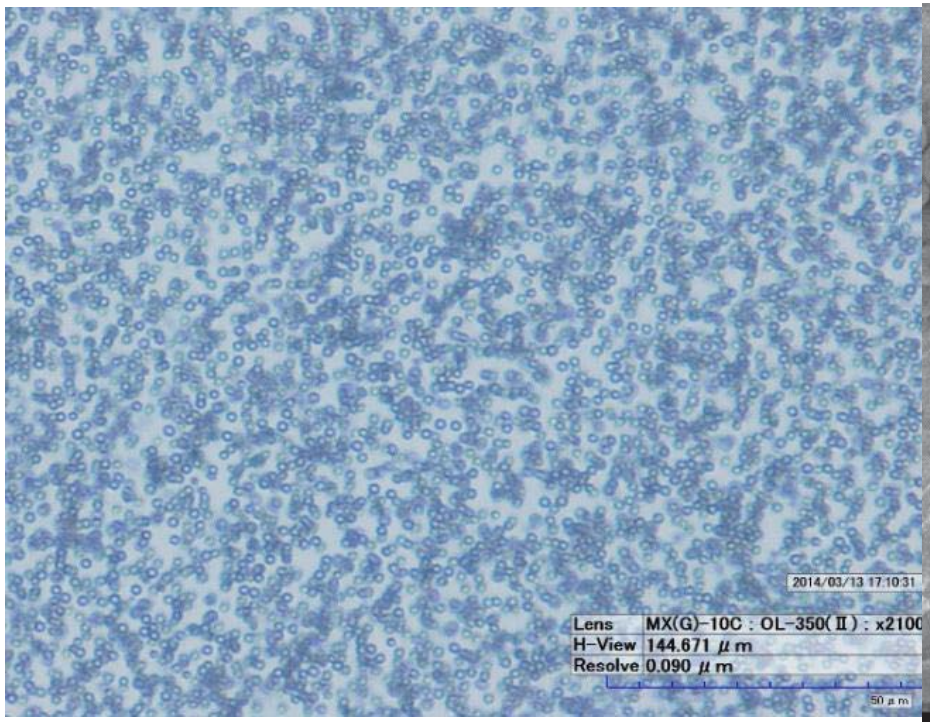
Time	Control	0.009% Inorganic 2-MBT Particles	0.3% PPA Particles 0.004% 2-MBT Particles	0.25% 8-HQ Particles 0.004% 2-MBT Particles	0.3% PPA Particles 0.25% 8-HQ Particles 0.004% 2-MBT Particles
Initial					
1 day					
6 day					
Before Wash					

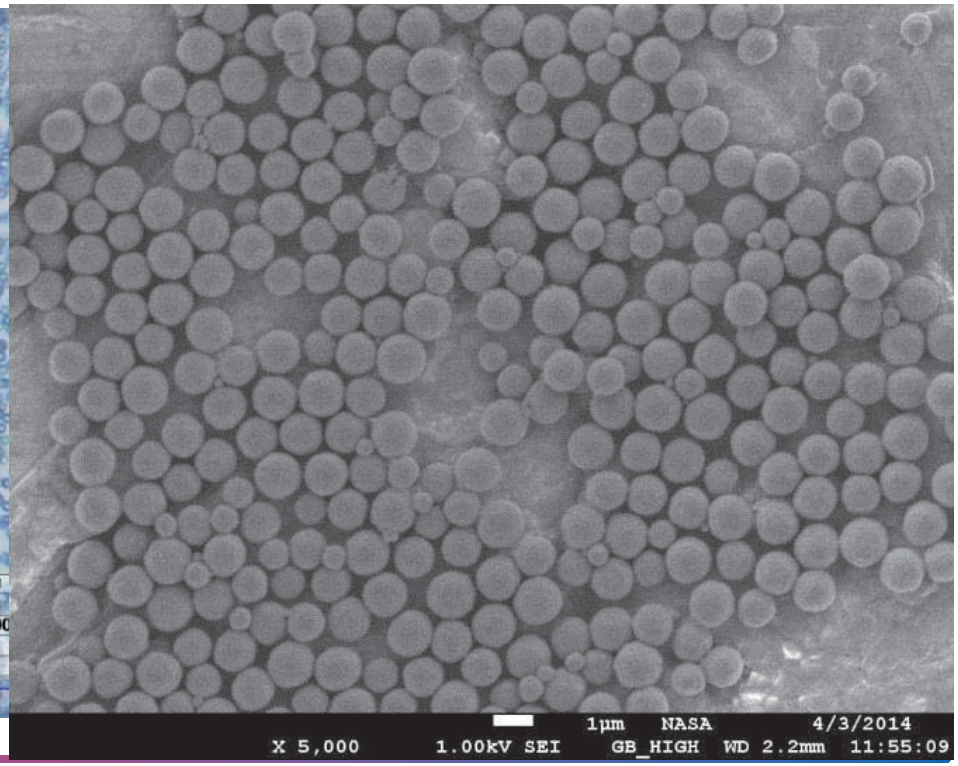
Conclusion

- Successful encapsulation of various inhibitors into organic & inorganic microparticles
- Release of inhibitor monitored over long periods of time → short- and longterm controlled release
- Corrosion protection of pure materials confirmed through electrochemical testing
- Particles effective at preventing corrosion in salt immersion testing
- Inhibitors combinations showing high corrosion inhibition efficiency

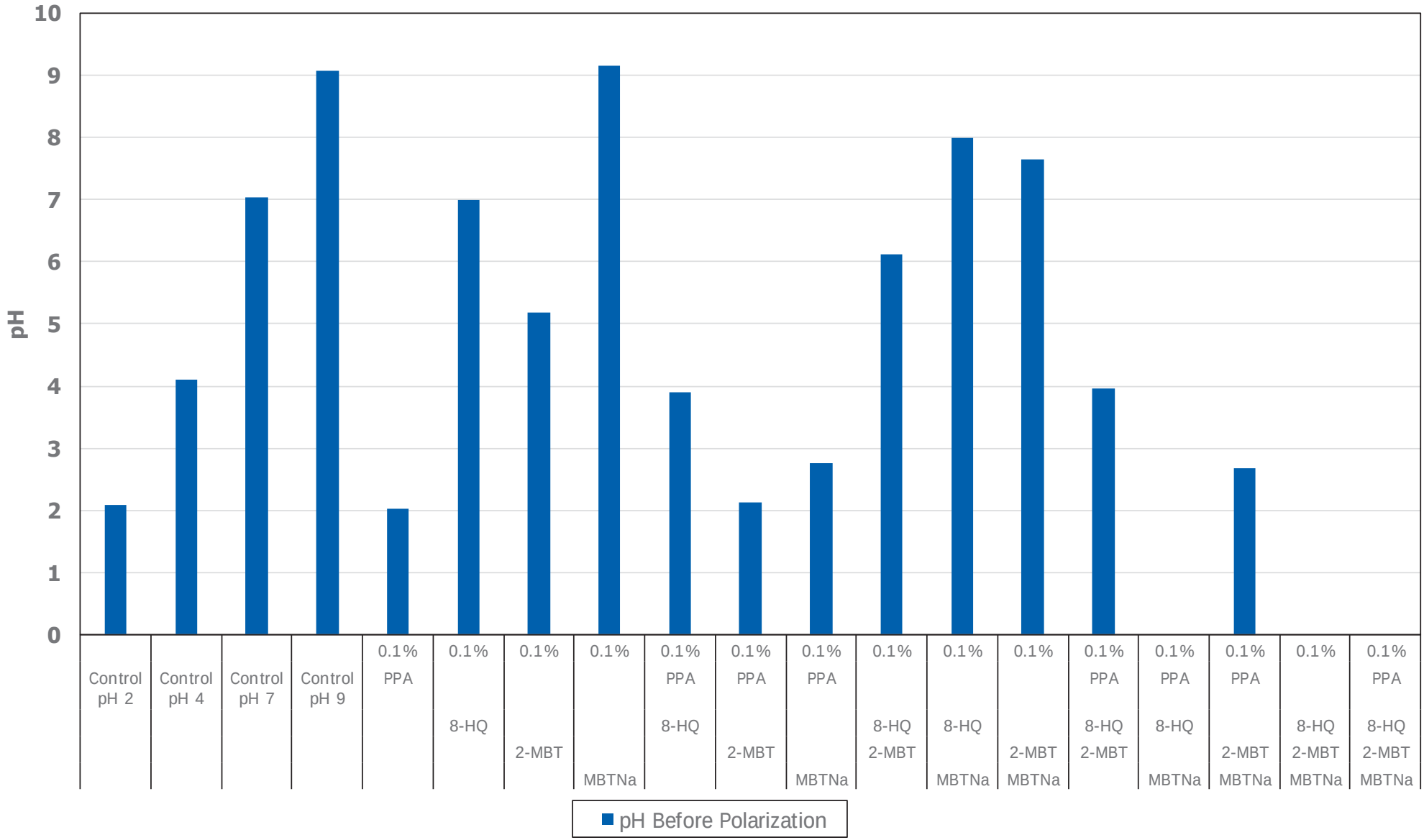
Synthesis: Organic Particles







Pure Inhibitor Solution pH



pH Change during Polarization