

**The 23rd Annual Rio Grande Symposium on Advanced Materials
Albuquerque, NM**

***Efficacy Testing of Biofouling Resistant Materials
for Marine Hydrokinetic Technology***

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Sandia National Laboratories

Outline

- **Background**
- **Overview of Materials Tested**
- **Testing Methods**
- **Testing Results**
- **Summary**



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Alternative Water Energy Technology

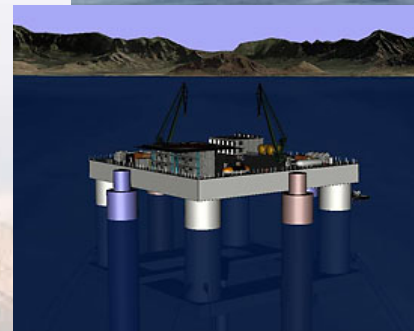
Conventional Hydropower



Marine Hydrokinetic



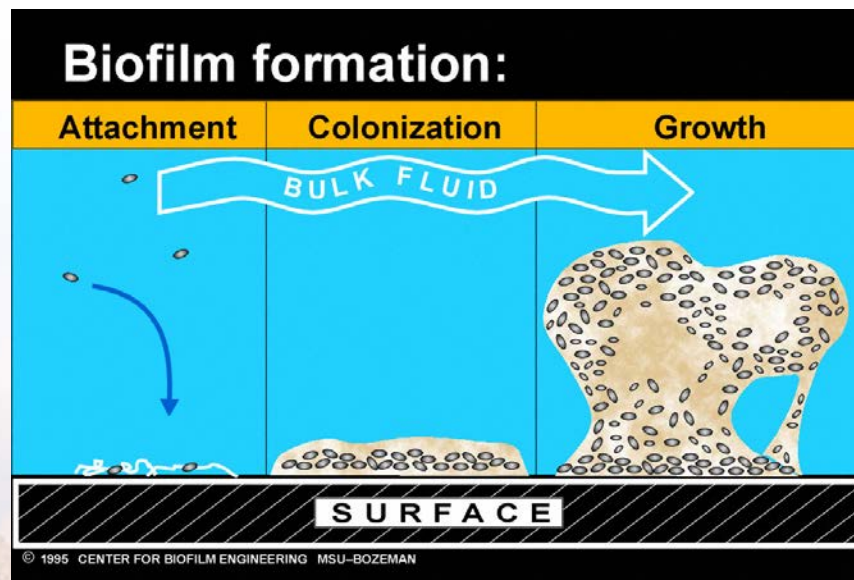
Ocean or Marine Energy



Biofouling Is Caused By Biofilms

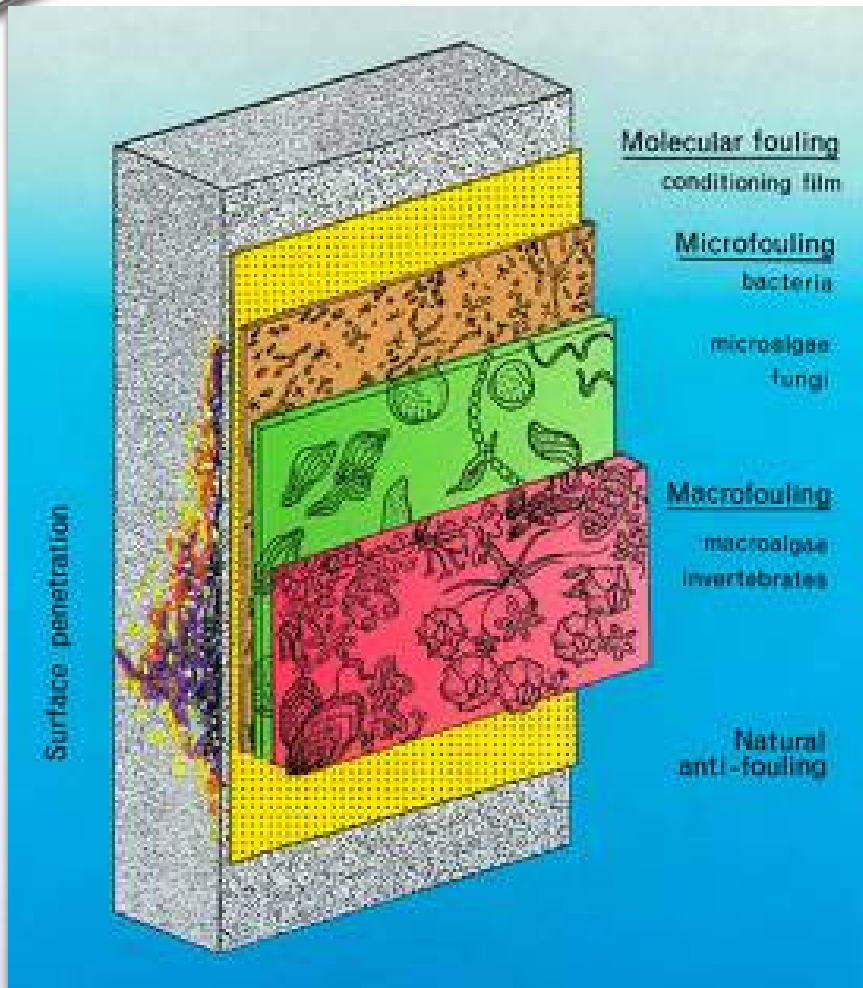
Colonies of microorganisms attached to a surface and encased in extracellular polymeric substances (EPS, aka slime).

- Able to trap nutrients for their own growth
- Protected from antibiotics and other anti-microbial agents



Reproduced with the permission of Center of Biofilm Engineering, Montana State University

Marine Fouling Occurs Over Both Time & Length Scales

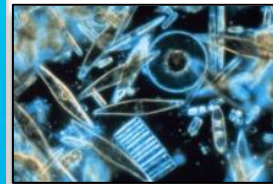


Molecular Fouling (1 min.)

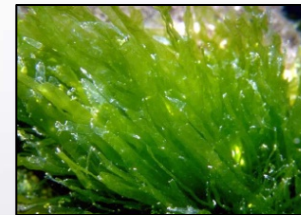
Bacteria (1-24h)



Microalgae/Fungi (1 wk)



Macroalgae/Invertebrates (2-3 wks)



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Tested Commercial Coatings

Biocidal Coating



The screenshot shows the ePaint website. The header features the ePaint logo with the tagline 'The New Wave of Bottom Paint' and an image of a sailboat. Below the header, there's a navigation bar with links like 'Product Updates?', 'Sign Up Here for a My ePaint Account', 'Login', 'View Cart', and 'Checkout'. The main content area has a yellow banner with the text 'Welcome to ePaint! The Company That Invented and Perfected Copper-free Antifouling! Celebrating 20 Years of Excellence'. Below this is a 'Summer Special! Free Shipping for Online Orders.' with a disclaimer. To the right, there's a 'Latest News' section with three articles: 'Y2K', 'EP2000: 2011 Practical Sailor Editor's Choice Product', and 'Washington Becomes First State in the Nation to Ban Copper Bottom Paint'. At the bottom, there are three product images: 'EP-SN1', 'ECOMINER', and 'EP-20'.

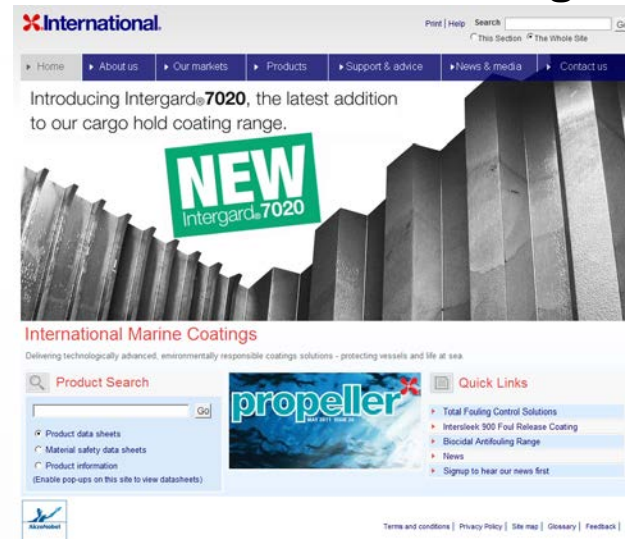
■ EP-2000

- Zinc pyrithione

■ SN-1

- SeaNine211
- Used in > 95% of coast guard aluminum fleet

Foul Release Coating



The screenshot shows the International Marine Coatings website. The header features the International logo and a navigation bar with links like 'Home', 'About us', 'Our markets', 'Products', 'Support & advice', 'News & media', and 'Contact us'. The main content area has a banner for 'Intergard 7020' with the text 'Introducing Intergard 7020, the latest addition to our cargo hold coating range.' Below this is a section for 'International Marine Coatings' with the tagline 'Delivering technologically advanced, environmentally responsible coatings solutions - protecting vessels and life at sea'. There's a 'Product Search' bar and a 'Quick Links' section with links like 'Total Fouling Control Solutions', 'Interleek 900 Foul Release Coating', 'Biocidal Antifouling Range', 'News', and 'Signup to hear our news first'. At the bottom, there's a 'Terms and conditions' link and a 'Feedback' link.

■ INT-757

- Fouling release coating
- Silicone based polymers

■ INT-970

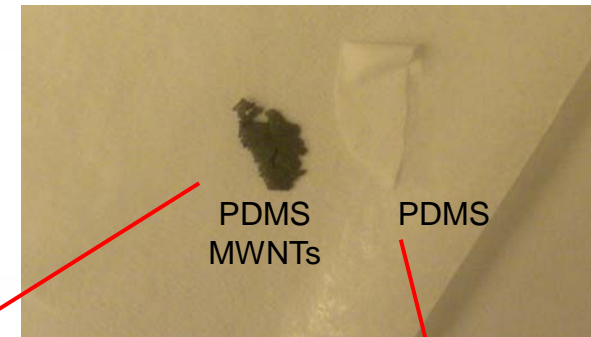
- Fouling release coating
- Silicone based polymers



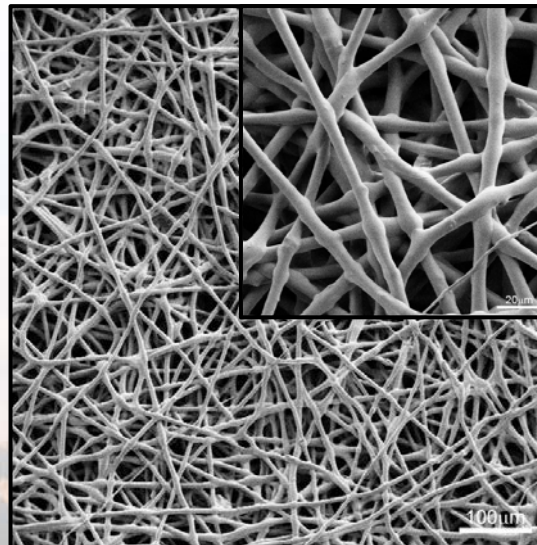
Tested Carbon Nanotube Coatings

- Electrospinning technique developed by Dirk (SNL) and Hedberg-Dirk (UNM)
- Based on antimicrobial activity observed by Schiffman and Elimelech (2011)

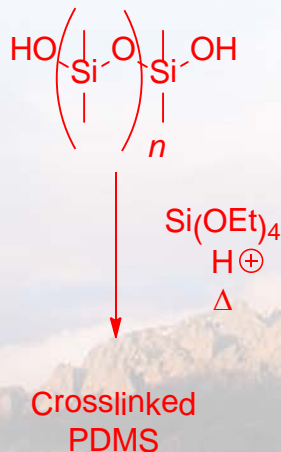
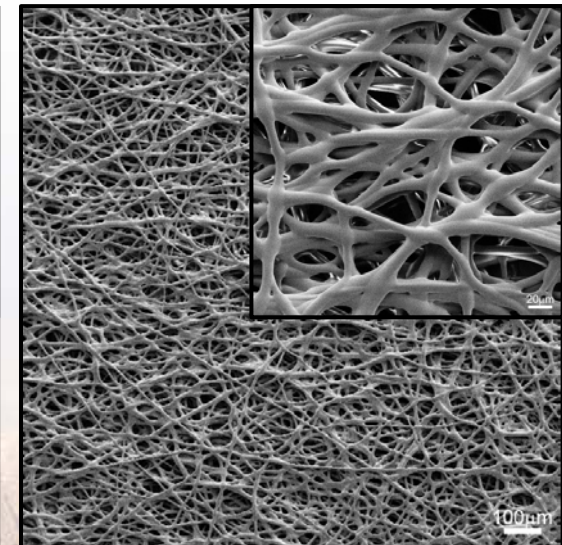
Electrospun PDMS



PDMS/MWNTs

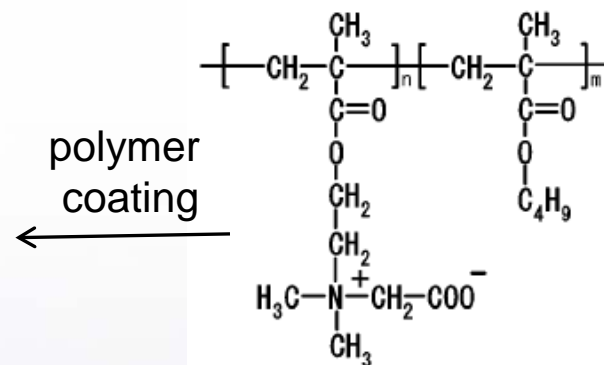
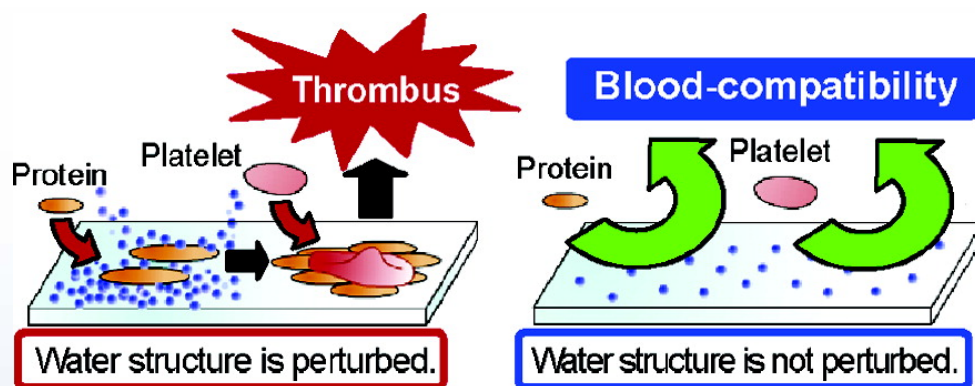


PDMS



Tested Zwitterionic Polymer Coatings

- Zwitterions are neutral dipolar molecules with nonadjacent positive and negative charges (amino acids)
- Show resistance to adsorption of proteins



- Do not perturb the native hydrogen bonded network of water near the surface

Published in: Hiromi Kitano; Susumu Tada; Takayuki Mori; Kohei Takaha; Makoto Gemmei-Ide; Masaru Tanaka; Mitsuhiro Fukuda; Yoshiyuki Yokoyama; *Langmuir* **2005**, 21, 11932-11940.

DOI: 10.1021/la0515571



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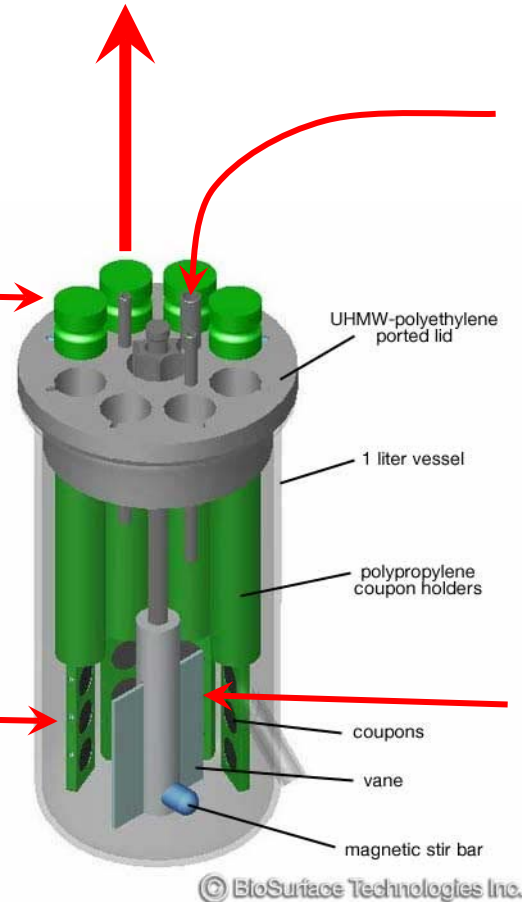
Used CDC Reactor for Biofouling Testing

Sampled after 24 hours of flow

Inflow seawater and nutrients

8 rods

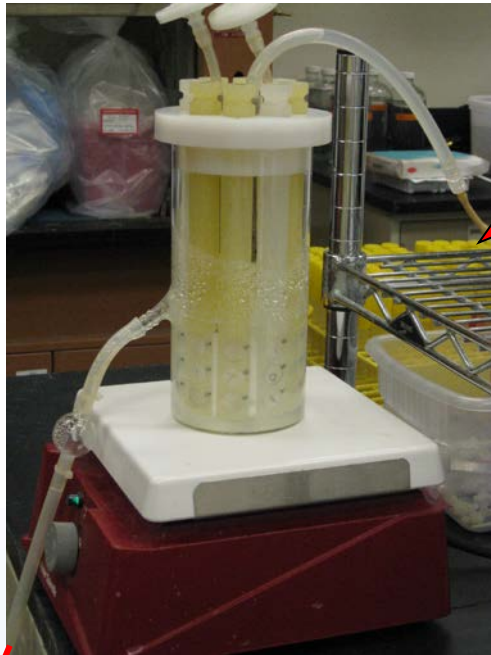
**3 coupons per rod
24 samples total**



Stir bar provide a moderate shear environment

Tested biocidal activity against *P. fluorescens*

CDC Reactor

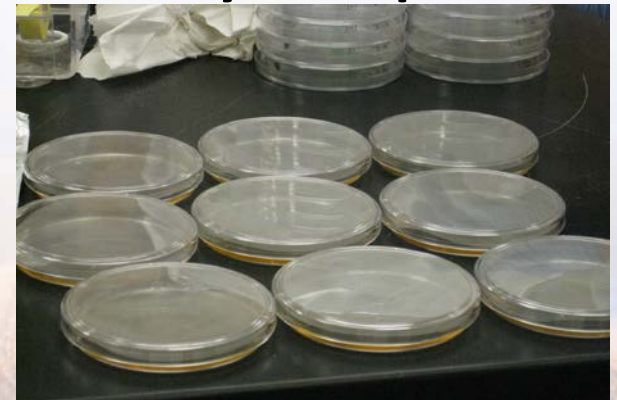


Nutrients
and
seawater in

- Fill reactor with seawater and nutrient solution
- Inoculate
- 24 hour batch phase
- 24 hour phase with nutrient and seawater flow
- Sample
- Quantify biofilm density with plate counting

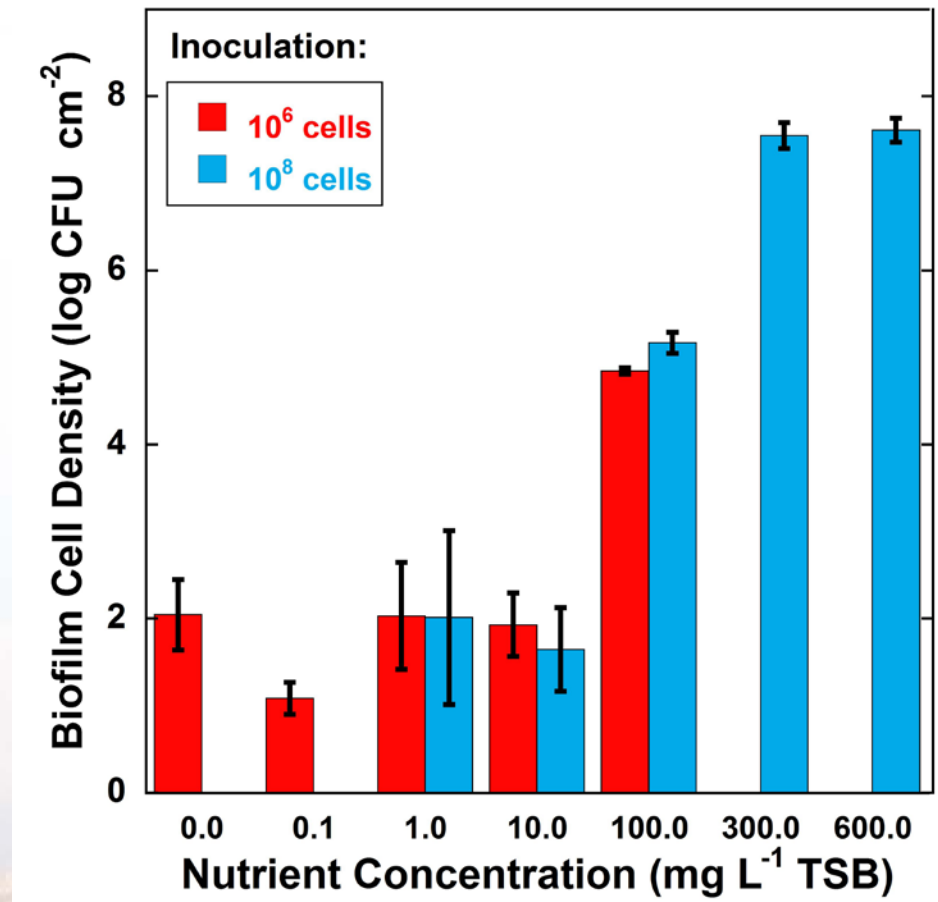
Outflow

- Tested coatings on 6 different materials



Used ASTM Protocol E 2562-07

- Vary number of number of cells added
- Varied concentration of nutrients during batch phase
- Varied concentration of nutrients during flow phase



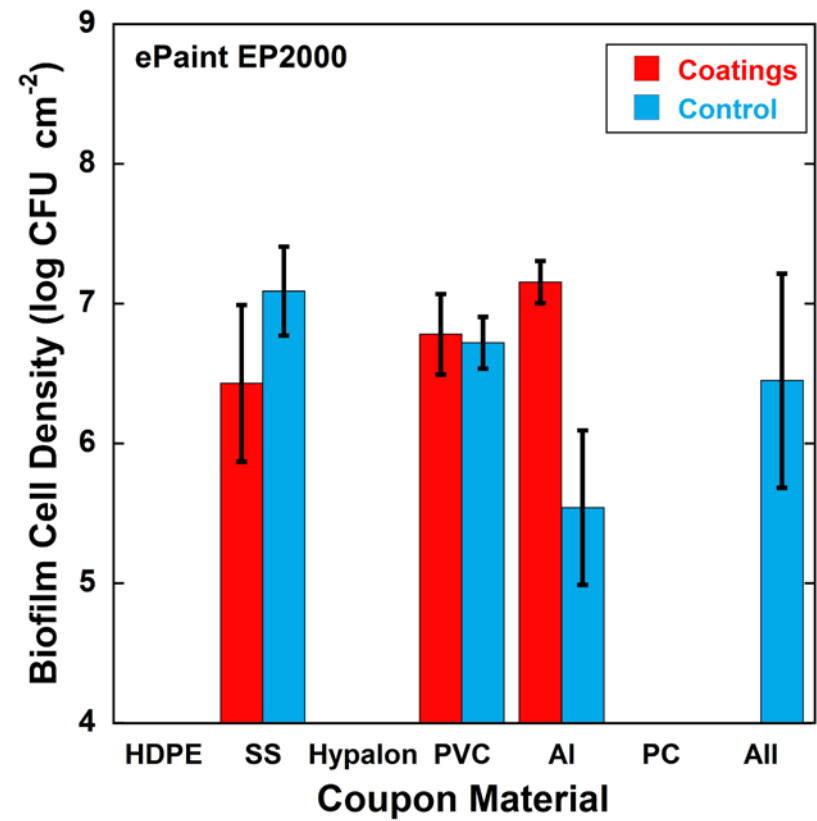
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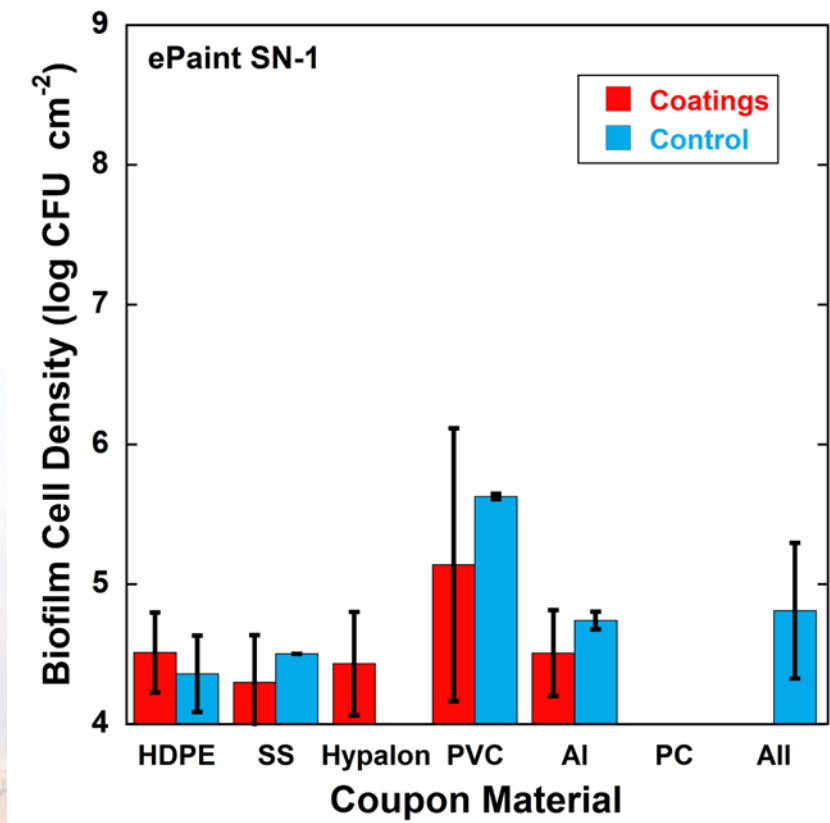
ePaint – EP2000

- Did not show significant decrease in biofilm growth



ePaint - SN-1

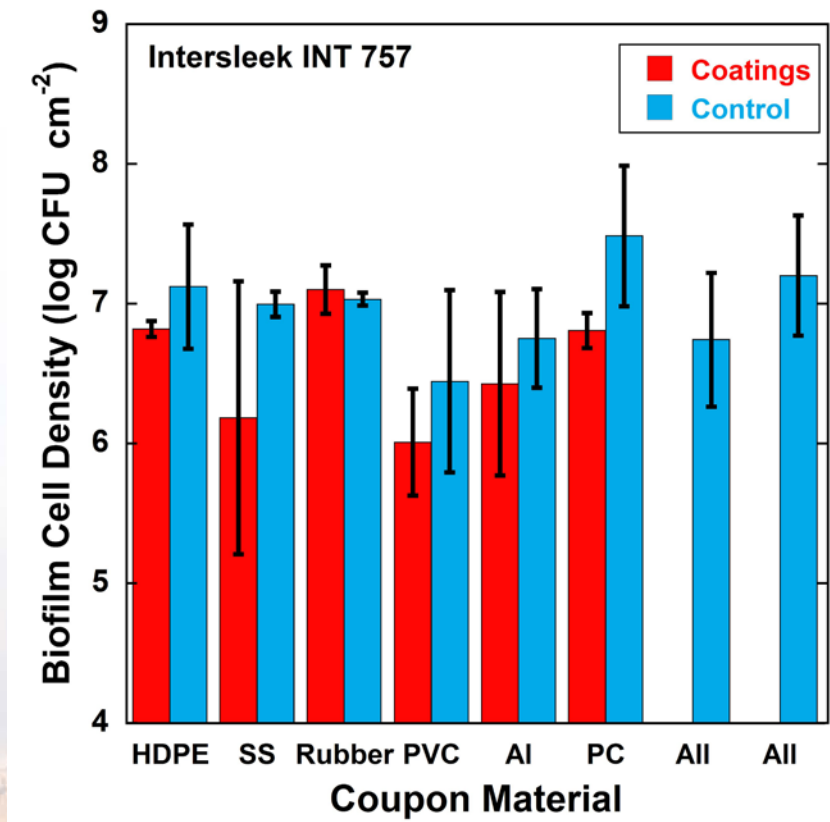
- ~ 4 log reduction in biofilm density compared to other coatings
- Low biofilm density also observed on control coupons
- SeaNine211 leaching into the reactor?



International Paint – INT-757

- Biofouling reduction observed
- Difference statistically significant for polycarbonate (79% reduction)
- Difference statistically significant for stainless steel (85% reduction)
- Less than 1 log reduction

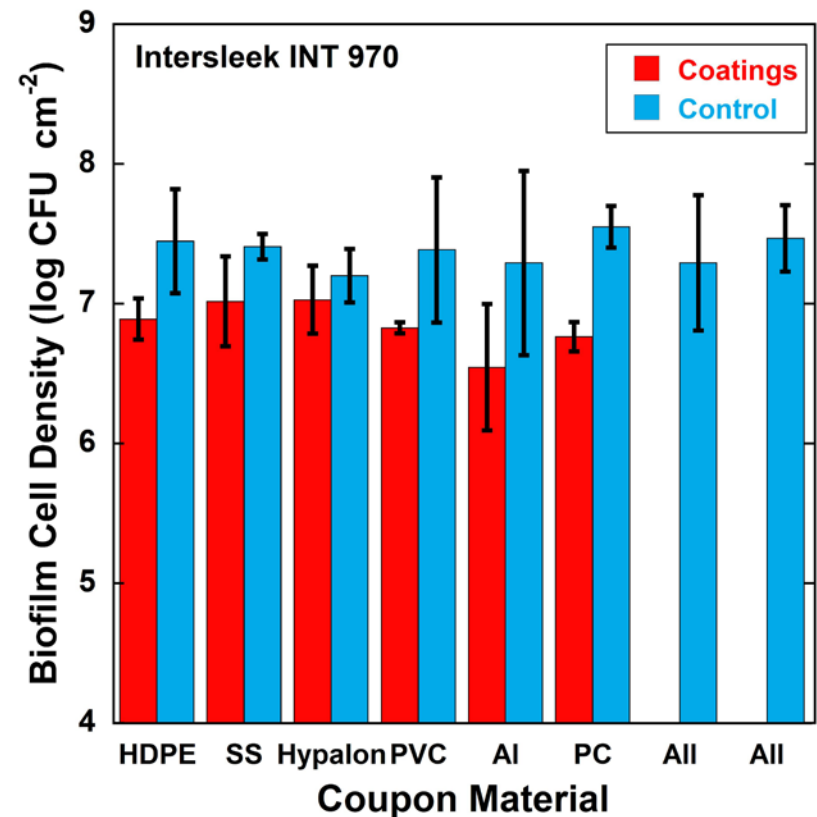
Fouling Release Coating



International Paint – INT-970

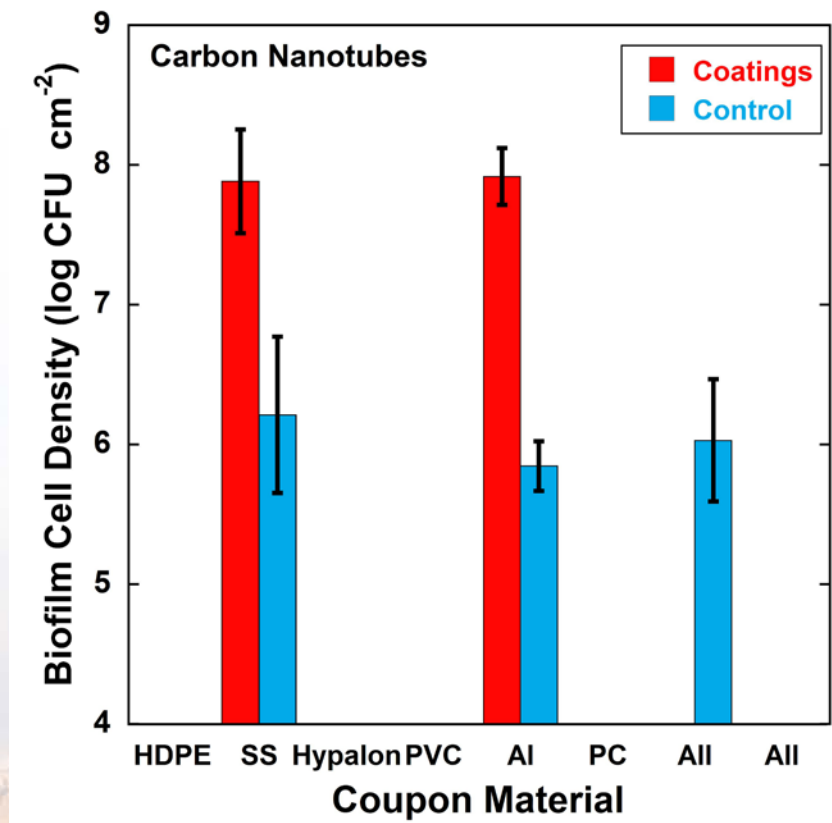
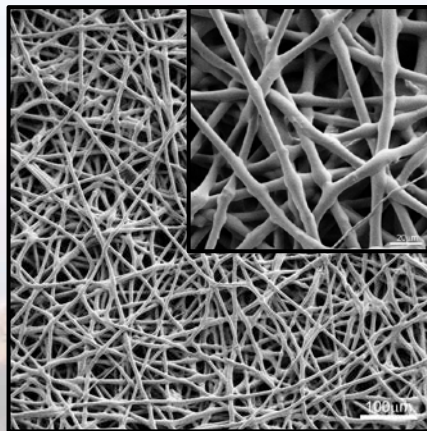
- Biofouling reduction observed
- Difference statistically significant for all materials except hypalon rubber
- Reduction ranged from 59% to 84%
- Less than 1 log reduction

Fouling Release Coating



Carbon Nanotube Coatings

- Cell densities *higher* for carbon nanotube coatings
- Assume due to higher surface area of the coating for cell attachment
- Developing additional coatings with lower surface area



Zwitterionic Coatings

- Biocidal activity only observed on PVC
- 47% reduction observed

