

**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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Outline

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



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Alternative Water Energy Technology

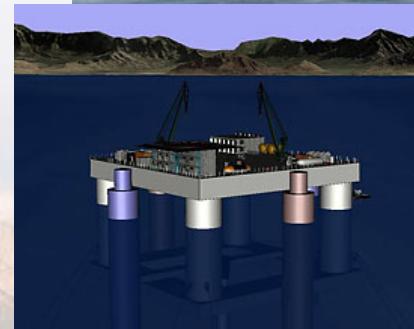
Conventional Hydropower



Marine Hydrokinetic



Ocean or Marine Energy



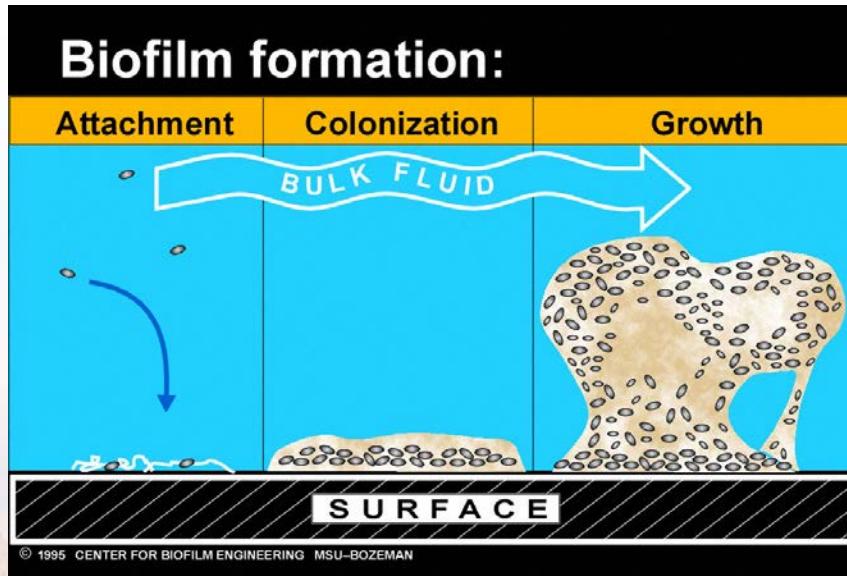
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Biofouling Is Caused By Biofilms

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

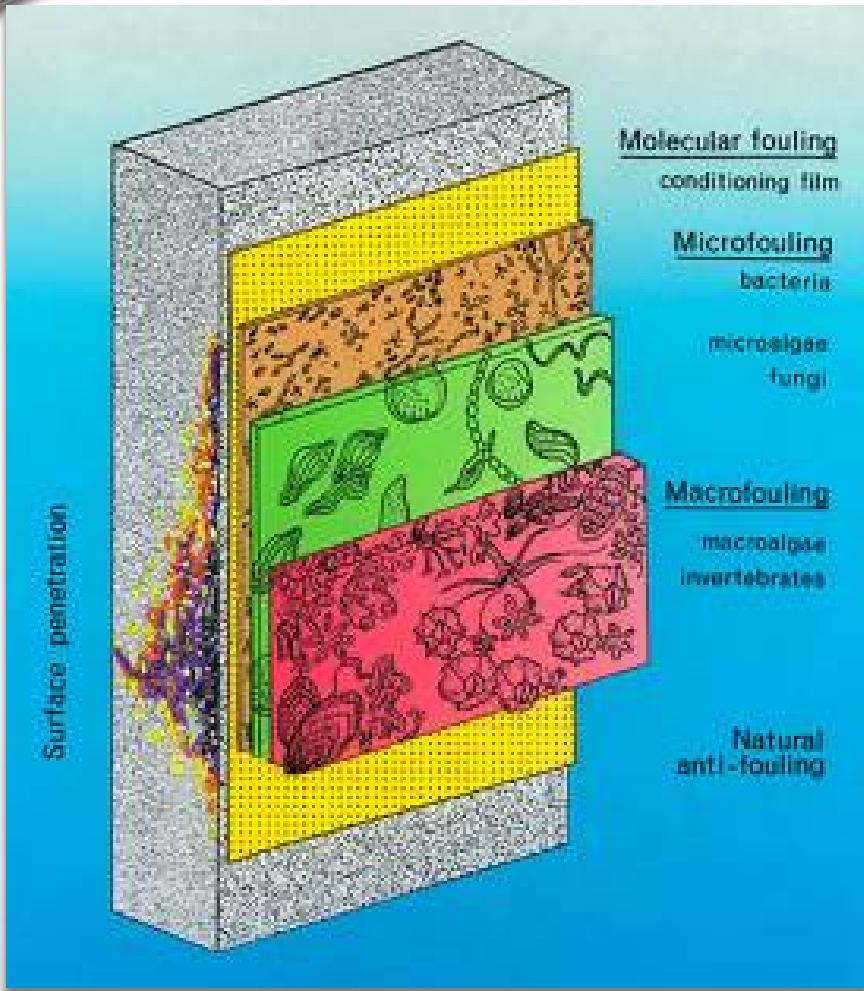


Reproduced with the permission of Center of Biofilm Engineering, Montana State University



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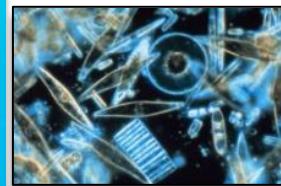
Marine Fouling Occurs Over Both Time & Length Scales



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 ePaint website homepage features a large image of a sailboat on the water. The header includes the ePaint logo and the tagline "The New Wave of Bottom Paint". Below the header are links for "Product Updates?", "Sign Up Here for a My ePaint Account", "Login", "View Cart", and "Checkout". A "Welcome to ePaint!" section highlights "The Company That Invented and Perfected Copper-free Antifouling!" and "Celebrating 20 Years of Excellence". It also mentions a "Summer Special! Free Shipping for Online Orders." A note specifies that the free shipping offer applies to online orders only, is valid for orders shipped within the continental US only, and does not apply to Puerto Rico or Alaska. Shipping is via FedEx Ground, standard shipping. Orders placed by noon will ship same day. No coupon code is required. Free shipping offer will automatically be applied to qualified online orders at checkout. Not valid on previous orders. Limited time offer. The "Latest News" section includes a "Y20G" entry about ePaint being the newest member of the Yacht to Be. It also mentions EP2000 as a 2011 Editor's Choice Product and Washington becoming the first state in the nation to ban copper-based antifouling. The bottom of the page shows three product cans: SN 1 Antifouling, ECOMINER, and ZD Antifouling.

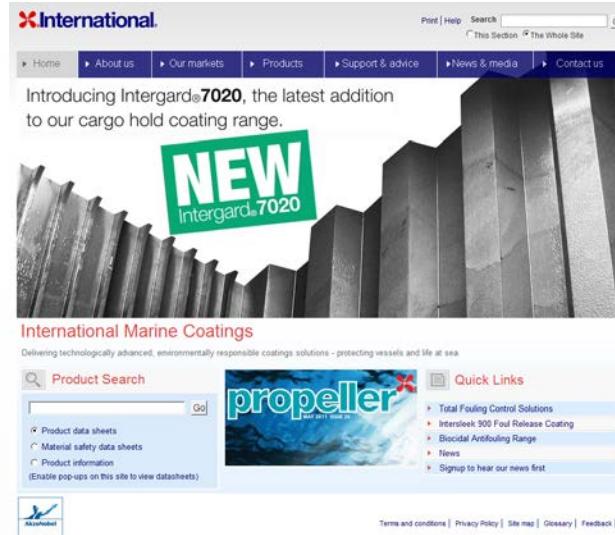
■ EP-2000

- Zinc pyrithione

■ SN-1

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

Foul Release Coating



The Intergard website homepage features a large image of a ship's hull with a "NEW Intergard 7020" graphic overlaid. The header includes the Intergard logo and links for "Print", "Help", "Search", "This Section", "The Whole Site", "Home", "About us", "Our markets", "Products", "Support & advice", "News & media", and "Contact us". A section titled "Introducing Intergard 7020, the latest addition to our cargo hold coating range." is displayed. The "International Marine Coatings" section emphasizes "Delivering technologically advanced, environmentally responsible coatings solutions - protecting vessels and life at sea." A "Product Search" bar is available, and a "Quick Links" sidebar includes links for "Total Fouling Control Solutions", "Interseal 300 Foul Release Coating", "Biocidal Antifouling Range", "News", and "Signup to hear our news first". The footer links to "Terms and conditions", "Privacy Policy", "Site map", "Glossary", and "Feedback".

■ INT-757

- Foul release coating
- Silicone based polymers

■ INT-970

- Foul release coating
- Silicone based polymers

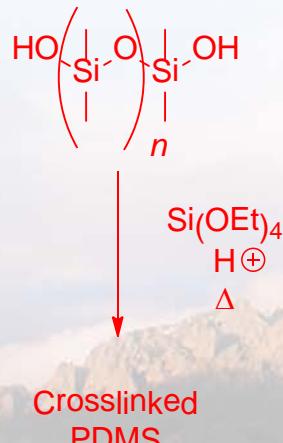


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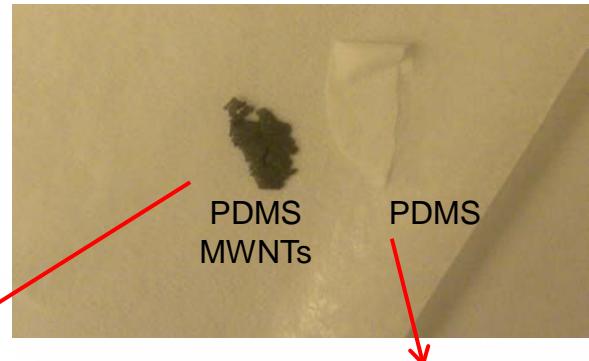


Tested Carbon Nanotube Coatings

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

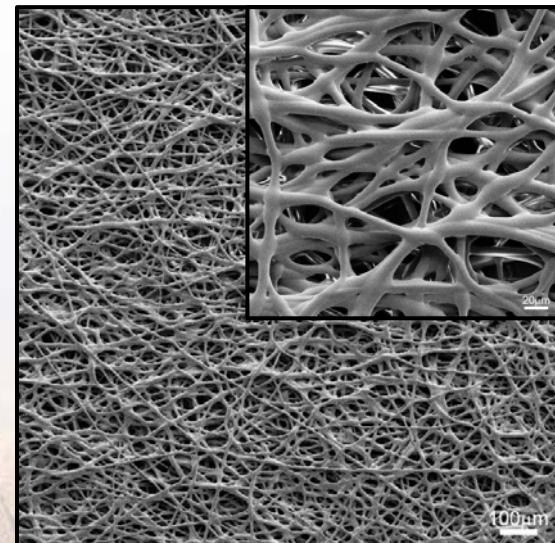
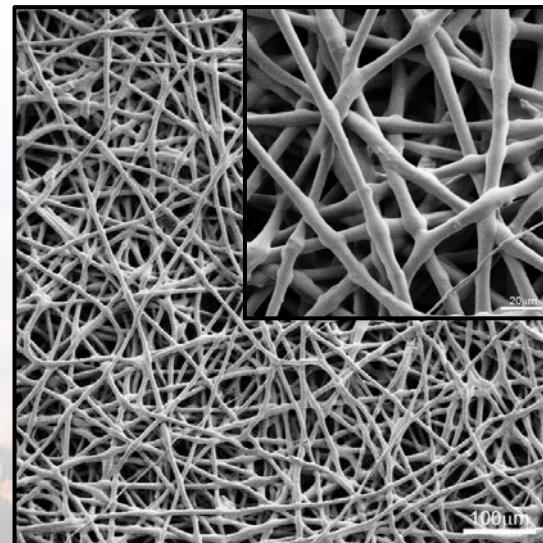


Electrospun PDMS



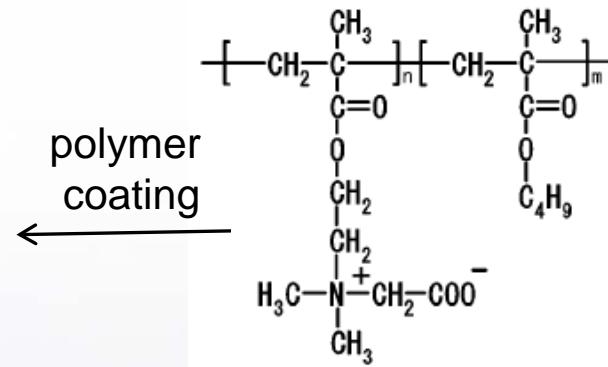
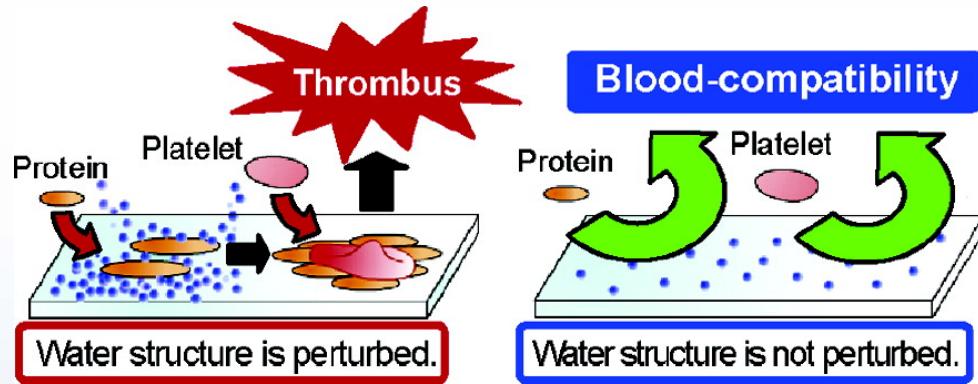
PDMS/MWNTs

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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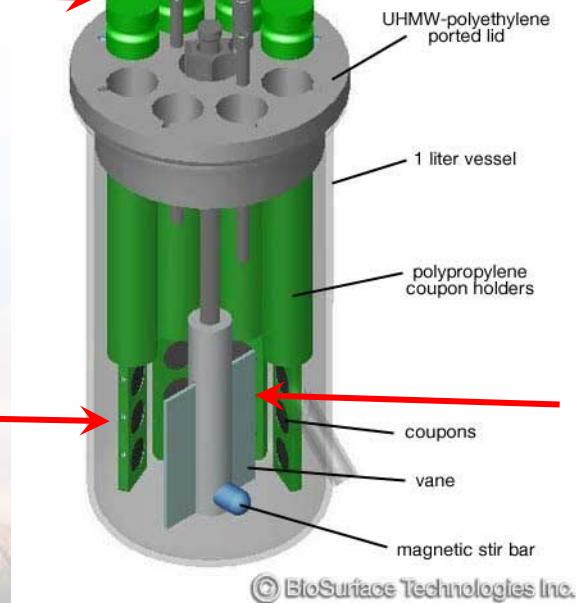


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Used CDC Reactor for Biofouling Testing

Sampled after 24 hours of flow

8 rods



3 coupons per rod
24 samples total

Inflow seawater
and nutrients

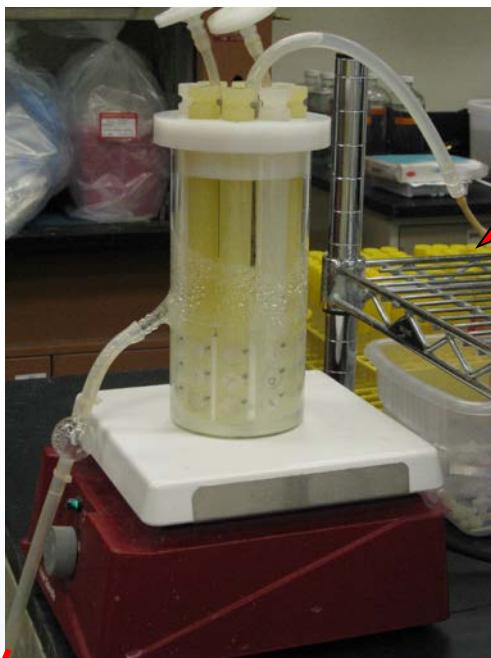
Stir bar provide a
moderate shear
environment



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*Tested biocical activity against *P. fluorescens**

CDC Reactor



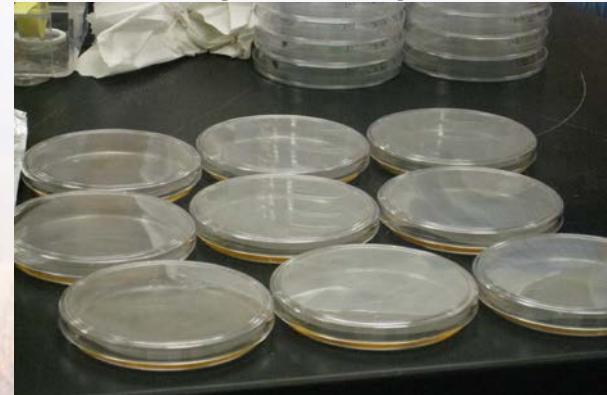
Nutrients
and
seawater in



Outflow

- 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

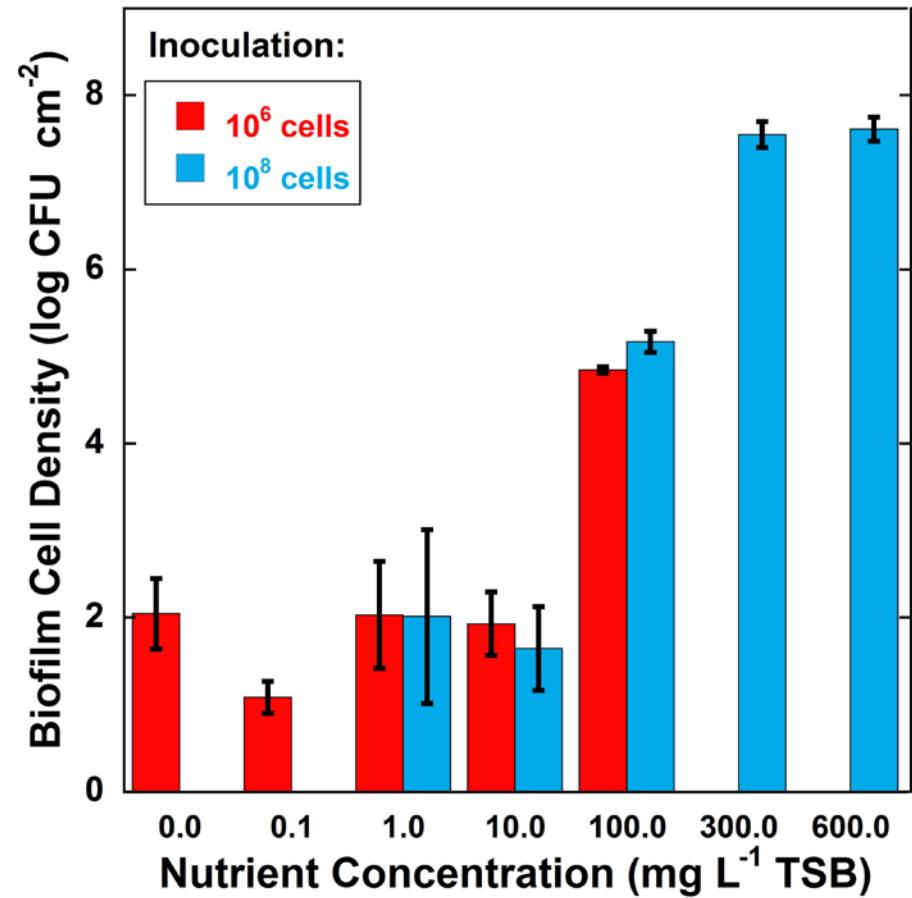
- Tested coatings on 6 different materials



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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



Outline

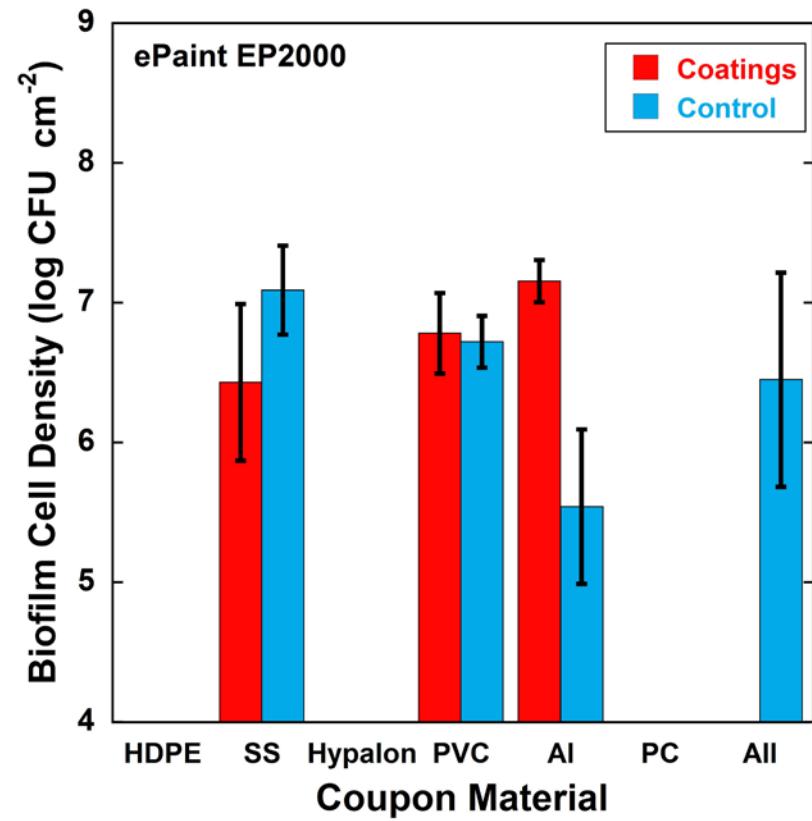
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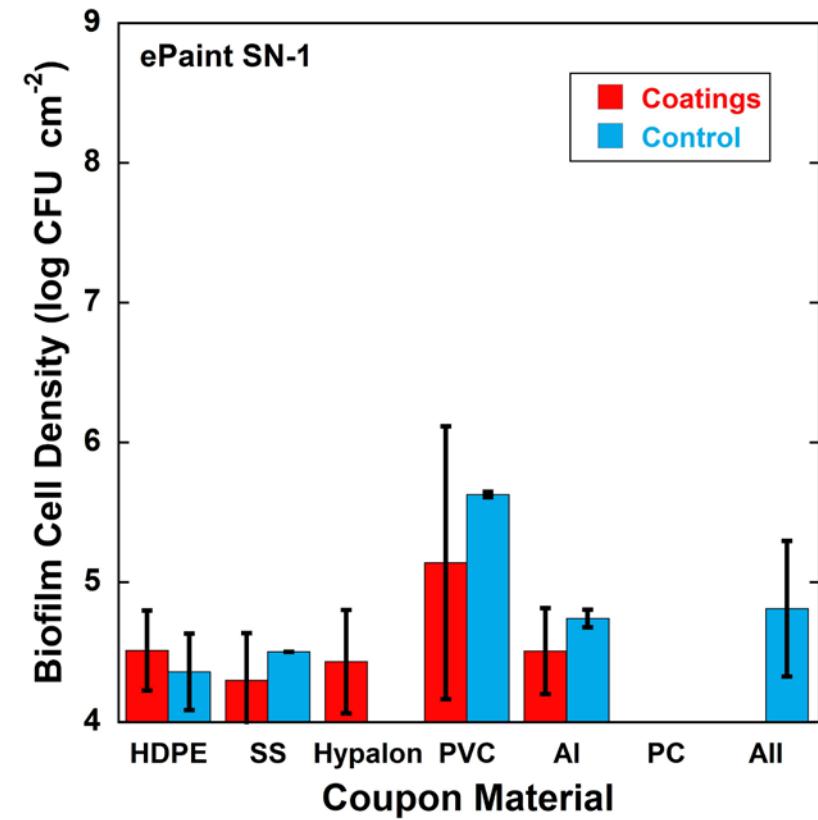
ePaint – EP2000

- 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?

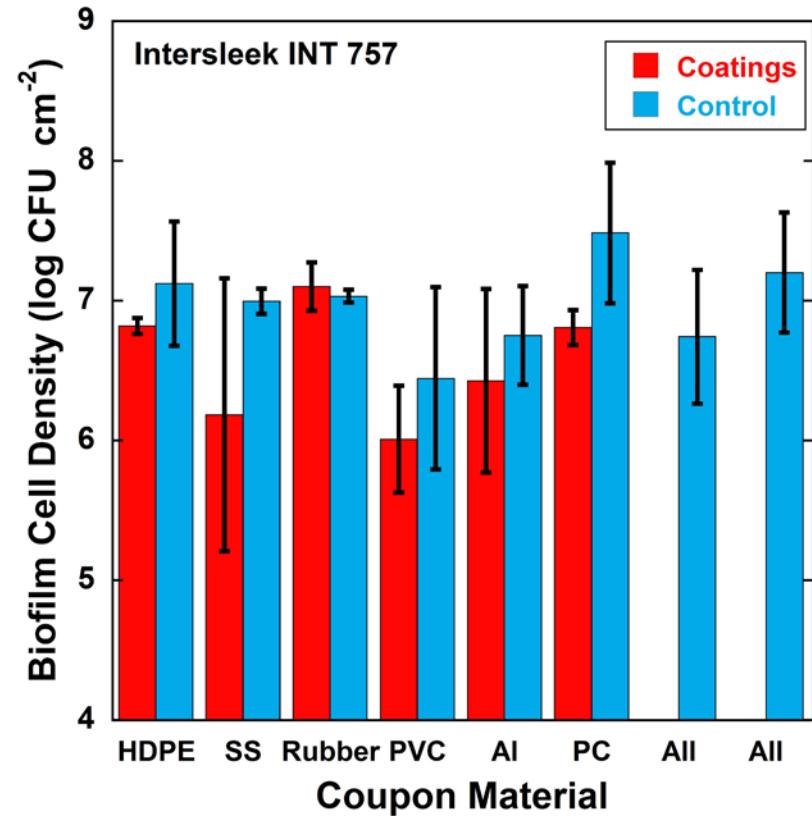


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International Paint – INT-757

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

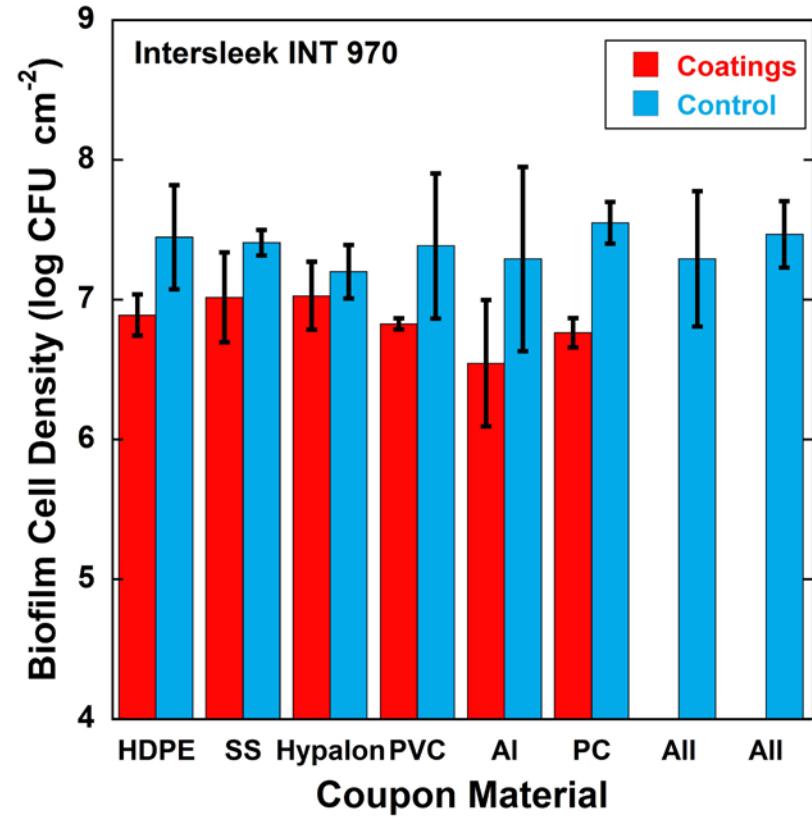
Fouling Release Coating



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

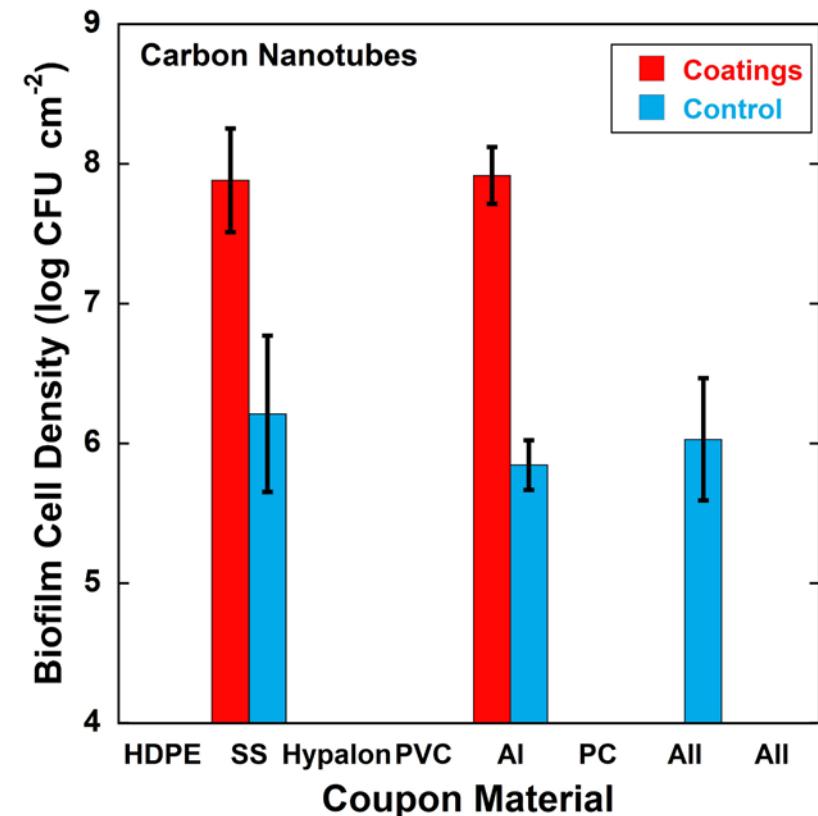
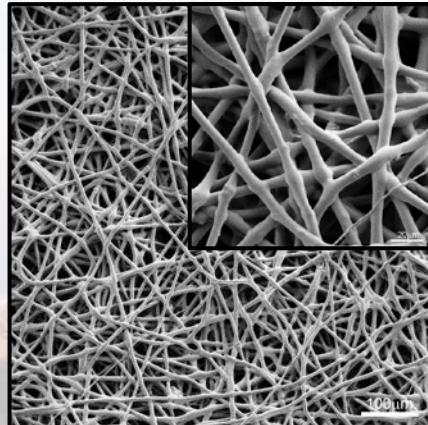
Fouling Release Coating



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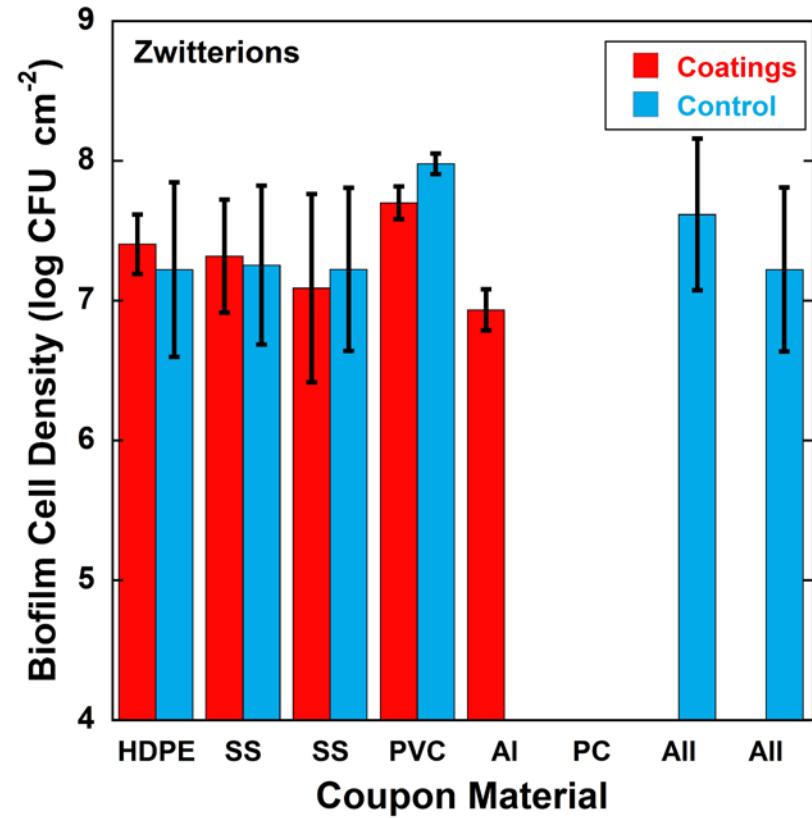
Carbon Nanotube Coatings

- 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



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