Biodegradation and Bioremediation in Oiled Marine Environments

Considerations in understanding Biodegradation and developing, testing and applying bioremediation products
Bioresmediation vs Biodegradation

Biodegradation is the process whereby natural organisms degrade oil compounds.

Bioresmediation is a human activity targeted at enhancing the rates at which oil compounds are naturally degraded by organisms.
What’s New With Biodegradation?

• Hydrocarbon degrading bacteria are present in all seas at low concentrations

• The science of genomics is identifying many previously unknown hydrocarbon-degrading marine microbes

• Natural biodegradation rates of specific hydrocarbons are being measured
  - they take days to weeks in water
  - Months to years if oil buried in beach sediment

• There are now dozens of papers in the peer reviewed literature
What’s New With Biodegradation?

- **It takes a Village.** No single microorganism can degrade all compounds in oil. When oil spills in the water, dozens of species “bloom”, each choosing their preferred hydrocarbon compounds.

- **The Rate at which Oil Degrades Increases with Surface Area of oil.** Dispersed oil particles (natural or otherwise) offer thousands of times more surface area than slicks, tar mats or tar balls.

- **Degradation Rates decrease with Temperature.** Compounds in oil undergo natural biodegradation in Arctic conditions, but at slower rates than in warm environments.

- **Oxygen and nutrients are consumed** (old news)
Genomics identifies functional species* of hydrocarbon-degrading bacteria

* Some Scientists call them Operational Taxonomic Units
What’s New With Bioremediation?

How can we help Nature speed the Process?

National Contingency Plan (NCP) Subpart J
(including the National Product Schedule NPS)
- 49 Products Listed
- Effectiveness is compared to Nutrient Control
- USEPA proposed revisions of SUBPART J
  (Now available out for public comment)

National Response Team (NRT)
- Bioremediation Fact Sheet being revised

Scientific (Peer Reviewed) Literature
- Dozens of papers testing new products, formulations and methods

Vendor Advertisements and Brochures
- We need to confirm the claims using science
The World of Oil Spill Biodegradation Science

• I conducted a Literature Search of journal papers on marine oil spill bioremediation

• 130 peer reviewed papers since 2010

• **Operationally,** most products have not been field-tested: little peer-reviewed science published at this scale

• There are peer reviewed papers on many products that are **not** on the EPA Product schedule
Technologies Being Tested as reported in the Scientific Literature

- Nutrients and Oxidants
- Mechanical
- Microbial consortia
- Oleophilic fertilizer
- Urea
- Dispersants
- Clay Minerals
- Polymers
- Molasses
- Nano Materials
- Magnetites
- Chitosan (from fish wastes)
- Sawdust
- Mushroom spent compost
- Phyto-remedians
- Rhizo-remedians
- Temperature Increase
- Modified fishmeal
- TiO$_2$
Examples


Formulations

- Liquids
  - Water soluble
  - Oleophilic – (Inipol)
  - Subsurface Injection products - PES
- Pellets and Granules (Customben)
- Product Applications combined with Tilling
- Nutrients
“Substrates” Tested

- Water, sediment, slicks, mostly in the laboratory, some in the field

- Field Studies: mainly oiled beaches, marsh and mangrove sediments (but not in US since 1994)

- A half dozen papers have addressed bioremediation in water with variety of treatments

- Using various oils and fuels, but no “standard” oil
Other Bioremediation Methods

• **Phyto-remediation** – repopulate damaged marsh with new plantings.
• **Oxygenating** sub-surface sediments in gravel intertidal beaches
• **Disperse** oil back into water so natural biodegradation can proceed (products with surfactants)
Gaps

• Practically no literature on effectiveness of NPS products in scaled-up (operationally-relevant) studies

• Hardly any literature on the ability of treatments to reduce toxicity of treated oiled sediments or water
The Anecdotal “Science” of Bioremediation

- Advertisements have very few citations to effectiveness of treatments at **operational scales**

- Videos showing oil disappearing are not supported by hard data on biodegradation; some appear to disperse

- Many anecdotes:
  - We did a bucket test and were impressed
  - Our products have been sold and used worldwide

- Literature suggests researchers have **abandoned tests with microbial formulations** in favor of testing “biostimulants”
Humans

Improving the Information for Decision-Makers
Four Scales of Testing Effectiveness and Effects of Bioremediation Treatments

1 - Bench-scale Laboratory, LSU

2 - Marsh Mesocosm, NOAA

3 - Intentional Beach Plot Oiling, Delaware

4 - Actual Oil Spill, Galveston Bay, 1990
What Needs To Be Monitored?

- Total Petroleum Hydrocarbons
- Polycyclic Aromatic Hydrocarbons and Alkanes
- Hopane and Analyte-to-Hopane Ratios
- Nutrients (N, P)
- Microbial Biomass
- Microbial Composition (actual degraders)
- CO2 Production
- Toxicity Reduction of Treated Substrate
- Visuals
Elements of Monitoring
(Design)

- **Time Series** for rate trends (>3 sampling events)
- **Controls** (Sterile and Nutrient Treatment)
- **Replication** (N>3, preferably 5)
- **Randomization** of Treatments
- **Publish** Results in Peer-reviewed Journals
Define What Marine/Aquatic Situations are targets of the Technology Testing

Open Water?
Above high tide (Supra-tidal)

Intertidal Shorelines
   Sand and Gravel Beaches
   Mudflats
   Marshes
   Mangroves
   Coral Reefs
Define What Oil is the Testing Target

Fresh Crude Oil?
- Light - API 40
- Medium - API 25
- Heavy – API 15

Weathered Crude Oils

Fuel Oils (fresh or weathered)
- Diesel
- Intermediate Fuel Oils
- Bunker Oil

Emerging Oils
- Bakken
- Oil Sands
- Biofuels
Logistical Considerations

• Application Rate: One-time or continuous?
• Wash Out: Product removal by tidal flushing
• Scale: amount of product really needed?
• Access: Disturbance, mechanical injury
• Product/Oil Ratio
• Monitoring:
  – Visual? Chemical? Toxicity Reduction?
  – Replication?
Goal of Bioremediation:
What are you trying to accomplish?

• Remove visible oil?
• Reduce concentrations of toxic oil components?
• Reduce toxicity of oiled substrate?
• Enhance recovery & recolonization of marine life?
• Reduce damage to historic and cultural resources?
Field Testing Needed

- Delaware (1994) was the last full scale field testing in the US with robust, scientifically satisfying, published results.
- Unfortunately the study did not test any commercial product. But the design is clearly applicable.
- Intentional shoreline oiling experiments are being done in other countries.
Thank You

And

Please Review USEPA’s proposal for revisions to the National Contingency Plan, Subpart J

Federal Register  Vol. 80, No. 14  January 22, 2015