NRPOP - Northern Region Persistent Organic Pollution Control Laboratory
- An Overview of Oil Spill Research

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Northern Region Persistent Organic Pollution Control (NRPOP) Lab

First of its kind in Canada with national and international recognitions
Major funding from CFI, NSERC, NL Government, PRNL, etc.

Target Pollutants
- **Persistent and organic** pollutants – petroleum hydrocarbons and by products (esp. oil spills), polycyclic aromatic hydrocarbons (PAHs), produced water, marine (ballast/bilge) wastewater, other industrial oily wastewater, contaminated sites, etc.
- **Emerging** pollutants (EPs) in ocean and coastal environments - chemical surfactants, pesticides, flame retardants, disinfection byproducts, pharmaceutical and cosmetic products (PPCPs), nano-particles, microplastics, etc.

Target Environments
- Cold regions including North Atlantic, Arctic and sub-arctic areas
- **Marine and coastal environments**, etc.
Professors

3 core professors, 10+ adjunct/associated professors, and 30+ collaborators globally

Postdocs and Students

About **20-30 trainees at any time** incl. 4+ postdocs/RAs, 10+ PhD, 10+ masters students, and some work-term UG students; hosted 40+ visiting scholars worldwide; graduated students well placed in academia, industry and government

International Collaborations

- **Institutional** collaborations with Univ of British Columbia, McGill Univ, Univ of Victoria, McMaster Univ, Dalhousie Univ, Univ of Regina, Univ of California Berkeley, Stanford Univ, Cornell Univ, Maryland Univ, Univ College of London, Nanyang Technological Univ, Peking Univ, Beijing Normal Univ, Ocean Univ of China, etc.

- **Governmental** collaborations with Environment Canada, Fisheries and Oceans Canada, Natural Resources Canada, NL Department of Environmental Conservation, US EPA, US NOAA, CSIRO, UNDP, etc.

- **Industrial** collaborations with PRNL, ExxonMobil, Suncor, Equinor (Statoil), ECRC, ABS, SINTEF, Cedre, Vale Inco, Nestle, etc.

**⇒ multiple-scale R&D and real-world applications**

Major Research Expertise ➞ marine/inland oil spill response and cleanup, contaminant fate, transport and effects, marine/coastal pollution prevention & mitigation, advanced water/wastewater treatment, environmental nanotech, environmental biotech, site remediation, process simulation & control, system optimization, risk/impact assessment, AI-aided decision making, etc.

NEWFOUNDLAND & LABRADOR, CANADA

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Featured Facilities

- **Advanced analytical instruments** (GC/GC-MS, GC-FID/ECD, HPLC-MS/MS, IC, AAS, TPH, TOC, spectrometers, AES, viscometer, contact angle goniometer, etc.)

- **Biological and nanomaterial devices** (PCR, fermentor, Microtox, respirometer, bio-safety carbinet, glovebox, freeze-dryer, NanoSight, LISST, microreactors, etc.)

- **Physical simulation chambers/models** (e.g., batch-/bench-/pilot-scale reactors/tanks incl. cohosting a 3.6m soil tank and 12m wave/spill tank)

- **Data/image processing tools and modeling software** - GNORM, OSCAR, MEDSLIK, LINGO/LINDO, ArcGIS, AutoCAD, Matlab, Worldviz VR, Hololens, etc.

- **Faculty of Engineering** - towing/wave tank, deep-water tank, ice tank (w wind tunnel), cold rooms (-20°C; x3), AUV and gliders, etc. (NRC – 200m ice/wave tanks, large-scale 3-D printers, etc.)
Area 1: Biosurfactant producers and production

Area 2: Bio-aided oil pollution mitigation

Area 3: Enhanced monitoring and analysis

Area 4: Oily wastewater treatment

Area 5: Dynamic simulation, integrated assessment and intelligent decision making

~100 refereed journal publications and 6 patents/disclosures in the past 5 years (e.g., JHM, EP, WR, BT, FEE, JCP, STOTEN, Chemosphere, JEM, MBP, EnvSoft, ESPR, JEI, RSC Adv, GA)
Research Area 1: Biosurfactant Producers and Production

1-1: Biosurfactant producer screening and genetic engineering

Research outputs:
1. **140+ surfactant production strains** were screened from the North Atlantic ocean and coasts, including one new strain and **one first discovered strain** with surfactant production ability as well as a variety of characteristic strains.
2. By genetic shuffling, ultraviolet mutation and enzyme technology, etc. high efficient mutation strains were obtained. The best strain can increase production capability with over **200+ times CMC**.

"improved bacterial mutation technology" has a great significance in the future.
1-2: Waste based biosurfactant production

Large scale biosurfactant production face challenges from high production cost ➔ selection of economical raw material is important

Fishery waste
Remove the heads, tails, and viscera immediately, twice at medium speed with blender, frozen and stored at -20°C

waste: water 1:1 ➔ (50g+50mL)

Enzyme inactivation
Heating at 95 °C in the water bath for 10 min

Hydrolysis
Water bath at desired condition (Table 3-1)

Enzyme inactivation
Heating at 95 °C in the water bath for 10 min

Centrifugation
6,000×g, 20 min

Supernatants freeze dry

Fish Peptone (FP)

Degree of hydrolysis (DH)

• Cod waste
• Tuna waste
• Brewery waste
• Composting ...

Research outputs:
1. Various local waste resources (e.g., cod, tuna, brewery, etc..) were evaluated and proved as a promising biosurfactant producing substrate.
2. A cost reduction (10%-20%) was achieved with a productivity enhancement (~10%)

N2-6P N3-4P N3-1P 21332

Bacillus strains
Research outputs:

1. Investigated the immobilization of biocatalyst on porous carrier nano-material to enhance cell density to promote biosurfactant productivity

2. Improved the understanding of cultivation setups to shed light on the application of fixed bed biofilm reactor for catalyzing bioproduct generation
Research Area 2: Bio-Aided Oil Spill Cleanup

2-1: Bio-dispersion for marine oil spill response and cleanup

Performance of biosurfactant based dispersants? ➔ surface-active properties, effectiveness, toxicity

<table>
<thead>
<tr>
<th>Surface-active parameters</th>
<th>Units</th>
<th>Surfactin</th>
<th>Rhamnolipids</th>
<th>Trehalose lipids</th>
<th>Emulsins</th>
<th>Corexit 9500A</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC</td>
<td>(mg/L)</td>
<td>13.01</td>
<td>1355.71</td>
<td>199.16</td>
<td>500512.65</td>
<td>32.41</td>
</tr>
<tr>
<td>Minimum surface tension</td>
<td>(dynes/cm)</td>
<td>28.98</td>
<td>39.97</td>
<td>34.90</td>
<td>57.06</td>
<td>39.96</td>
</tr>
<tr>
<td>CEC</td>
<td>(g/L)</td>
<td>1.56</td>
<td>&gt;1016</td>
<td>19.37</td>
<td>14.73</td>
<td>1.98</td>
</tr>
<tr>
<td>Maximum E24</td>
<td>(%)</td>
<td>60.00</td>
<td>0.00</td>
<td>63.33</td>
<td>65.00</td>
<td>56.25</td>
</tr>
<tr>
<td>CMC/1000CEC</td>
<td>1</td>
<td>0.0083</td>
<td>&lt;0.0013</td>
<td>0.010</td>
<td>33.98</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Biosurfactants

<table>
<thead>
<tr>
<th></th>
<th>5 min exposure</th>
<th>95% confidence range</th>
<th>15 min exposure</th>
<th>95% confidence range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfactins</td>
<td>0.243</td>
<td>0.122-0.486</td>
<td>0.255</td>
<td></td>
</tr>
<tr>
<td>Trehalose</td>
<td>&gt;6.150</td>
<td>NA&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&gt;6.150</td>
<td>NA&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Rhamnolipid</td>
<td>0.968</td>
<td>0.730-1.285</td>
<td>0.977</td>
<td>0.614-1.556</td>
</tr>
<tr>
<td>Emulsins</td>
<td>&gt;5.005</td>
<td>NA&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&gt;5.005</td>
<td>NA&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Research outputs:

1. Biosurfactants generated by different bacteria ➔ evaluated as candidate for dispersant development (Surfactin/Trehalose lipids)
2. The optimum oil dispersion effectiveness achieved ➔ when combining the abilities of surface/interfacial tension reduction and emulsion stabilization in a balanced manner
3. Oil spill and dispersion in deep water (up to 3,000 psi or ~2000 m deep) by chemical and biological dispersants
2-2: Bio-enhanced coastal washing and bioremediation

- Mechanism evaluation of biosurfactant enhanced bioremediation

- Biosurfactant enhanced flushing/bioremediation

- Pilot scale evaluation of biosurfactant enhanced soil remediation

Research outputs:
1. Bio-enhanced coastal remediation technologies  evaluated in multi-scales for oil pollution cleanup and heavy metal removal

2. Physical and numerical simulation, system optimization, and their coupling  cost reduction and efficiency improvement
1. Screen marine demulsifying bacteria in Atlantic ocean, and evaluate the key parameters that affect the demulsification process.

2. Contribute to the development of biological demulsification of oily wastewater stream.
Research Area 3: Environmental Monitoring and Analysis

3-1: Advancement of oil analysis

- **VSA/LLME-GC/MS analysis**

<table>
<thead>
<tr>
<th>Current methods</th>
<th>New methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex</td>
<td>Rapid and simple</td>
</tr>
<tr>
<td>Time/solvent consuming</td>
<td>Low-expense and toxic</td>
</tr>
<tr>
<td>Hard to trace in environment</td>
<td>Efficient for intensive detection</td>
</tr>
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</table>

**Research outputs:**

- **Oil compound analysis in complex matrix:**
  Vortex- and Shaker-Assisted Liquid–Liquid Microextraction (VSA-LLME) coupled with (GC-MS) ➔ trace levels (> 10 ng/L) of dissolved PAHs in offshore produced water

- **Biomarkers and fingerprinting:**
  screening of reliable biomarkers ➔ identification of spill source and weathering status of dispersed oil

- **CSIA ➔ quantitation method to monitor the biodegradation of naturally/chemically dispersed oil in ocean environment**
3-2: Phospholipid fatty acid (PLFA) based microbial community analysis

- Sulfate-reducing bacteria (SRB) qualification/quantification in reservoir samples
- Microbial community analysis during oil biodegradation

**Research outputs:**

1. **Development of PLFA quantification method** ➔ routine analysis of samples with high oily and salinity properties in marine environment ➔ elucidate dynamic changes of the microbial community structure, and associated biodegradation mechanism during biodegradation

2. Application: PLFA analysis for profiling microbial communities in offshore produced water, oil contaminated soil and sludge samples
Research Area 4: Oily wastewater treatment

4-1: Enhanced oxidation processes and nano-microbial enhancement for wastewater treatment and reuse

Enhanced oxidation processes (EOPs): ozonation + UV/LED + nano-catalysts/MOFs + ultrasonication + biosurfactants + continuous flow micro-reaction + microbial fuel cells

Management technologies: process simulation + process control + system optimization

Key Research Areas
Research Area 4: Oily wastewater treatment

Research outputs:
1. Nanoscale catalytic materials ➔ High activity, good stability, makes reaction possible under visible light
2. Integration with microbial enhanced methods ➔ reduce cost and make process green and less environmental impact
3. Design of EOPs reactor and the optimization of reaction conditions ➔ make the technology possible for industrialization, and finally realize recycling, and "zero pollution emissions"
4. Multi-scale tests and application of the coupling use of the EOPs and nano-microbial enhancement for industrial wastewater treatment and reuse (oil & gas, petrochemical, pesticide, pharmaceutical, shipping, etc.) with high cost-efficiency
Key research outputs:

- **Nanoscale catalytic materials**: High activity, good stability, makes reaction possible under visible light.
- **Mechanisms/pathways**: Unveils HCs removal, degradation pathways and intermediates, toxicity change during the process.
- **Integration with enhancement methods**: Reduces cost and makes process green and less environmental impact.
- **Design of EOP reactors and optimization of reaction conditions**: Industrialization and "zero pollution emissions".
- **Provide feasible and effective expressions of uncertainties and simulation/assessment results into environmental decision-making**.

Simulation-based process control and operation planning.
4-2: Integrated decanting system for marine oil spill response and on-site treatment of decanted water

- **Initial oil volume**
- **Terra Nova**
- **Fresh/Weathered heavy crude**

High-efficiency and potential for applications in fields:

- Oil spill response ➔ on-site decanting for disposal at sea (save time and improve response capability)
- Light crude, fresh oil, weathered oil ➔ demulsifiers can increase oil solubility and decrease decanting time (up to 50%)
- Enhanced oxidation processes (EOP) ➔ TPH (~400 ppm) reduced to <15 ppm (IMO std.) within 15-30 min; Removal rate (50 min): TPH: 98% & PAH (NAP): 93% ➔ promising for discharge at sea
- Integration of gravity separation + demulsification + EOP ➔ from O/W of 30/70 to >90% separation and TPH <15 ppm
4-3: Hydrophilic Mesh and Activated Carbon for Oil Water Separation (Decanting)

Research outputs:

High potential for on-site treatment of decanted water.

1. Reach up to 99% TPH removal if combining with a polishing process using graphene oxide.

2. The mesh showed 98% TPH removal with water polishing. After treating by the mesh and polishing, the TPH in water was 30 ppm and 5 ppm respectively (initial 290 ppm).

3. Applying a low voltage of charge improves the surface hydrophilicity of the mesh in seawater. An oil water separation setup using this technique will be developed to test the TPH removal efficiency.
Research Area 5: Dynamic simulation, integrated assessment and intelligent decision making

5-1: Integrated decision support systems for environmental emergency management

Environmental emergency (e.g., oil and chemical spills) ➔ strong needs in effective response decision making tools

Spill risk assessment and response modeling
Oil spill simulation: GNOME and OSCAR + uncertainty analysis

Response resources allocation/optimization → Decision support systems (DSS)

Spill vulnerability assessment & planning
5-2: AI aided optimization and human factor analysis

Emergency response decision making – AI aided optimization

Research outputs:
1. Integrate artificial intelligence (AI) with simulation-optimization coupling approaches to support environmental modeling and decision making
2. The first time to consider human factors and risk/uncertainty levels in a quantitative way during oil spill response decision making
vEER: Visualization Platform for Environmental Emergency Response Decision Support – Marine Oil Spill Response DSS

User Training

Multiple sites interaction networks

Mobile Terminal Networks

Emergency Response & Quick Analysis and Decision Making

Response equipment training

Emergency response training

HQP Training Layer

Response equipment training

Virtual reality technology (VR)

Visualization Hardware Platform

Software Supporting System

Risk analysis models

Decision Making Scenarios

Decision Making Layer

Overview of the vEER system: AR/VR aided response training and decision making.

Pilot-scale Virtual Reality Modeling Platform for Offshore Oil Spill Response Decision Support
Persistent, Emerging and Oil PoLlution in the Environment

“A pan-Canadian and global network”

Oil spills, POPs, and emerging contaminants
Marine & coastal environments; cold regions

→ Engineering and Managerial SOLUTIONS!

Detection, identification, and quantification
Fate, behaviors, and transformation
Prevention, control, and remediation
Assessment, simulation, and decision making
Ecotoxicological and socio-economic effect analysis
Health and community impact and mitigation

• Global cluster of expertise and partnerships
• Multidisciplinary research and tech transfer
• 3-tier training strategy - HQP, professionals and communities (esp. Indigenous People)
• Evidence-based support for stakeholders

✓ 180+ members incl. 130+ academic researchers & 150+ HQP from 21 Canadian & 13 intl institutions;
40+ Canadian partners incl. 7 fed., 4 prov./ municipal, 9 ind., 7 NGO etc. and international partners
THE VISION OF BETTER TOMORROW

Cutting-edge R&D  Diverse Research Expertise  Multi-disciplinary Research Network  Technology Transfer
Growing risk of oil spills globally in marine and coastal environments \(\rightarrow\) sustainable development?

- Accidental/chronic oil pollution and deep water spills
- Intelligent planning and decision making
- Human thinking and behaviors in response
- Eco-friendly and efficient mitigation tech
- Training of next-generation researchers and responders
- International and cross-disciplinary collaboration

Need: Long-term, stable and dedicated funding support

Our R&D goals/targets
Acknowledgements

- NRPOP Lab researchers (Drs. Tahir Husain, Helen Zhang, etc.)
- Gov/Institutions: NSERC, CFI, DFO/CGC, ECCC, PRNL, CAPP, Suncor, ExxonMobil, ECRC, etc.
- Memorial University and other institutions
- Etc.
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