Research on bioremediation of petroleum hydrocarbons in groundwater in cold climates: Limitations or opportunities?

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Acronyms:

CORONA = Consortium for Research on Natural Attenuation
EC = Environment Canada
INAC = Indian & Northern Affairs Canada
NWRI = National Water Research Institute
NWT = Northwest Territories
PERD = federal Program for Energy Research and Development
U of A = University of Alberta
WCSB = Western Canada Sedimentary Basin
Acronyms:

LNAPL = light nonaqueous phase liquid
MNA = monitored natural attenuation
PHCs = petroleum hydrocarbons
VFAs = volatile fatty acids (acetate, butyrate, propionate)
Acknowledgments

Main funding: PERD, EC, INAC

Coordination with CORONA at Alberta sites (2002-2004)

Collaboration with University of Calgary (isotope and microbial analyses)
Acknowledgments

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John Voralek, Charles Talbot, Ross Neureuther (NWRI)
Ron Breadmore, Rob Duschene (INAC)
Kim McLeish (Komex International Ltd.)
Patricia Coyne (NWT Dept. Transportation)

Laboratory analyses:
Renu Grewal, Susan Brown, Helena Steer (NWRI)
Maxxam Analytics (Alberta sites)
Jela Burkas (U of A)
Topics covered

- Background information
- Study #1 - Sulfate reduction / WCSB
  - NWRI and Komex
- Study #2: Northern spills
  - NWRI and U of A
Bioresidemiation of PHCs: Trends since early 1990s

- Rapid global expansion of applications
  - Thousands in Canada
- Has become a “preferred” approach
  - Active and passive technologies
  - in-situ and ex-situ
Bioremediation of PHCs in groundwater at “warm” sites:

- Various electron acceptors linked to anaerobic microbial degradation of PHCs in groundwater
  - $O_2$, $Fe^{3+}$, $Mn^{3+},^{4+}$, sulfate, nitrate
- Strains of microorganisms, consortia
- Enhanced in-situ bioremediation
- Intrinsic bioremediation (MNA)
Review: Bioremediation of PHCs in soil/groundwater at cold climate sites (NWRI and U of A, 2005)

- List of successful soil applications growing
- Biopiles and landfarms most common
- Often used for fuel spills
- Cold climate is generally not a major deterrent; documented biodegradation at < 10°C in a number of sites, lab studies

- groundwater research/applications rare
Gap in knowledge about bioremediation of PHCs in groundwater

- How applicable at colder sites?
  - upstream oil and gas sites in WCSB
  - Arctic Canada / permafrost
  - fractured rock settings
Study #1: Role of sulfate reduction in PHC plumes in groundwater, WCSB (NWRI & Komex)

2002-05
Groundwater in WCSB:
Temperatures $\sim 5-10^\circ\text{C}$
Sulfate concentrations often $>1,000 \text{ mg/L}$
$= \text{most abundant potential electron acceptor}$
“D” Site, Alberta

PHC-contaminated profile

Reference profile
Typical existing well at this site

Injection well

Sediment samples
Contaminated profile

Reference profile

- Sulfate- S
- Acetate C
- C6- C10 hydrocarbons
Contaminated profile

Reference profile

- **Sulfate- S**
- **Acid Vol. S**
- **Cr- Red. S**
Overall sulfate reduction rate ~ 5 mg/L per day
Extraction / Analysis of DNA from Sediment Samples

• DGGE profiles of eubacterial 16S rDNA fragments
• Indicated sulfate reducing bacteria (Desulfosporosinus spp.) and other anaerobes (e.g. Geobacter)
“E” Site, Alberta
Injection test
July-November, 2003

inferred sulfate reduction rate: ~5 mg/L per day
Conclusions: Study #1

- Significant rate of sulfate reduction in PHC plumes in groundwater in WCSB
- Low temperatures (5-10°C) don’t impede in-situ bioremediation
- Cold-adapted bacteria present
- Seasonal infiltration of sulfate to water table important
- Promise for active/passive bioremediation approaches

Journal publications in submission/prep.
Study #2: Fate of petroleum spills, northern environments (NWRI & U of A) 2004-2008

Unique, pioneering study of fate & behaviour of PHCs in groundwater at spill sites in Arctic Canada

- fractured rock, permafrost
- terrace deposits, Mackenzie pipeline route
Spill investigation: Colomac mine

Fate/transport/degradation of PHCs in “active” layer (seasonal thaw), fractured rock above permafrost

Diesel fuel tank farm area

Photo: I. Holubec Consulting Inc.
• Address large gaps in understanding of behavior/fate of petroleum spills in fractured rock/permafrost setting.
Steeves Lake

- Bedrock Monitoring wells

100 m

- Power House
- Mill
- Leach Tanks
- Warehouse
- Fuel Tanks
- Tank Farm

Environment
Canada

Environnement
Canada
Bedrock: metamorphosed sediments
• meta-greywacke, meta-argillite

3 main sets of fractures
1. Sub-vertical, parallel to foliation, includes “slaty cleavage”
2. Sub-horizontal
   Sub-vertical, ~ normal to 1,2
Hydraulic testing, August 2005
Preliminary hydraulic test results:

**MW-19**

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Preliminary sampling results: Aug/05

- Typical groundwater temperatures: 1-4°C
- Wide hydrocarbon distribution (LNAPL, dissolved)
- VFAs present (propionate, butyrate)
- Elevated iron, manganese, low O₂ (most < 0.5 mg/L) near neutral pH
F1 (C₆-C₁₀) concentrations
August, 2005

- > 10 mg/L
- > 1 mg/L, < 10 mg/L
- > 0.1 mg/L, < 1 mg/L
- < 0.1 mg/L

Steeves Lake

Power House
Mill
Leach Tanks
Warehouse
Fuel Tanks
Tank Farm

100 m

> 0.1 mg/L, < 1 mg/L
> 1 mg/L, < 10 mg/L
> 10 mg/L
Dissolved Fe concentrations
August, 2005

Steeves Lake

- > 10 mg/L
- > 5 mg/L, < 10 mg/L
- > 1 mg/L, < 5 mg/L
- < 1 mg/L

- Power House
- Mill
- Warehouse
- Leach Tanks
- Fuel Tanks
- Tank Farm
- Pipeline

100 m

Environment
Canada

Environment
Canada

N

> 1 mg/L, < 10 mg/L

< 1 mg/L

> 10 mg/L

> 5 mg/L, < 10 mg/L
Spill investigation: Wrigley airport

Address information gaps on groundwater conditions & fate of petroleum spills along pipeline corridor
Airport established in 1942 to service US Army's Canol pipeline

Taken over by Canadian govt. in mid-40’s

Currently managed by NWT Dept. Transportation

Photo Source: NWT Archives
Terrain:
- On terrace of sandy silt along Mackenzie R.
- Underlain by thick sand and gravel unit
- Forest, muskeg, hot springs in area

Groundwater:
- Community water supply
- deep, unfrozen year-round, at ~ 0-5°C
Initial drilling program: October, 2005

Preliminary results:
• “channelized” flow in sand & gravel above clay
• PHC contamination
Anticipated Research Outputs

1. **Updated conceptual models**
   - LNAPL & dissolved PHCs, fractured rocks with permafrost
   - dissolved plumes in groundwater, pipeline corridor

2. **Evaluation of in-situ bioremediation potential**
   - Appropriate for PHC in groundwater in north?
   - MNA feasible?