Soil washing with a surfactant solution: Pilot test at a gas station (Laval, Québec, Canada)

By:

Maxime Grenier, M.Sc. student - INRS
Richard Martel, Research supervisor - INRS
Luc Trépanier, Uta Gabriel, Clarisse D.-Rancourt and Thomas Robert - INRS
Jean-Marc Lauzon - TechnoRem

Centre - Eau Terre Environnement

INRS
Université d'avant-garde

Context

- Gasoline is persistent in soils and groundwater
- Most conventional in situ remediation technologies cannot or struggle to reach environmental standards for groundwater and soil quality

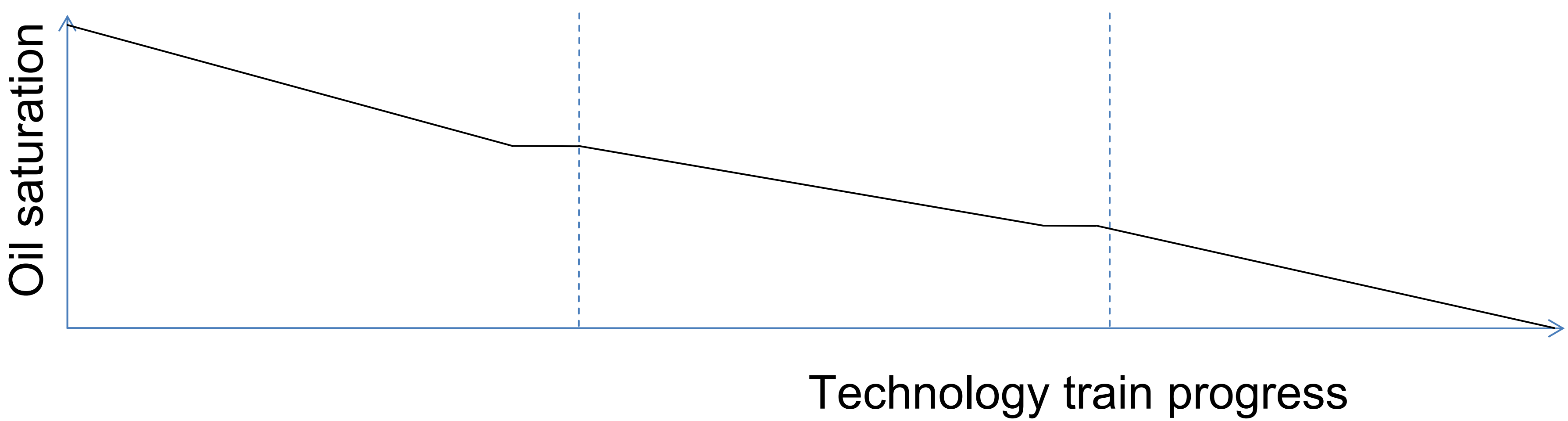
In situ technologies limitations

- *Slurping:* At residual saturation, gasoline is immobile and unrecoverable (in the saturated zone).
- *Chemical oxidation:* Gasoline adsorbed or trapped into pore spaces resists to oxidation.
- *Soil* washing:
  - Generates huge volume of washing solutions that have to be treated or disposed of
  - Ingredients costs make this technology non economical if not recycled

Research project

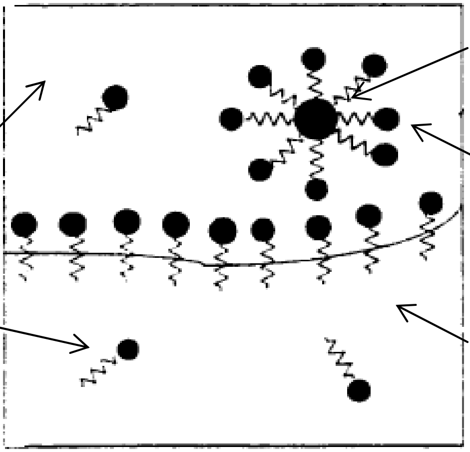
- Coupling slurping and chemical oxidation with soil washing to reach environmental standards

Slurping → Surfactant solution (solubilization / mobilization) → Chemical oxidation



Surfactant solution theory

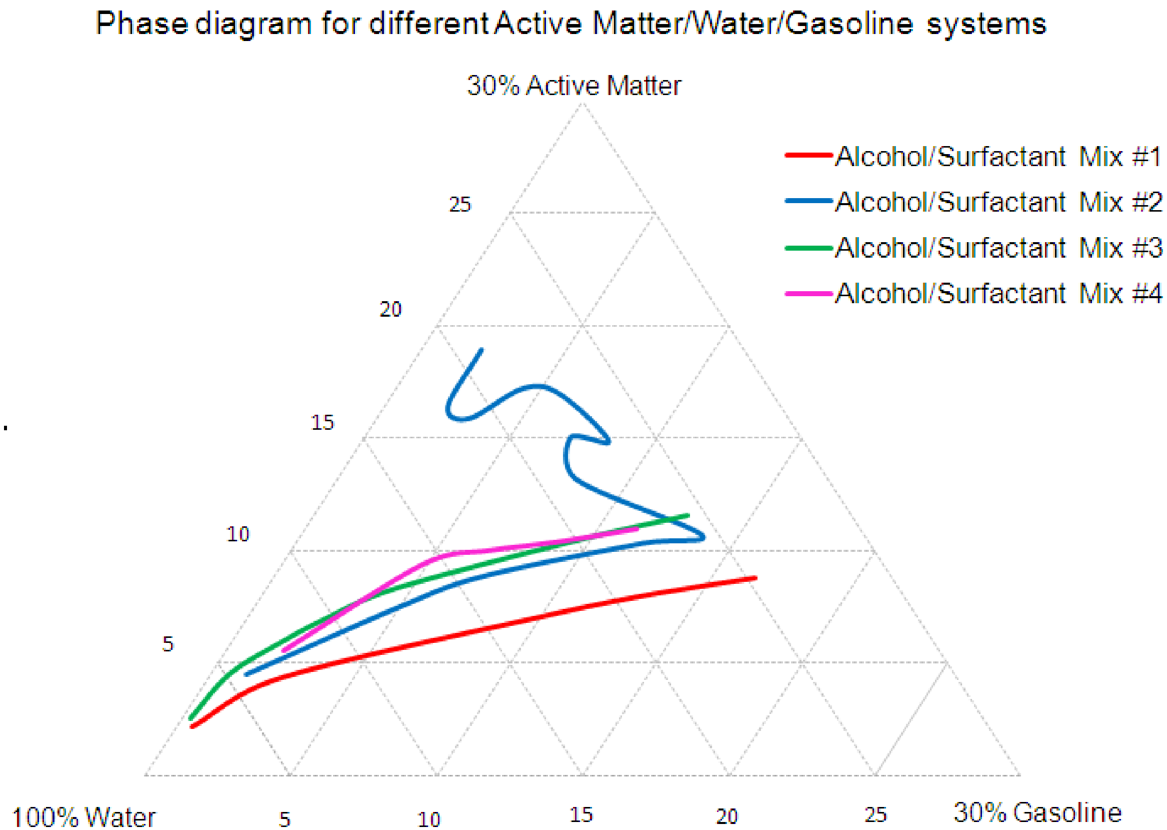
- Surfactant solution = surfactant + cosolvent + water
- Surfactant: amphiphilic molecule: 2 different polarity parts, 1 hydrophilic and 1 lipophilic



- Formation of micelles
- Two main recovery mechanisms:
  - Solubilization: Active matter (surfactant + cosolvent) partitions preferentially into the aqueous phase
  - Mobilization: Active matter partitions preferentially into the oil phase (oil volume is increased and mobilized via an oil bank)

Preliminary Steps (Prior to Pilot Test) → Phase Diagrams

- Identify promising surfactant/cosolvent solutions by titration (Cloud point technique)

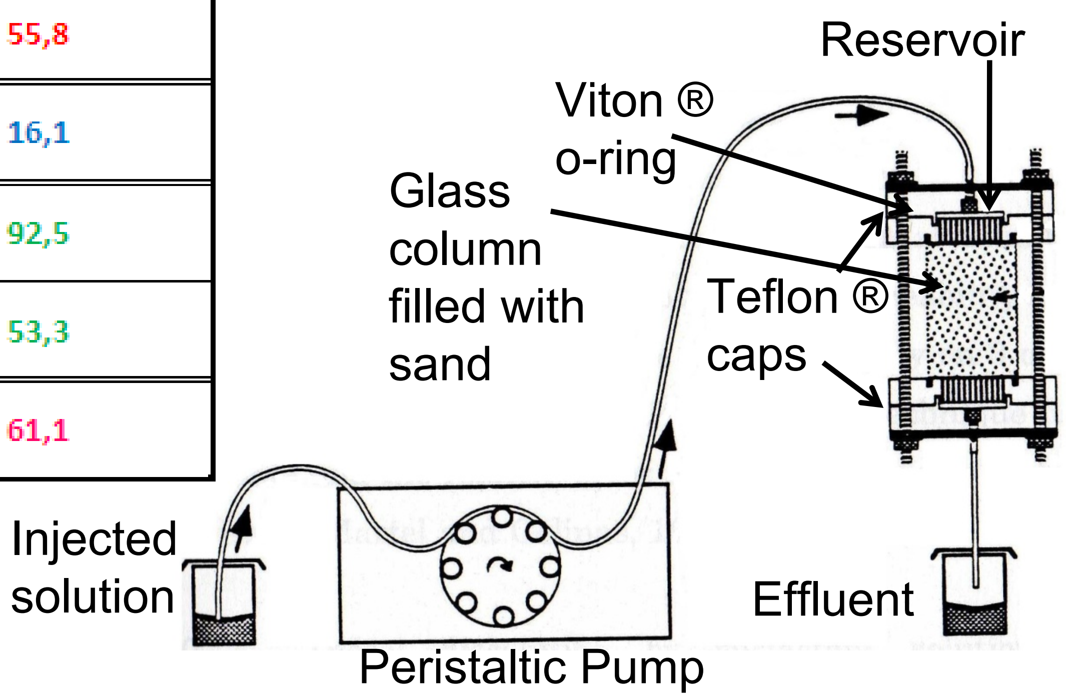


Preliminary Steps (Prior to Pilot Test) → Sand Columns Experiment

- Select optimal surfactant/alcool solution → Sand columns experiment

#	Solution	Gasoline Recovery %
1	Alcohol/Surfactant Mix #1 7,5% active matter	94,2
2	Alcohol/Surfactant Mix #1 5,0% active matter	55,8
3	Alcohol/Surfactant Mix #2 5,0% active matter	16,1
4	Alcohol/Surfactant Mix #3 7,5% active matter	92,5
5	Alcohol/Surfactant Mix #3 5,0% active matter	53,3
6	Alcohol/Surfactant Mix #4 5,0% active matter	61,1

Recovery %: (Gasoline collected mass in effluent / gasoline initial mass in sand column) x 100



1,8 PV of washing solution injected

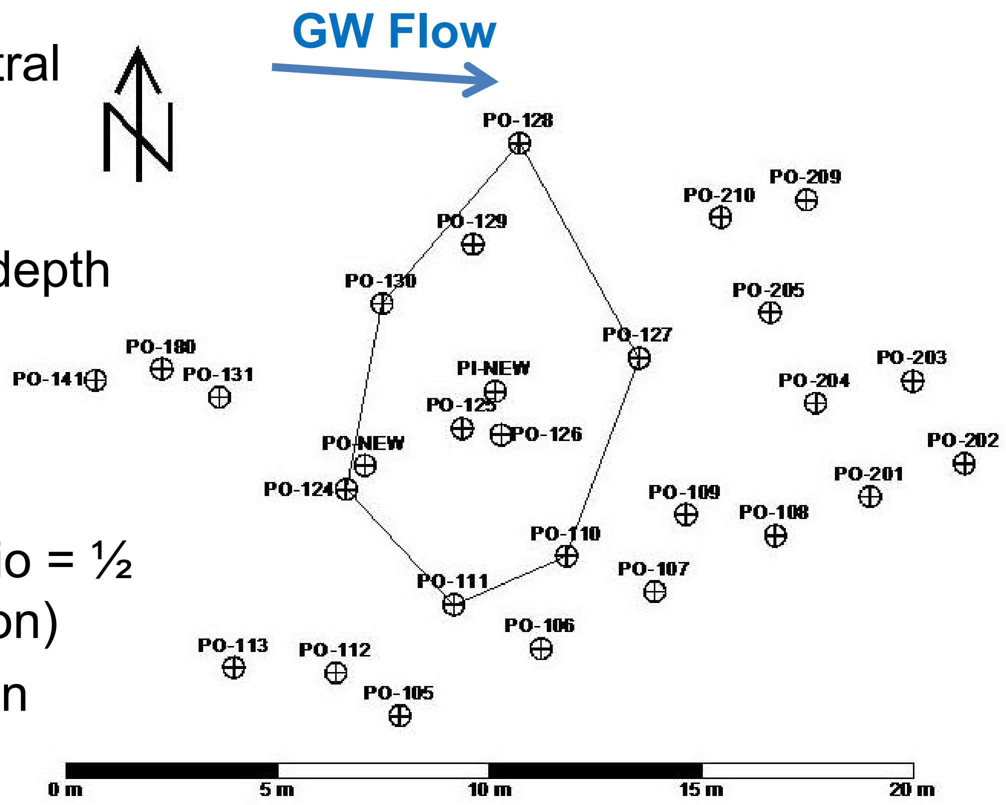
Field Context

- Gas station location: Laval, Québec (5km north of Montréal)
- Two spill/leak episodes (1962 and 2005) from pipes and underground storage tank (UST)
- Estimated plume area: 2500 m^2
- Geology: Silty sand with limestone boulders underlain by a fractured limestone bedrock.
- Water table at 7,0 m depth
- Slurping was made over a period of 12 months


GHTIMES
essoires pour fumeur
smoking accessories

Pilot Test – Cell specifications

- 7-point hexagonal pattern (Central injection + 6 extraction wells)
- Cell area: 45 m^2
- Targeted depth interval: 7-8 m depth
- Cell volume: 45 m^3
- Total porosity: 20%
- Cell PV: 8,7 m^3
- Injection/extraction flow rate ratio = ½ (Feflow – Numerical modelisation)
- Injection – Extraction wells mean distance: 4,26 m
- 4 observation wells inside and 11 outside cell



Pilot Test – Process and equipment

Injected Solution Pathway

1. **Solution 1 m^3 tote tank**
2. Diaphragm Pump
3. Gate Valve + Flowmeter
4. Injection Well
5. Aquifer
6. Extraction well
7. Bladder Pump
8. Effluent 1 m^3 tote tank
9. Open-top Container
10. Effluent treatment and disposal

Pilot Test – Process and equipment

Injected Solution Pathway

1. Solution 1 m^3 tote tank
2. **Diaphragm Pump**
3. Gate Valve + Flowmeter
4. Injection Well
5. Aquifer
6. Extraction well
7. Bladder Pump
8. Effluent 1 m^3 tote tank
9. Open-top Container
10. Effluent treatment and disposal

Pilot Test – Process and equipment

Injected Solution Pathway

1. Solution 1 m^3 tote tank
2. Diaphragm Pump
3. **Gate Valve + Flowmeter**
4. **Injection Well**
5. **Aquifer**
6. Extraction well
7. Bladder Pump
8. Effluent 1 m^3 tote tank
9. Open-top Container
10. Effluent treatment and disposal

Pilot Test – Process and equipment

Injected Solution Pathway

1. Solution 1 m^3 tote tank
2. Diaphragm Pump
3. Gate Valve + Flowmeter
4. Injection Well
5. Aquifer
6. **Extraction well**
7. **Bladder Pump**
8. Effluent 1 m^3 tote tank
9. Open-top Container
10. Effluent treatment and disposal

Pilot Test – Process and equipment

<u>Injected Solution Pathway</u>

1. Solution 1 m^3 tote tank
2. Diaphragm Pump
3. Gate Valve + Flowmeter
4. Injection Well
5. Aquifer
6. Extraction well
7. Bladder Pump
8. **Effluent 1 m^3 tote tank**
9. Open-top Container
10. Effluent treatment and disposal

Pilot Test – Process and equipment

Injected Solution Pathway

1. Solution 1 m^3 tote tank
2. Diaphragm Pump
3. Gate Valve + Flowmeter
4. Injection Well
5. Aquifer
6. Extraction well
7. Bladder Pump
8. Effluent 1 m^3 tote tank
9. **Open-top Container**
10. **Effluent treatment and disposal**

Pilot Test – Costs of chemicals

- 300 kg of pure surfactant at 10,80$/kg = 3 240 $
- 300 kg of cosolvent at 3,70$/kg = 1 110 $
- 180 kg of salt (NaCl) at 0,55$/kg = 100 $
- 5 kg of polymer at 11,90$/kg = 60$

Total cost of chemicals = 4510 $ (45 m^3 of contaminated soil)

Unit cost ≈ 100 $/m^3 of contaminated soil

Field Test – Injection Steps

1. Reach steady state
   - Injection/pumping of water
   - Water level monitoring until steady state (stabilized)
2. 5 m^3 (0,57 PV) of salted water bank (Pre flush)
3. 4 m^3 (0,46 PV) of micellar solution (Washing)
4. 4 m^3 (0,46 PV) of micellar – polymer solution (Washing + sweep)
5. 10 m^3 (1,15 PV) polymer solution (Rinse)

PV calculus based on total porosity of 20%

Field Test – Water Sampling

Objectives

- Establish initial conditions in the cell
- Follow the injected fluids in the cell
- Measure recovered gasoline from the cell

Sampling locations

- Extraction wells
- Injection well
- Observation wells
- Effluent reservoir
- Injection reservoir

Over 500 liquid samples taken

Field Test – Water Sampling

Effluent reservoir

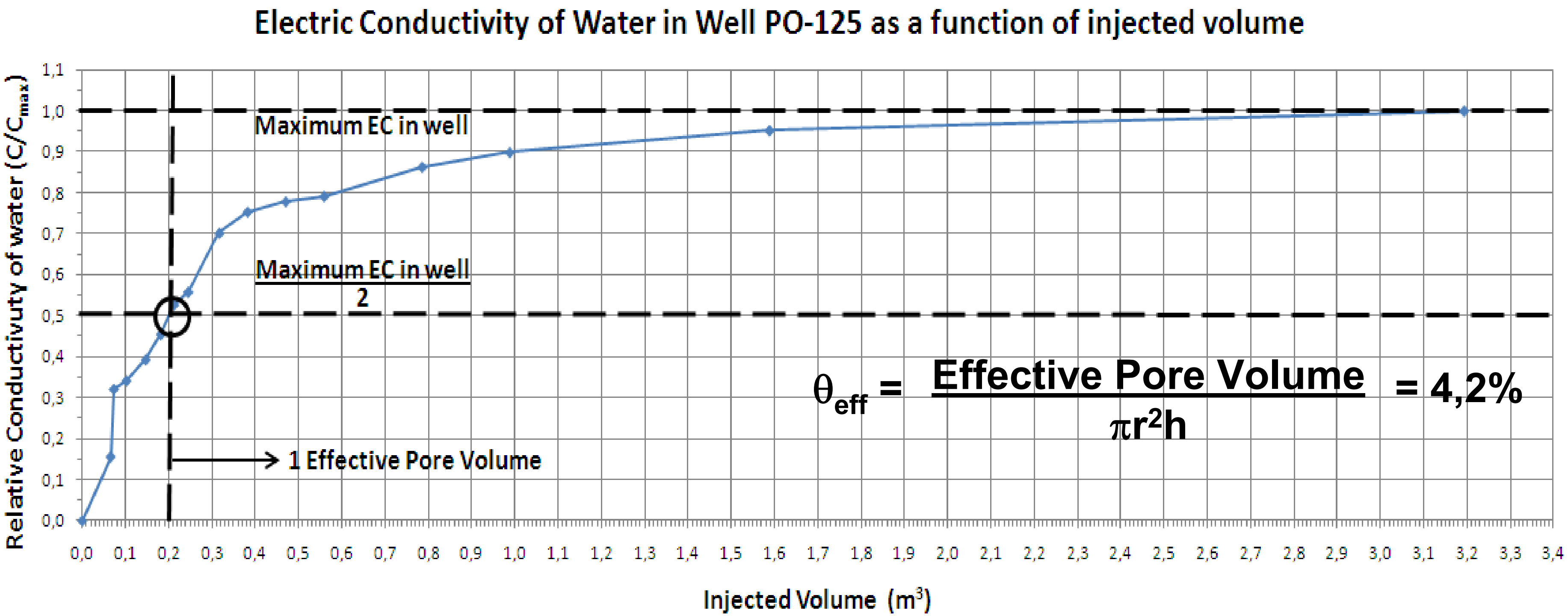
- Homogenize the effluent in the reservoir prior to sampling

Field Test – Water Sampling

Observation wells

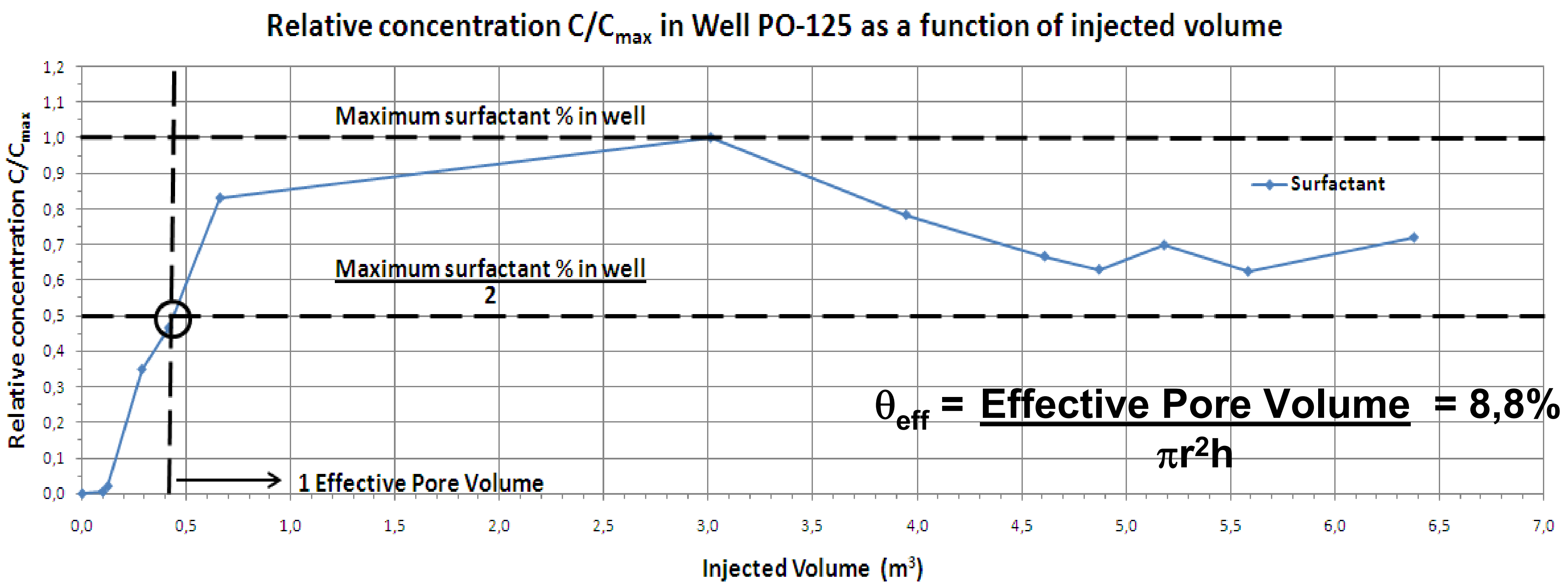
- Low flow sampling: Peristaltic pump via a flexible Viton® tubing connected to a ¼'' Teflon ® tubing

Effective porosity estimation
→ from salted water bank breakthrough curve



Radius from injector well to well PO-125: 1,23 m

Effective porosity estimation
→ from micellar solution bank breakthrough curve



Increase of effective PV (4,2% → 8,8%) partly caused by solubilization/mobilization of absorbed gasoline in porous media by micellar solution

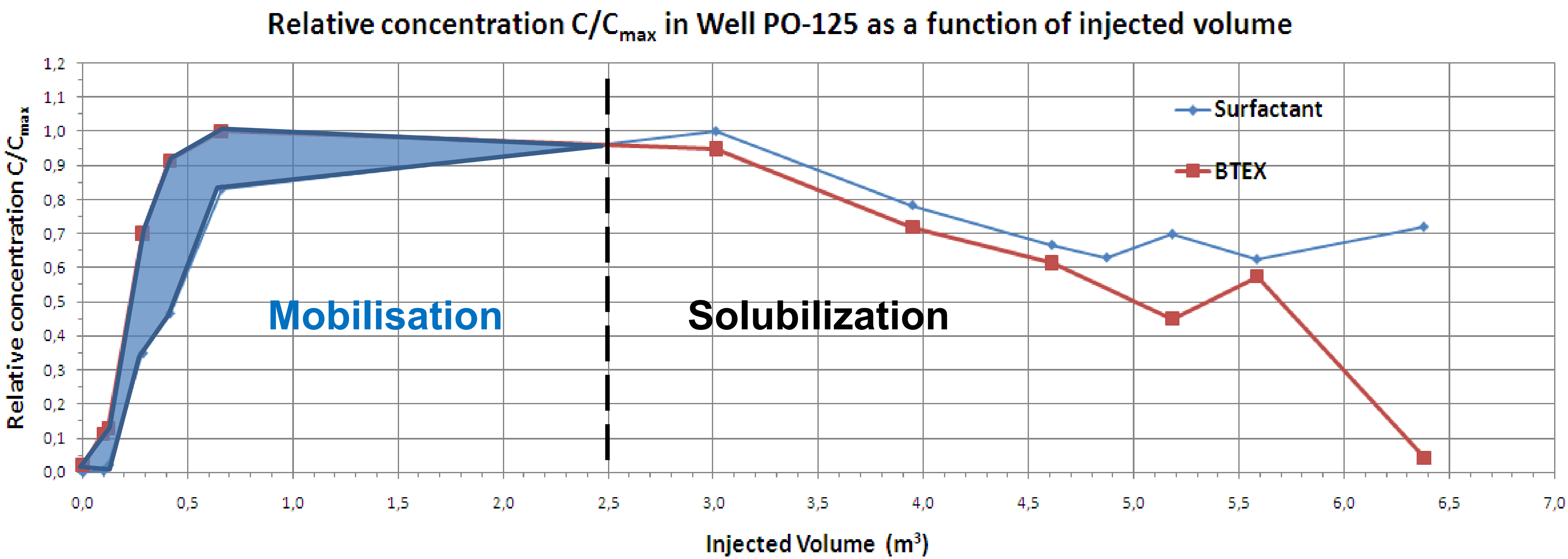
Effective porosity of silty sand

- Usually estimated at: 20%* *Payne et al. 2008*
- From tracer tests: less than 10% (2% – 10%)*
- Present Case: 4,2% to 8,8%

Injected solutions PV adjustment

1. 5 m^3 Pre flush: 0,57 PV $\rightarrow$ 2,74 PV (θ_{eff} = 4,2%)
2. 4 m^3 Micellar solution: 0,46 PV $\rightarrow$ 1,04 PV (θ_{eff} = 8,8%)
3. 4 m^3 Micellar - Polymer solution: 0,46 PV $\rightarrow$ 1,04 PV (θ_{eff} = 8,8%)
4. 10 m^3 Polymer solution: 1,15 $\rightarrow$ 2,61 PV (θ_{eff} = 8,8%)

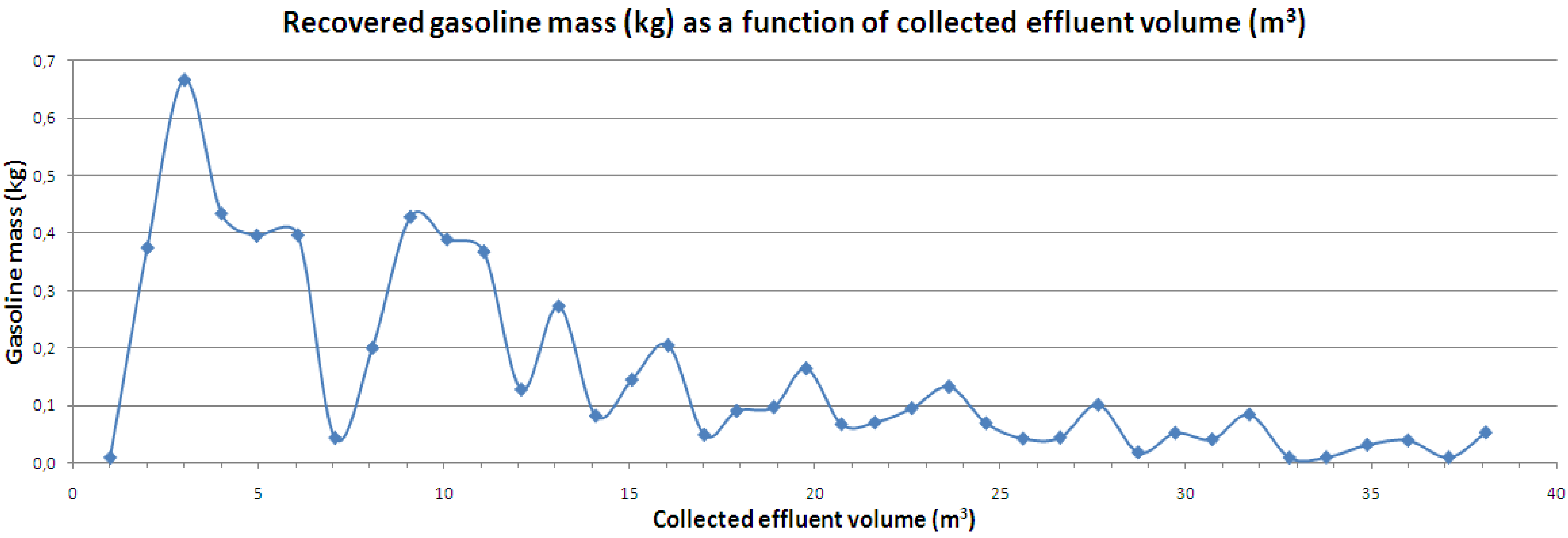
Gasoline vs Surfactant breakthrough curves in well PO-125



Gasoline bank arrives before surfactant solution bank = Mobilization (as an oil bank)

Gasoline concentrations follow surfactant concentrations = Solubilization

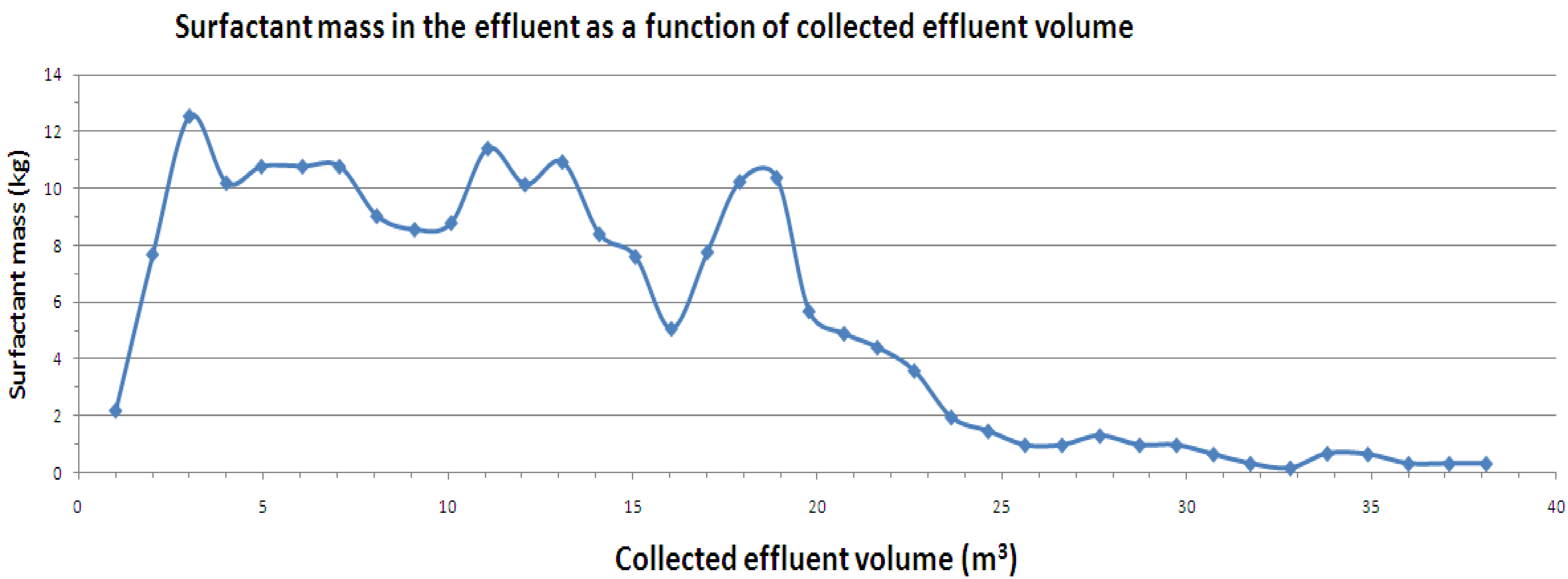
Gasoline recovery in effluent



Total recovered gasoline mass: 5,9 kg (7,5 L)

Remediation impact on gasoline concentrations in soil: 67 mg/kg removal

Surfactant recovery in effluent



Total recovered surfactant mass: 204,1 kg (72% of initial injected mass)
28% of initial injected mass (81 kg) in the cell

Surfactant concentrations in water after Pilot Test

- Mean surfactant % per well (in cell): 0,0185%
- Estimation of equivalent surfactant mass for the whole cell:

  0,0185% x 43,5 m³ x 8,8% x 1155 kg/m³ = 81,8 kg

  $\%_{surfactant} \times V_{cell} \times \theta_{eff} \times \rho_{surfactant}$

Surfactant Balance

Recovered in effluent:	204,1 kg
Inside the cell:	81,8 kg
Total:	285,9 kg
Real mass injected:	284,9 kg

No washing solution went out of the cell! (Injection/Extraction flow rate ratio with Feflow modelisation was correct)

Gasoline concentrations in wells of the cell

Well #	Before Test (mg/L)	After Test (mg/L)	↑Or ↓ In concentrations	Surfactant % after test (% m/V)
PO-new	3,02	0,729	↓	< 0,01
PO-111	1,64	0,69	↓	< 0,01
PO-124	2,46	3,17	↑	0,02
PO-125	0,76	3,29	↑	0,03
PO-128	7,60	17,11	↑	0,03
PO-129	9,03	27,80	↑	0,02
PO-130	4,04	9,83	↑	< 0,01

Gasoline available in solution for following chemical oxidation!

Conclusion

- Laboratory tests are necessary prior to soil washing (eg: phase diagrams and sand columns)
- Ingredients costs for soil washing: 100$/m^3 of contaminated soil (Lower cost for a larger project)
- Effective porosity must be determined via tracer test prior to washing solution injection.
- Effective porosity will increase during soil washing and is related to initial oil saturation
- Gasoline is recovered by two mechanisms: Mobilization and Solubilization
- Impact of washing solution remediation:
  - Direct: Decreases gasoline mass in soils
  - Indirect: Helps chemical oxidation by bringing adsorbed / trapped gasoline into solution to be oxidized

Thank you!

INRS
Université d'avant-garde

Questions?