Effects of high temperature remediation processes on soil properties and function

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Strathclyde STARs

• PhD students
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  – Neil McCosh

• Academic collaborators
  – Charles Knapp
  – Richard Lord
  – Caroline Gauchotte-Lindsay (Univ of Glasgow)
  – Alessandro Tarantino
Organic Contaminants

- Petrochemicals
  - Oil
  - Fuel products (e.g., petrol, diesel, kerosene)
- Solvents
  - Chlorinated (e.g., trichloroethylene (TCE))
  - Non-chlorinated (e.g., benzene, toluene)
- Pesticides
- Coal Tar
- Creosote
High Temperature Remediation

In situ thermal

<table>
<thead>
<tr>
<th>Remediation technique</th>
<th>Maximum T (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water extraction</td>
<td>300</td>
</tr>
<tr>
<td>Thermal desorption</td>
<td>100-450</td>
</tr>
<tr>
<td>Heated soil vapour extraction</td>
<td>300</td>
</tr>
<tr>
<td>Incineration</td>
<td>850</td>
</tr>
<tr>
<td>Smouldering remediation</td>
<td>600-1100</td>
</tr>
</tbody>
</table>

In situ smouldering
Chemical Analysis Before & After Remediation

Coarse Sand | Sand + Fresh Coal Tar | Inside Combustion Zone | Outside Combustion Zone
---|---|---|---
70,000mg/kg | <0.1mg/kg | up to 1000mg/kg
Ex Situ STAR Trial #1

Conc (TPH) = 31,000 mg/kg ± 14,000 mg/kg

Conc (TPH) = 10 mg/kg ± 4 mg/kg
In Situ STAR
In Situ Pilot Test Results

Before

After
Aggressive Remediation Questions

• How do we link small-scale (laboratory) results to field behaviour?
• What is the fate of co-contaminants?
• What happens to the soil during/after treatment?
• Can we fully rehabilitate brownfield sites?
Potential Changes to Soil Properties

• From literature related to wildfires we can predict that STAR will:
  – Destroy OM and microbes
  – Volatilise inorganic nitrogen
  – Possibly volatilise phosphorous
  – Decompose and aggregate clays

• Nutritionally-poor soil is expected with poor structure;
• These projections are extrapolated from studies dealing with exposure temperatures relevant to thermal remediation (200-500°C) but cooler than STAR (600-1100°C);
• A very small number of papers do deal with higher temperatures but tend to be very specific with applications;
• Experimental evaluation is essential.
Changes in Soil Geochemistry

- Three soils from Aberdeenshire (urban, rural, acidic forest soils)
- Contaminated with 80g/kg coal tar and treated with STAR

- OR -

- Dried at 105°C and exposed for 1hr at [ambient – 1000°C]
- Soil geochemical characterisation followed after cooling

<table>
<thead>
<tr>
<th>Soil</th>
<th>Peak Temperature</th>
<th>Residual Contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1100°C</td>
<td>14.2 mg/kg TPH</td>
</tr>
<tr>
<td>B</td>
<td>1000°C</td>
<td>16.3 mg/kg TPH</td>
</tr>
<tr>
<td>C</td>
<td>1000°C</td>
<td>15.9 mg/kg TPH</td>
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</tbody>
</table>
Soil Geochemistry – High Temperatures

Effects of heat treatment only. No contaminant used in these experiments.

Soil Geochemistry – High Temp & Smouldering

Summary:
- Organic matter and nitrogen decreases as T ↑
- Mobilisation of clay and silt-sized particles as T ↑
- Cation exchange capacity reduces as T ↑
- Elevated pH*
  - Sand only: pH ↑ as T ↑
  - Soil + OM: pH ↓ as T ↑
  - Results for coal tar + no contaminant only
- Essential to explore other contaminants and exposure times
Plant Regrowth (1)

Air dry 105°C 250°C 500°C 750°C 1000°C Smouldered
Plant Regrowth (2)

control

1000°C + 20% compost

1000°C
Regrowth is possible in small batches. What happens in dynamic systems?
Infiltration and Capillary Rise

Sand dried at 105°C for 24hrs + exposed to [ambient – 1000°C] for 1hr –OR– contaminated with coal tar and treated with STAR

- Water infiltrates much more rapidly but there is capillary rise (albeit less)
- Sand pH decreases slightly with thermal treatment, significantly with STAR
- Soil pH increases slightly with thermal + STAR treatment if organic matter present
Permeability - Constant Head Test

Coefficient of permeability (m/s)

Time (min)

transient

steady-state

Sand - Untreated
Sand - SM
10% Clay (5% MC)
10% Clay (Dry)
10% Clay - SM
Changes to the Grain Surface

Microscope images of thin sections of sand grains (polarised light)

Hypothesis: Exposure to elevated temperatures and STAR treatment changes the structure of the grain surface.
Changes to the Grain Surface

A – polarised light  
B – unfiltered light  
C – cross-polarised light

Specific surface area (BET analysis)
Changes to the grain surface

Original and crushed grains for XRD Analysis

Raman analysis of the sand grains

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grains</th>
<th>Analysis points</th>
<th>Quartz</th>
<th>Tridymite</th>
<th>Cristobalite</th>
<th>Dumortierite</th>
<th>Geothite</th>
<th>Hematite</th>
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<tbody>
<tr>
<td>untreated</td>
<td>5</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>500°C</td>
<td>3</td>
<td>5</td>
<td>0.60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.40</td>
<td>0</td>
</tr>
<tr>
<td>1000°C</td>
<td>3</td>
<td>9</td>
<td>0.56</td>
<td>0.22</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.22</td>
</tr>
<tr>
<td>smouldering remediation</td>
<td>12</td>
<td>37</td>
<td>0.32</td>
<td>0.16</td>
<td>0.08</td>
<td>0.22</td>
<td>0.14</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Changes to the Grain Surface

Micro CT internal scans of sand grains before and after STAR
Changes to the Grain Surface

3D RENDERING OF SAND GRAINS

BEFORE

AFTER

BEFORE

AFTER

AFTER
Changes to the Grain Surface

Internal cross-sections of many grains
Changes to the Grain Surface

BEFORE

AFTER
Conclusions

• Water dynamics changed in soil
• Potential link to physical changes at the grain surface
• Chemical effects may be important as well
• Nutrient retention decreases after exposure to elevated temperatures, particularly at 250°C
• pH changes seem linked to organic content
  – Thermal + sand/clay: pH decreases slightly
  – STAR + sand/clay: pH decreases
  – STAR + soil + OM: pH increases
• Nutrient losses affect regrowth
  – Can be overcome by amendments
  – May be challenged by altered water dynamics
Effects of aggressive remediation on soil properties

S. Zihms, A. Pape, A. Tarantino and C. Switzer

- Multi-point Raman analysis on sand grains and constituents of synthetic & whole soils
- Micro CT evaluation of other materials/grains
- Permeability characterisation of transient state infiltration
- Shear strength testing
Frankensoils: Bringing Dead Soils Back to Life

A. Pape, N. McCosh, C. Switzer, C. Knapp, R. Lord and W. Sloan

How does life start again in an inert material?

While tapping into the University’s history…
Fate of Co-Contaminants
A. Robson, A. Tarantino and C. Switzer

- Mercury and other potentially toxic element co-contaminants may be mobilised as soil conditions change from thermal or STAR remediation.
- pH changes and oxidation may lead to release or sequestration.
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- Ross Blake
- Rory Hadden
- John Jeffrey
- Joe Farina

Commercial inquiries about STAR:  
http://star.siremlab.com

Patent Applications
GB 0525193.9
PCT/GB2006/004591
WO/2007/066125