Geochemical Characteristics of Oil Sand Tailings and Bitumen Upgrading By-Products, Alberta, Canada

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Oil Sands Production in Alberta, Canada

- Alberta has the third largest oil reserve in the world (170 billion barrels).
- Most oil occurs in association with three oil sand deposits.
- Bitumen is obtained by surface mining and in-situ extraction.

Image credit Alberta Government  http://oilsands.alberta.ca/reclamation.html
Bitumen Extraction from Mined Oil Sands

Mined oil sands are crushed and bitumen is extracted using a process of gravity separation and flotation.

Image credit Suncor Energy Inc.
Oil Sands Tailings

Suncor Tailings Pond 1 in 2002

Dried MFT

- Fine tailings are deposited into ponds where they settle to form mature fine tailings (MFT) containing about 30 to 40 wt.% solids.
- MFT is mixed with polymer and dried in thin lifts to become dried MFT.
Bitumen is upgraded to lighter hydrocarbon products through a process of reductive coking.

Some coke is utilized for heat generation resulting in bottom & fly coke ash.
Overview of ARD Potential

Quartz
Kaolinite
Mica
Microcline
Clinochlore
Albite
Pyrite
Siderite
Calcite
Ankerite
Ankerite
Ti oxides
Zircon
Tourmaline

An oil sands particle

Image credit Alberta Government
http://www.energy.gov.ab.ca/oilsands/793.asp
Study Objective

To geochemically characterize the metal leaching & acid rock drainage (ML/ARD) potential of oil sand tailings (FTT, MFT, dried MFT) and bitumen upgrading by-products (coke & coke ash) from the McMurray Formation.
Approach

- Used methodologies typically applied to coal & metal mine wastes.
- Included:
  - Mineralogy (XRD, μ-XRD)
  - Element composition (XRF, four-acid digestion)
  - Sulfur speciation (ASTM D2492)
  - Total inorganic carbon (by difference)
  - Acid-base accounting (including siderite-corrected Sobek NP)
  - Net acid generation (NAG) with & without Dean Stark extraction to remove residual bitumen
  - Humidity cell testing (minimum of 20 weeks)
Acid Potential

Error bars indicate 95% confidence interval.

Sulfur Speciation (ASTM D2492)

- Sulfate
- Sulfide
- Insoluble

Gypsum
Fe, Al sulfates
Pyrite

Sulfur associated with carbonaceous matter
Acid Neutralization Potential

- Primarily associated with calcite & ankerite dissolution.
- Three determinations:
  - Inorganic C determined as the difference between total C and residual C
  - NP associated with Ca & Mg in calcite & ankerite (CaNP) from QXRD
  - Sobek NP with siderite-correction

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Acid Neutralization Potential

Poor relationship likely attributable to high organic C content & hydrophobicity

More consistent relationship but differences observed
Acid Rock Drainage Potential

Coke & coke ash (not shown) contained less than 0.1% sulfide & were classified as non-PAG.
Acid Rock Drainage Potential

![Graph showing pH levels over Humidity Cell Cycle (weeks)]

- pH ≤ 5 acidic
- pH > 5 non-acidic

Legend:
- HC-1 MFT
- HC-2 MFT
- HC-3 MFT
- HC-4 Dried MFT
- HC-5 Dried MFT
- HC-6 Dried MFT
- HC-7 MFT
- HC-8 MFT
- HC-9 MFT
- HC-10 Coke Ash
- HC-11 Coke Ash
- HC-12 Coke Ash
- HC-13 Dried MFT
- HC-14 FTT
- HC-15 MFT
- HC-16 MFT
- HC-17 Coke
- HC-18 Coke
- HC-19 FTT
- HC-20 FTT
Trace Element Leaching Potential

- Tailings bulk composition showed enrichment of Co, Mo, Ni, Se & U in comparison to global average values for sandstone.
- Coke & coke ash bulk composition showed elevated V, Ni & Mo in comparison to tailings.
Trace Element Leaching Potential

Ni (mg/kg/week) vs Humidity Cell Cycle (weeks)

Mo (mg/kg/week) vs Humidity Cell Cycle (weeks)
Summary of ML/ARD Potential

• Tailings, coke & coke ash had low ML/ARD potential due to low sulfide content.

• FTT is a possible exception.
  – Classified as potentially acid-generating by static test methods.
  – No acidity observed in humidity cell tests.

• Generally low metal mobility under neutral to alkaline pH.

• Greater element leaching from coke ash due to soluble sulfates & oxide phases.
Application of ML/ARD Potential Methods to Oil Sands

• Sample hydrophobicity requires dispersants & sonification to allow reagents to properly react with samples.

• Quantitative XRD may be an alternative to wet chemistry methods for inorganic C determination.

• Application of siderite-corrected Sobek NP to oil sands tailings requires further investigation.
Application of ML/ARD Potential Methods to Oil Sands

• Application of humidity cell rates to site conditions requires careful consideration of:
  – Sample hydrophobicity
  – Scaling
  – Likely limited oxygen diffusion due to high organic C & moisture content.