COSIA CHALLENGE

Mobilizing the world's minds and resources to improve environmental performance.

Tailings Clay Challenge

SOLUTION DESCRIPTION:

This challenge seeks solutions to modify clay properties (e.g., surface, bulk, chemical, physical, etc.) to effect beneficial changes in tailings behaviour. Two examples of changes of interest include:

- Surface modification of clay minerals to enhance dewatering and consolidation rates in excess of currently available treatment technologies based on anionic polymeric flocculants
- Improved understanding of clay – water – organic interactions in fluid fine tailings, as well as associated minerals that contribute to observed fluid properties, and how such interactions can be leveraged to enhance the positive attributes of high surface area clay minerals for sequestration of Constituents of Potential Concern (CoPCs).

CREATED: September 28, 2017

All projects are evaluated and actioned as they are received.

CHALLENGE SPONSOR:

COSIA's Tailings EPA is sponsoring this challenge.

The Tailings EPA is seeking solutions to transform tailings from waste into a substrate that speeds land and water reclamation, without causing negative environmental impacts in other areas.

COSIA has four Environmental Priority Areas (EPAs): Water, Land, Tailings, and Greenhouse Gases (GHGs).

For more information on this COSIA Challenge please visit **www.cosia.ca**

Canada's Oil Sands Innovation Alliance (COSIA) accelerates the pace of environmental performance improvement in Canada's oil sands through collaborative action and innovation. COSIA Members represent more than 90 per cent of oil sands production. We bring together innovators and leading thinkers from industry, government, academia and the wider public to identify and advance new transformative technologies. Challenges are one way we articulate an actionable innovation need, bringing global innovation capacity to bear on global environmental challenges.

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WHAT TO SUBMIT TO COSIA

COSIA requires sufficient non-confidential, non-proprietary information to properly evaluate the technology.

Some items that will be especially important to present in your submission are:

- Concept and basic unit operations
- Technical justification for the approach (e.g. laboratory batch or continuous experiments; pilot or demo plants; process modeling; literature precedent)
- Describe quantities and qualities of utilities and consumables that are required
- Energy inputs – quantity and type(s)
- Capital and operating cost estimates if available based on described capacity targets
- 3rd party verification of your proposed technology. 3rd party verifiers should be reputable, independent engineering companies if possible
- Basis of cost estimation, including estimation scope, contingency, etc.
- IP status of your proposed technology
- What operating environment restrictions might your technology face:
    - Explosive atmospheres
    - Severe weather
    - Power fluctuations

FUNDING, FINANCIALS, AND INTELLECTUAL PROPERTY

COSIA Members are committed to identifying emerging technologies and funding the development of the technologies to the point of commercialization, while protecting the Intellectual Property (IP) rights of the owner of the technology.

Successful proposals can receive funding from COSIA members to develop and demonstrate the technology in an oil sands application. Multiple technologies may be funded, at the discretion of the Members.

HOW TO SUBMIT TO COSIA

Submit a summary of your solution using COSIA's Environmental Technology Assessment Portal (E-TAP) Process, available at: **http://www.cosia.ca/initiatives/etap/idea-submission-form**

Please note: ETAP is a staged submission process. The initial submission requires only a brief description and limited technical information. Upon review by COSIA, additional information may be requested. Instructions for submission are provided on the ETAP site.

All information provided is non-confidential. COSIA will respond to all submissions.

DETAILED SOLUTION DESCRIPTION

The COSIA Tailings Environmental Priority Area Steering Committee seeks leading-edge technologies to explore the bulk and surface attributes of oil sands clay minerals to effect a beneficial behavioral change in the tailings. The solution may leverage a considerable body of open literature that describes the chemistry, behavior, and unique properties of oil sands tailings. The solution will have a path to scale-up to a commercial deployment.

Such a modification could take several forms. Some examples, meant to inspire, but not to limit, include:

- Improvement for reclamation timelines. Clay properties determine tailings behaviours and, in turn, reclamation timelines. Modification of clay properties to accelerate dewatering and consolidation, would facilitate reclamation activities. Examples of such a change could include modifying the clay surface area to be hydrophobic to repel water to facilitate / accelerate separation of clay and water.
- Modification for sequestration of CoPCs. Poor dewatering and consolidation rates associated with oil sands fluid fine tailings are driven largely by clay minerals in fluid fine tailings. There is an opportunity to take advantage of high surface area clay minerals towards minimizing the footprint of fluid fine tailings and getting tailings ponds ready for terrestrial or aquatic reclamation, including permanent sorption sites for metals, organic CoPCs and CO_2 while accelerating the in-situ dewatering rates of fluid fine tailings.
- Modification to facilitate biological treatment/processes. Modification of clay chemistry could improve the characteristics of the clays as a substrate for biological use to increase algal or microbial activity. Such an example could include accelerating tailings consolidation, increasing CO_2 consumption, or production of a beneficial algal byproduct.

Such modifications should improve understanding of the clay properties and behaviours and would build on the considerable body of work in the public domain, some of which are referenced in the background section.

Solutions should not adversely impact the water chemistry or introduce novel agents that negatively affect extraction or reclamation targets.

Quantitative metrics:

A successful solution will substantially accelerate tailings dewatering beyond the Liquid Limit, usually around a clay to water ratio of 1.2, or >~60wt% +/-5 wt% solids for a fines dominated material such as FFT.

Of note – the immobile surface layer surrounding the clays is on the order of 1.2-1.6 nm in thickness, and as much as 2.5 nm in thickness. Removing all water from the clays except for the immobile surface layer typically results in a material near the liquid limit. Therefore, to dewater to the liquid limit and beyond will require a change in the properties of the clays themselves. This is, at its core, the reason for this Challenge Statement.

An objective is to modify the clay properties to achieve dewatering beyond this point within reasonable timeframe under saturated self-weight consolidation only in a deep depositional cell. This index performance should not include alternative drying techniques such as wick drains, freeze/thaw, desiccation, etc. The typical thickness of deep deposits could range from <10m to ~60m, and the dewatering timeframes could range a few years to a few decades, depending on the thickness of the deposit. This can be tested using a geotechnical beam centrifuge and/or through Seepage Induced Consolidation / Large Strain Consolidation testing and numerical modeling to predict consolidation rates. The solution should report these results for comparison against other potential solutions.

However, to screen techniques and formulations internally, lab tests are recommended, such as:

- Glass graduated cylinder settling tests for initial dewatering
- Capillary Suction Test for higher density FFT initial dewatering
- Centrifuge index tests for higher density FFT dewatering
- A Specific Resistance to Filtration using a pressure filtration setup can be used in the lab to compare solutions

To be comparable, solutions should leverage ASTM standards for measuring and characterizing the clays, water, and organics using oil sands process affected water:

- Methylene blue testing for clay activity (using the COSIA recommended method)
- PSD are recommended for characterization (Laser diffraction is sufficient)
- Atterburg Limits are recommended for evaluating the efficacy of the solution
- XRD for clay characterization is welcome but may not be critical

BACKGROUND

Surface mined oil sands operations are currently restricted to the Cretaceous McMurray Formation in the Athabasca oil sands deposit of North-Eastern Alberta, Canada. The McMurray Formation consists of several depositional environments with fluvial sands at the base transitioning to tidally influenced deposits through to marine sands at the top of the formation. Grain sizes vary from coarse sands in the fluvial channels to fine-grained clay-rich overbank deposits. The formation is not lithified and paleosols in some zones preserve Cretaceous aged soils.

Bitumen in the oil sands is biodegraded oil that migrated from source rocks buried to the west of the current deposits. Oil biodegradation to bitumen resulted in very low API gravity (around 8°). Consequently, this bitumen does not flow and is mined. Bitumen content in the formation is variable with the mineable range between 6 and 18 wt% bitumen. Mined oil sands contain up to 5 wt.% connate water and 80 – 85 wt% mineral solids. The overall formation consists of greater than 75 wt.% of the mineral solids as coarse sand (>44 μm) and the fine mineral component (<44 μm) is primarily silt sized. The clay-sized fraction (<2μm) dominates the behavior of fluid fine tailings, and are typically phyllosilicates. These phyllosilicate minerals span a range of properties. The most dominant phyllosilicate is the kaolin group. Kaolinite range from crystalline to highly disordered with specific surface areas ranging from less than 10 m^2/g to greater than 200 m^2/g. The surface of the smallest kaolinite crystallites show significant smectitic behavior with occasional concretions of nanocrystalline iron oxides and organic matter. The second most abundant mineral is mica, which also range from detrital, silt-sized muscovite to partially depotassifed mica (or illite) and illite-smectite (up to 70:30) with specific surface areas over 200 m^2/g.

To extract bitumen from oil sands, up to 1 m^3 of water per tonne of ore is mixed then transported in hydro-transport lines to liberate bitumen from the mineral solids. The bitumen is recovered in a froth layer in a primary separation vessel and flotation cells, while the bulk of the minerals are removed in both the fine and coarse tailings streams, which are often combined into a whole tailings stream. A small proportion of the mineral solids report to the bitumen froth and are subsequently recovered during secondary processing to further purify the bitumen. This is called the froth treatment tailings and is often separated from the whole tailings stream.

In conventional tailings deposition and dyke cell construction, tailings slurry, consisting of whole tailings or cyclone underflow is pipelined and discharged onto the tailings beaches inside the dyke or discharged into cells where dozers compact the material to form dykes. Upon discharge, the tailings slurry segregates such that the coarse sand material settles out near the discharge location and the release water runs down the beach to a pond, taking the fine-grained particles with it. The fines-water mixture (approximately 10 wt.% solids), reports to the pond at the end of the beach, and is commonly referred to as thin fine tailings (TFT). After a short time, the TFT settles to a somewhat denser state, about 30% solids by mass, and is referred to as mature fine tailings (MFT). TFT and MFT are both considered to be fluid fine tailings (FFT). Over 80% of the water used in the extraction process, referred to as oil sands process water or OSPW is recycled from the tailings ponds.

Over the past four decades, the industry has developed and deployed several technologies to rapidly dewater FFT so that the tailings can be reclaimed into a terrestrial landform. These technologies include non-segregating, consolidated or composite tailings, thickening, centrifugation, inline flocculation and deposition in thin lifts to achieve rapid initial dewatering. In all cases, the material created is further allowed to consolidate within a footprint amenable to terrestrial reclamation by using a variety of techniques including, wick drains, sand surcharge or atmospheric drying, amongst others. Ultimately, the dewatering of tailings is dictated by particle size with fine tailings dewatering at a slower rate than coarser tailings as permeability is heavily influenced by porosity (or void ratio).

This COSIA challenge combines the dewatering outcome of the technologies described above with sequestration of CoPCs such that as the deposit created settles and consolidates faster and expressed pore water or leachate from the deposit meet the regulatory guidelines appropriate for the final intended terrestrial or aquatic landform. CoPCs include residual bitumen in tailings, ultrafine phyllosilicate and associated minerals, metals and organic toxicity precursors.

APPROACHES NOT OF INTEREST

The following approaches are not of interest:

- Solutions that cannot be explained based on fundamental sciences - these will be subject to a higher degree of scrutiny and subject to a higher standard of empirical testing to demonstrate robustness of the approach.
- Use of synthetic tailings to determine a process fix in isolation, without reference to real oil sand tailings behaviors.

- Chemical or physical property interrogation that repeats the literature (except where improved method leads to more insight/overturns previous thinking). This will require the successful project team to be conversant with the available literature.

ADDITIONAL INFORMATION

List of references

Please consult the following non-exhaustive list of references for more information on this topic.

Critical resources:

1. An introduction to oil sands clays. CMS Workshop Lecture Series, vol 22. Omotoso, O. and Hockley, D. eds. 2018

2. Proceeding of Fine Tailings Symposium (1993), Fine Tailings Fundamentals Consortium (editor Joseph Liu), Oil Sand-Our Petroleum Future Conference. Edmonton, Alberta, April 4-7, 1993.

Other recommended resources:

1. Bayliss, P., & Levinson, A. (1976). Mineralogical review of the Athabasca oil sands deposits (Lower cretaceous, Mannville group). Bulletin of the Canadian Petroleum Geology, 24, 211-214.

2. Ignasiak, T.M., Kotlyar, L., Longstaffe, F.J., Strausz, O.P. and Montgomery, D.S. (1983) Separation and characterization of clay from Athabasca asphaltene. Fuel, v. 62, p. 353-362.

3. Kotlyar, L. S., Sparks, B. D and H. Kodama, H. (1984) “Some chemical and mineralogical properties of fine solids derived from oil sands”, AOSTRA J Res 1 99-106.

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5. Kotlyar, L. S., Sparks, B. D., H. Kodama, H. and Grattan-Bellew, P. E (1987) “Noncrystalline inorganic matter-humic complexes in Athabasca oil sand and their relationship to bitumen recovery”, Appl Clay Sci 2 253-271.

6. Mikula, R. J (1989). Suncor extraction plant samples characterization of mineral matter and clay-organic complexes. Division Report CRL 89-33 (CF). 30 pp

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8. Singh, B. and Gilkes, R. J (1992). Properties of soil kaolinites from south Western Australia. Journal of Soil Science, 43, 645-667.

9. Omotoso, O., Mikula, R. J., & Stephens, P. W. (2002). Surface area of interstratified phyllosilicates in Athabasca oil sands from Synchrotron XRD. Advances in X-ray Analysis, 45, pp. 391-396.

10. Wallace, D., Tipman, R., Komishke, B., Wallwork, V., & Perkins, E. (2004). Fines/water interactions and consequences of the presence of degraded illite on oil sands extractibility. The Canadian Journal of Chemical Engineering, 82, 667-677.

11. Omotoso, O., Mikula, R. J., Urquhart, S., Sulimma, H. & Stephens, P. W. (2006). Characterization of clays from poorly processing oil ands using synchrotron techniques. Clay Science, 12, Supplement 2, pp. 88-93.

12. Kaminsky, H., Etsell, T., Ivey, D., & Omotoso, O. (2006). Fundamental particle size of clay minerals in Athabasca oil sands tailings. Clay Science, Supplement 2, 217-222.

13. Adeyinka, O., Samiei, S., Xu, Z., & Masliyah, J. (2009). Effect of particle size on the rheology of Athabasca clay suspensions. The Canadian Journal of Chemical Engineering, 87, 422-434.

14. Kaminsky, H., Etsell, T., Ivey, D., & Omotoso, O. (2009). Distribution of clay minerals in the process streams produced by the extraction of bitumen from Athabasca oil sands. The Canadian Journal of Chemical Engineering, 87, 85-93.

15. Hooshiar, A., Uhlik, P., Kaminsky, H., Shinbine, A., Omotoso, O., Liu, Q., and Etsell, T. (2010). High resolution transmission electron microscopy study of clay mineral particles from streams of simulated water based bitumen extraction of Athabasca oil sands. Applied Clay Science, 48, pp. 466-474.

16. Schoonheydt, R.A. and Johnston, C.T. (2013) Surface and interface chemistry of clay minerals. Chap 5 In Handbook of Clay Science. 2nd Edition, Part A. Fundamentals. Ed. Bergaya, F., Theng, B. K. G., and Lagaly, G. Elsevier, Amsterdam. Pages 139-172.

17. Yuan X.S. and Shaw W. (2007).“Novel Processes for Treatment of Syncrude Fine Transition and Marine Ore Tailings,” Canadian Metallurgical Quarterly, 2007, Vol 46, p 265-272.

18. Yuan S., Bara B. and Siman R. (2013). “Development of Success Criteria for High Density Fluid Fine Tailings Flocculation in Oil Sand Industry,” Mine Waste and Tailings Conference, Banff, Alberta, November 3-6, 2013.

Theses

1. Kaminsky, H.A. W (2008). Characterization of an Athabasca oil sand ore and process streams. Edmonton. University of Alberta

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3. Hooshiar, A. (2011). Characterization of Clay Minerals in the Athabasca Oil Sands in Water Extraction and Nonaqueous Solvent Extraction Processes. Edmonton. University of Alberta