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EFFECT OF LIME COAGULATION ON STRENGTH AND ATTERBERG PROPERTIES OF CLAYS IN OIL SANDS TAILINGS

Romaniuk, N;[1] Gandhi, S;[2] Ozum, B;[2] Fox, J;[3] Leikam, J;[3] Tate, M[3]

[1] NIKOLAS ROMANIUK CONSULTING
[2] APEX ENGINEERING INC.
[3] GRAYMONT INC.

54th Clay Mineral Society Conference, 07 June 2017

Outline

- Oil sands fine tailings
- Dewatering of oil sands fine tailings
- Lime as a coagulant of clay minerals
- Experimental results of lime as a coagulant of clay minerals in oil sands tailings
- Summary, conclusions, and future work

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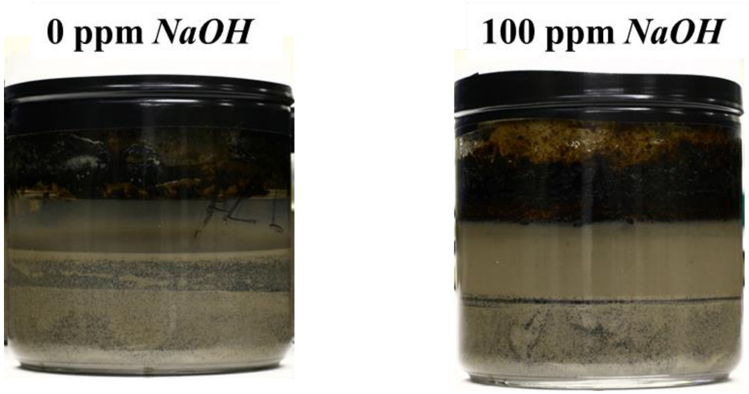
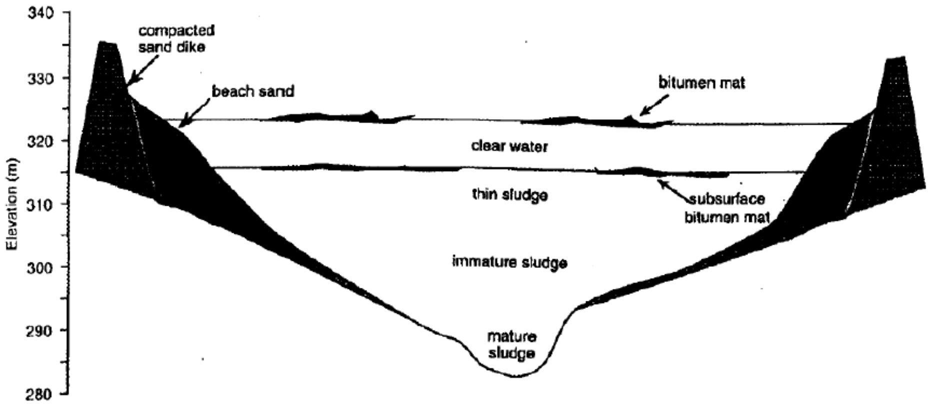
Oil sands fine tailings

- **Extraction Process**
  - Ore-Water slurry extraction process
  - Uses NaOH as a process additive to enhance recovery
  - Extraction process results in highly dispersed clay minerals



- **Tailings properties**
  - Tailings easily segregate upon beach deposition
  - Fine silts and dispersed clay minerals collect in ponds as Fluid Fine Tailings (FFT)
  - FFT settles slowly, resists consolidation, and is untrafficable



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Mineralogy of oil sands fine tailings

- **Most common clays in oil sands fine tailings are:**
  1. Kaolinite
  2. Illite
  3. Interstratified Smectites
  4. Chlorite

Mineralogical composition of various fractions (± 10 wt.%)

Sample number	Fraction (μm)	Clay minerals (w/w)					Non-clay minerals (w/w)				
		Kaolin	K–S	Illite	I–S	Chlorite	Quartz	Anatase	Rutile	Siderite	Pyrite
MFT	≤ 0.25	15	37	2	46	–	–	–	–	–	–
	≤ 2>0.25	26	24	18	15	3	9	–	–	–	–
	< 44>2	20	–	19	–	5	55	–	1	–	–
Thickener overflow	#1	13	16	11	40	–	9	–	–	–	–
Thickener overflow	#2	7	24	3	55	–	7	–	–	–	–
Froth solids	≤ 2	25	29	5	29	–	7	2	0.4	–	3
	≤ 10>2	14	–	11	–	–	23	1	2	17	5
	< 44> 10	7	–	12	–	0.7	45	2	2	13	12

Other minerals in the −44- to +10-μm fraction of the froth solids include calcite (2), dolomite (1), albite (1.2), K-feldspar (1) and magnetite (0.9).

O.E. Omotoso, R.J. Mikula / Applied Clay Science 25 (2004) 37–47

- **Abundance of clays is highly dependent on geological formations and facies**
  – Interstratified Smectites are most common in fluvial facies
  – Illite is most common in marine facies
- **All fine tailings will have different distributions of clays due to variability in ore bodies across operator leases**

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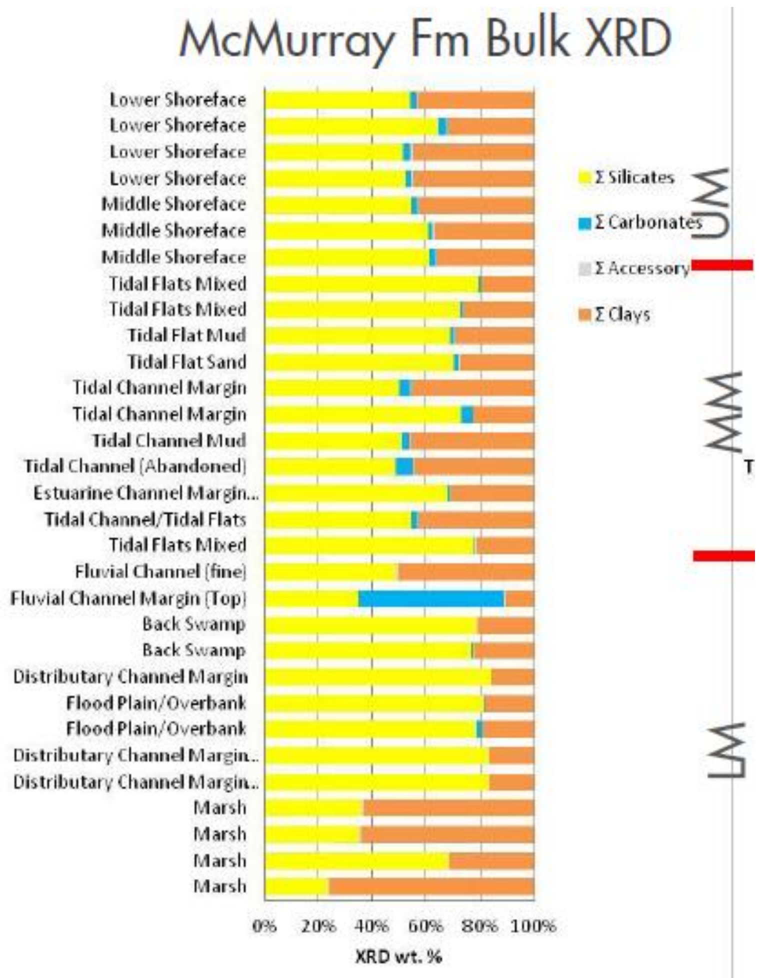
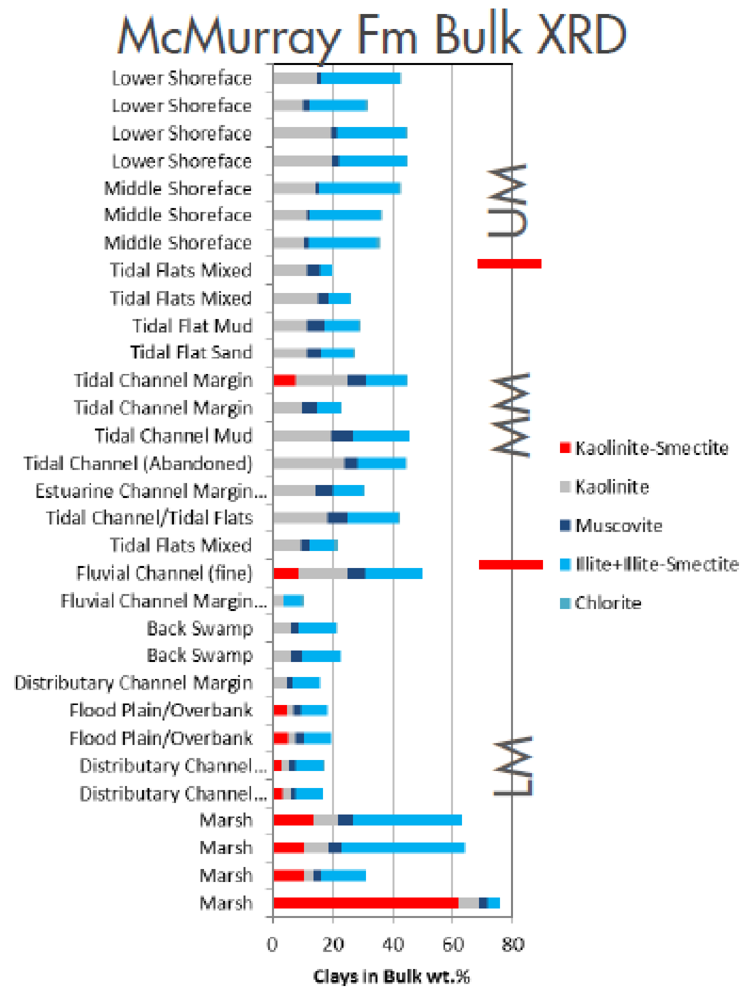
Mineralogy of oil sand tailings





Day-Stirrat, R, et al, 2015 Oil Sands Clay Conference

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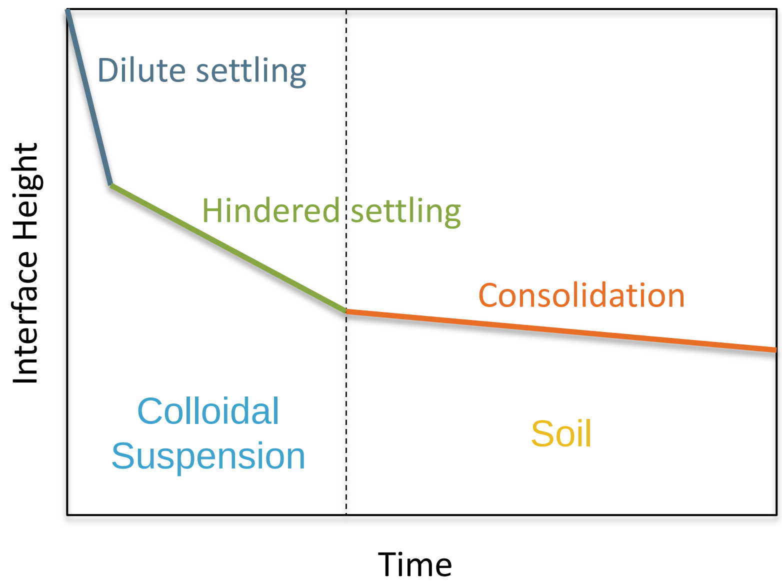
What is dewatering in oil sands fine tailings?

Colloidal Suspension

Soil

Phases of dewatering

- **Dilute settling**
  - Initial quick settling
  - Limited particle interaction
  - Ex: In-line flocculation at 0-20% solids content
- **Hindered Settling**
  - Slow settling
  - Significant particle interaction
  - Ex: Post thickener at 20%+ solids content
- **Consolidation**
  - Particle interaction dominates
  - Generally occurs with external load
  - Ex: Overburden co-mixing at 70%+ solids content



Effect of mineral surfaces on dewatering

- Particle size and surface area
  - Coagulation vs Flocculation
- Water film thickness
  - Ability of clay minerals to swell with water
  - Controlled by cation exchange

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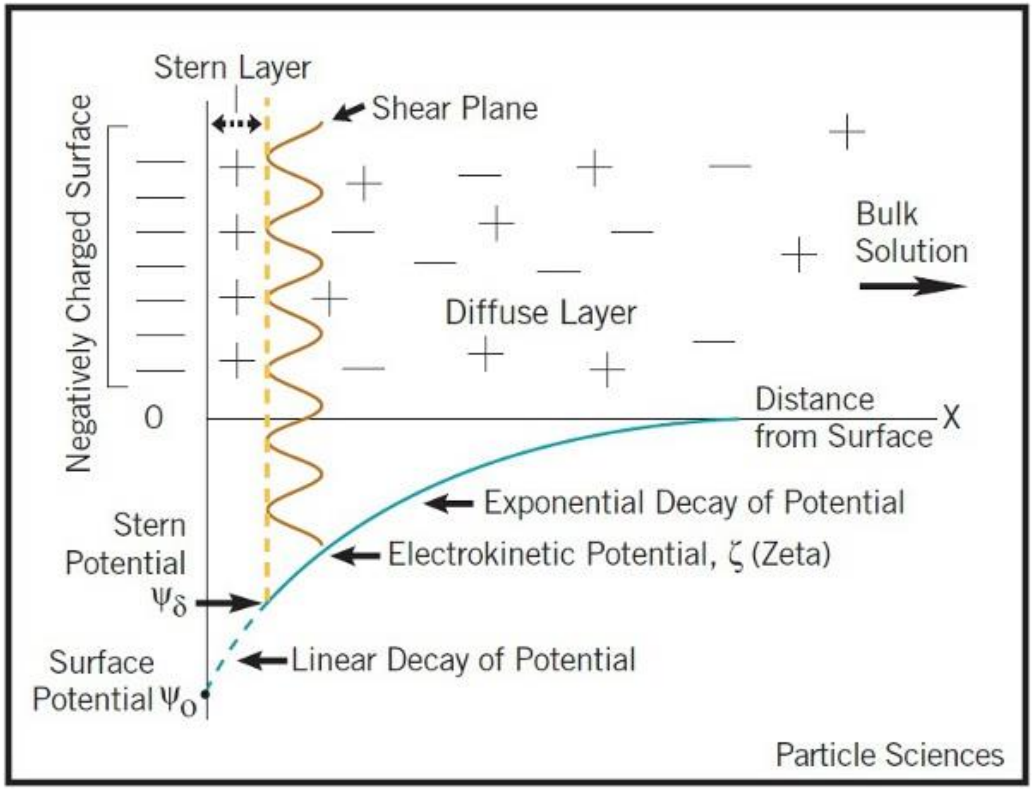
Where is water in oil sand fine tailings?

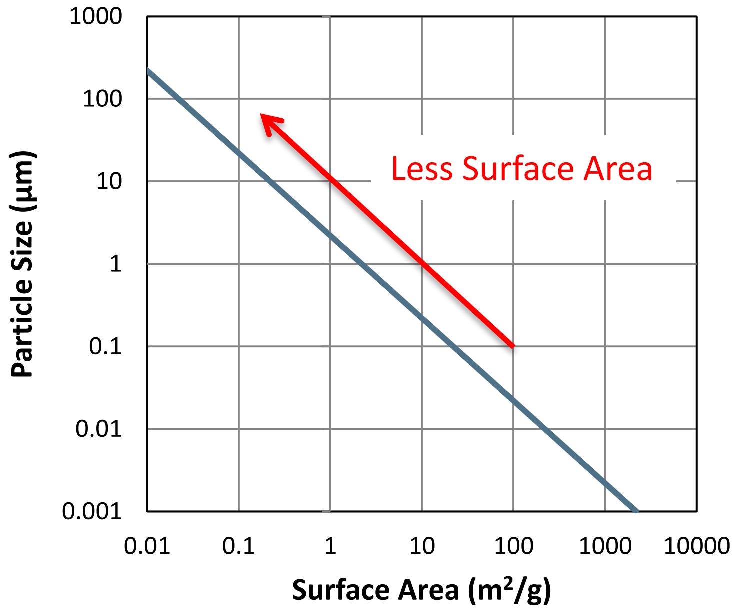
- **Water is bound in the hydration shell of ions associated with clay surfaces**
- **Bulk water**
  - Ions have no attraction to surface
  - Easy to remove
- **Diffuse layer**
  - Ions have some attraction to surface
  - Beyond the shear plane, so removal is somewhat easy
- **Stern layer**
  - Strong attraction to charged surface
  - Removal is very difficult and requires modification of the surface, such as ion exchange

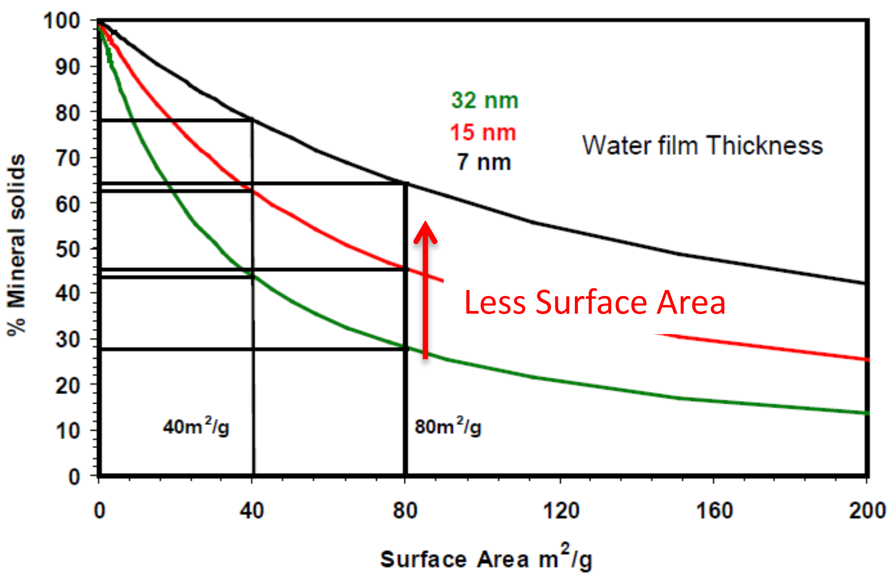


http://media.americanpharmaceuticalreview.com/m/28/article/133232-2.jpg

Changing surface properties can improve dewatering

- Decreasing clay surface area will provide more free water for removal
- Can be achieved by:
  - Increasing clay particle size
  - Changing surface chemistry to decrease water film thickness





Sethi, A, 2015 Oil Sands Clay Conference

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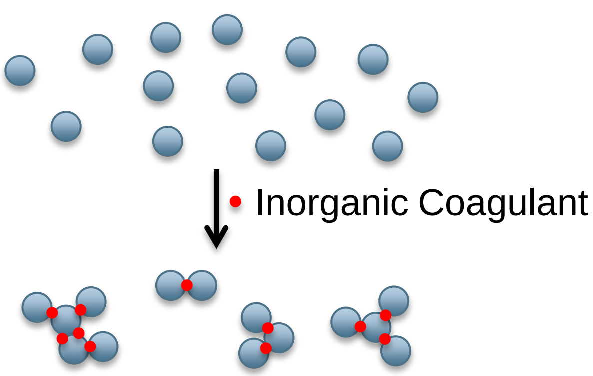
Coagulation vs flocculation in oil sands fine tailings

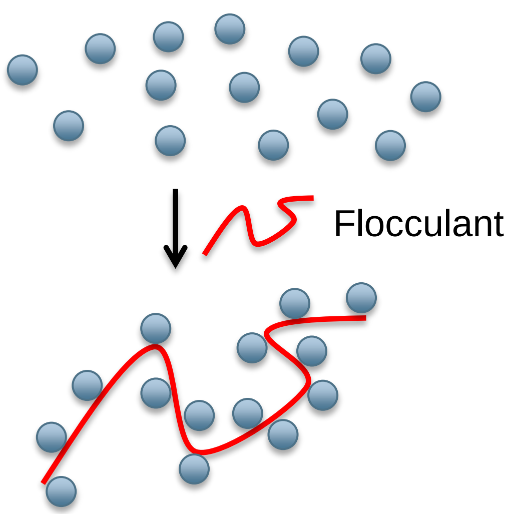
Coagulation

- Aggregation of clay particles through chemical bonding
- Modification and chemical reaction of clay surfaces by coagulants, such as lime, by ion exchange and pozzolanic reactions
- Results in particles of larger size held together by chemical bonds of varying strengths
- Improves all dewatering through reduced surface area resulting from increased particle size and reduced water film thickness



Flocculation

- Aggregation of clay particles onto a flocculant surface
- Particles adsorption onto large molecular weight flocculants, such as polyacrylamide polymers
- Results in very large and fragile flocs held together by weak intermolecular forces
- Enhances effects of gravity settling in dilute settling, accelerating initial dewatering



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How much dewatering is needed in oil sands fine tailings?

- **Significant dewatering is currently necessary because oil sands tailings have low strengths and high plasticity, thus a high solids content is necessary to make a trafficable material**
  - Oil sands fine tailings need to be above about 70% solids to be a trafficable material
  - Current technologies have success dewatering to 50% solids; however, remaining water is much more difficult to remove as much is associated with the water film in the stern layer
- **Chemical modification of clays to increase strength and decrease plasticity of oil sands tailings could provide a trafficable material at a lower solids content**
  - Tailings that are stable and stackable at a lower solids content require less dewatering, reducing treatment and processing costs
  - Chemical modification of clay surfaces can decrease surface area and release free water which should improve dewatering processes

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Lime as a coagulant of clay minerals

- **Lime, calcium oxide, provides calcium as Ca^{2+}, an inorganic coagulant**
- **Lime coagulation occurs by two mechanisms, ion exchange and pozzolanic reactions, dependent on pH**
  - In ion exchange, quick process where calcium bonds bridge clay particles
  - In pozzolanic reactions, slower cementitious stabilization resulting from the production of hydrated calcium silicates and calcium aluminates at high pH
- **Lime has significant impacts on process water chemistry**
  - Lime will initially react with bicarbonate and carbonates to form calcite
  - Lime will increase pH of system, which is necessary to form pozzolans
- **Lime can decrease plasticity and increase strength of clay materials**
  - Lime stabilization is well known to decrease plasticity index and increase shear strength
  - Provides a textural change from clay-like to a silt-like character

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Investigation of lime coagulation in oil sands tailings

- **Fluid fine tailings (FFT) were treated with different doses (as a %Wt) of lime and investigated for:**
  - Water release under pressure
  - Particle size analysis
  - Yield stress as a function of aging
  - Atterberg limits

Characterization of FFT used in experiments

FFT	Mineral Solids Content	Bitumen Content	MBI	Na+	Carbonate Alkalinity	pH
	%	%		ppm	ppm	
1	32.5	2.9	9.2	362	579	7.9
2	33.4	1.3	11.2	877	937	8.3

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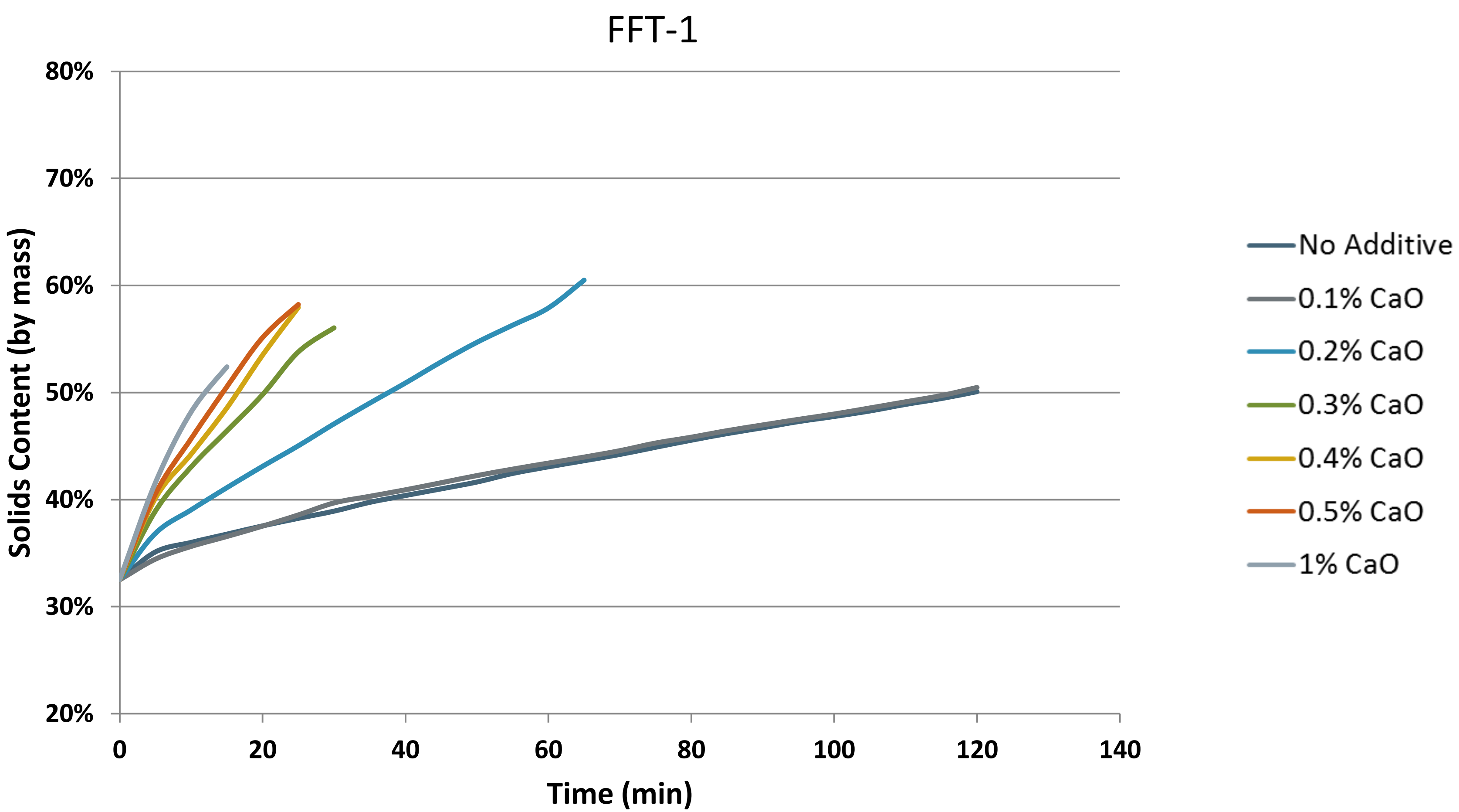
Effect of lime coagulation for dewatering oil sands fine tailings under pressure



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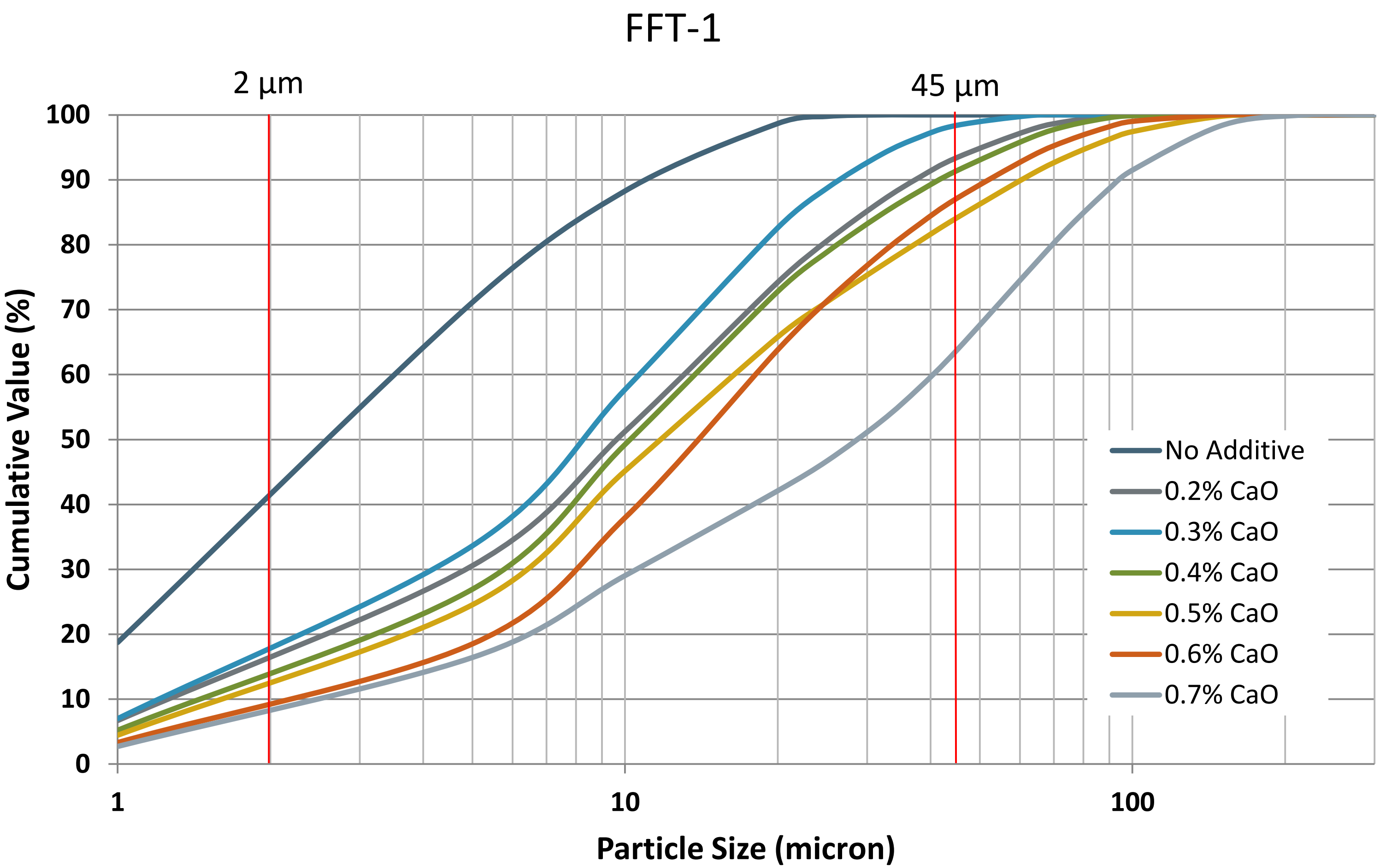
Effect of lime coagulation on oil sands tailings particle size



- pH above 12 was achieved with 0.7% Wt CaO dose

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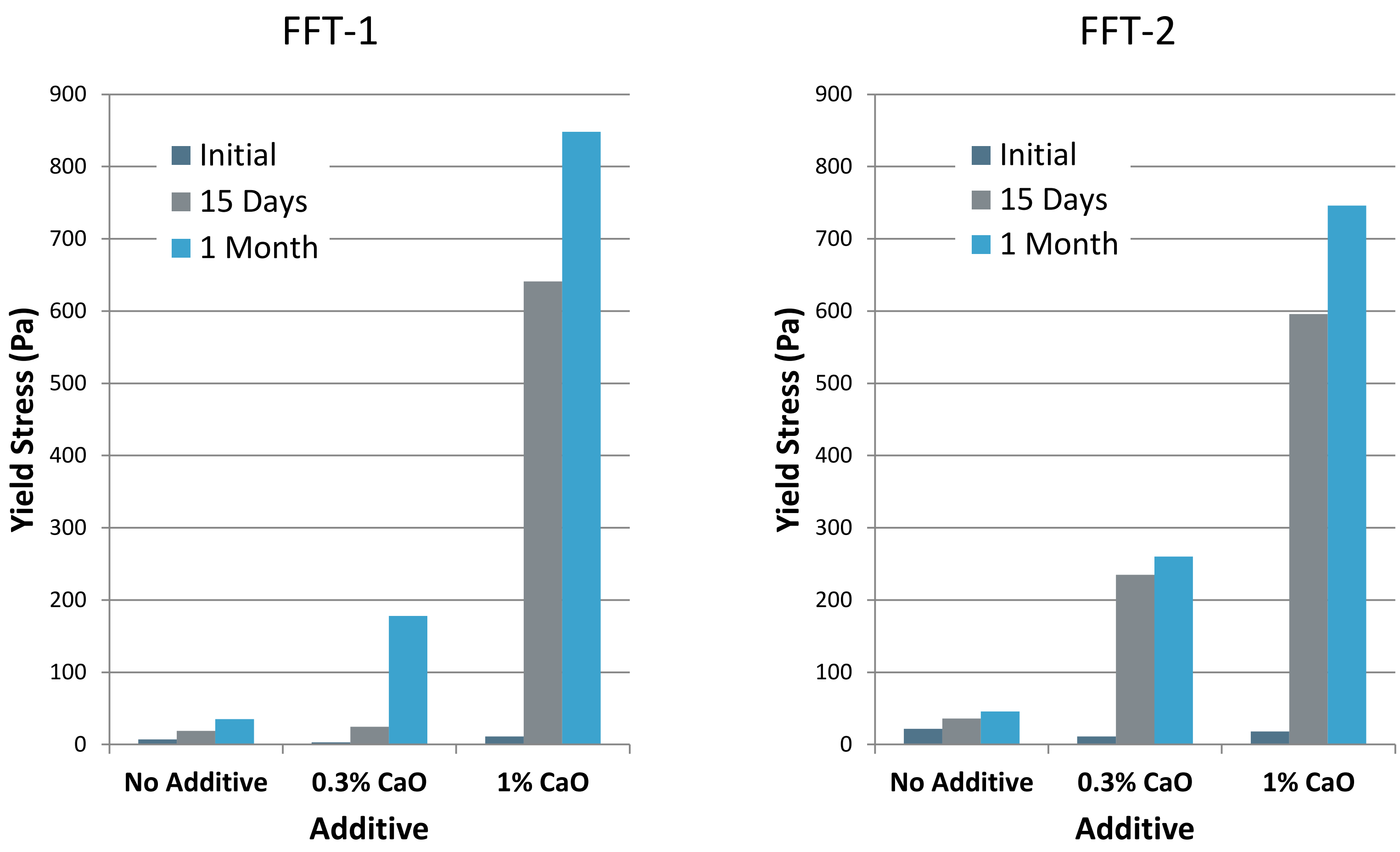
Effect of lime coagulation on oil sands fine tailings strength



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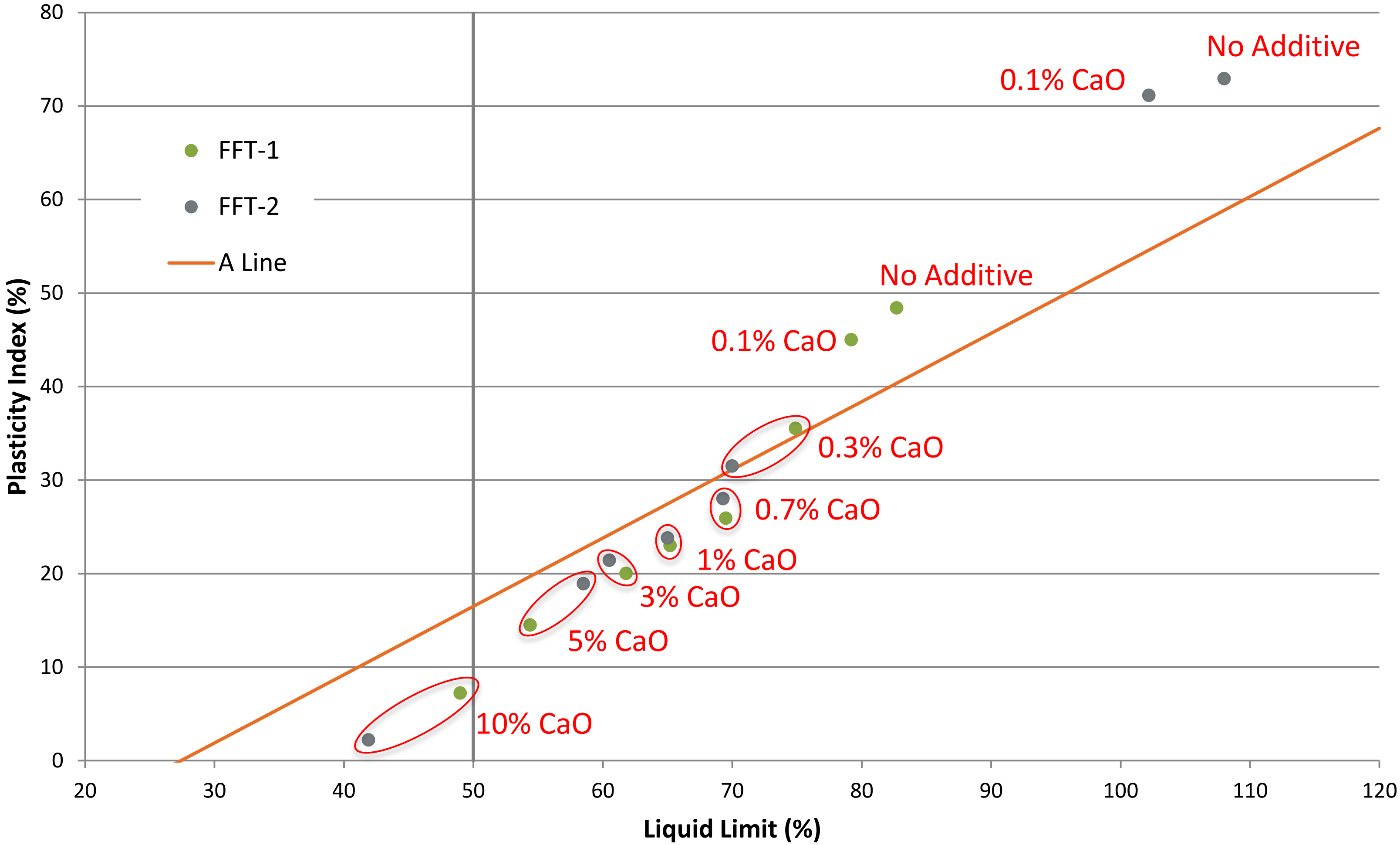
Effect of lime coagulation on oil sands fine tailings plasticity



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Summary of CaO Treated FFT Properties

- **CaO treatment enhances dewatering under pressure**
  - Dose dependent response, enhanced dewatering under pressure was observed starting at 0.2% Wt CaO and was maximized between 0.4% to 1% Wt CaO
  - Demonstrated an increase from 30 to 60% in solids content
  - Rate of dewatering was enhanced significantly, with the rate increasing with dose
- **CaO treatment is observed to increase the size of FFT particles**
  - Low doses provide a small increase in particle size
  - A significant increase in size is observed when treatment conditions reach above pH 12 with 0.7% Wt CaO dose, potentially due to pozzolanic reactions
- **CaO treatment increases strength as observed in yield stress measurements**
  - The 1% Wt CaO dose, which increases pH above 12, is observed to have a significant increase in the observed yield stress, increasing to about 700 Pa with 1% Wt compared to 200 Pa with 0.3% Wt and about 40 Pa with no treatment
  - Strength appears to increase overtime
- **CaO treatment is observed to significantly reduce both liquid limit and plasticity index**
  - CaO treatment appears to change FFT properties such that they appear to behave more silt-like
  - Change to silt like character occurs at 0.7% Wt CaO, which corresponds to pH increasing above 12

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Conclusions

- **Improvements to dewatering most likely results from a decrease in surface area of clays in oil sand fine tailings**
  - Surface area decreases by increase in particle size and chemical modification of clay surfaces which decreasing the water film thickness surrounding the clays

- **Improvement of strength and decrease in plasticity should allow for trafficable tailings at lower solids contents, thus less dewatering should be necessary to reclaim tailings**

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Future work

- Investigation and characterization of pozzolanic reactions that occur in lime treated oil sands fine tailings

- Determination of undrained shear strength in lime treated oil sands fine tailings

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