



Reduction of Environmental Impacts of Oil Sands Plants by Implementing Bitumen Extraction and Tailings Disposal Processes using Lime (CaO) Additive

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ABSTRACT

In Alberta, Canada, bitumen is produced by surface mining of Athabasca oil sands ore followed by ore-water slurry-based extraction processes, at a capacity exceeding 1.3×10^6 barrels/day. Clark Hot Water Extraction (CHWE) process developed in 1930s is used at all oil sands plants, which uses caustic NaOH as an additive to keep the pH of the extraction process slurry at about 8.2 to 9.0. Increase in slurry pH activates naphthenic acids in bitumen, which act as surfactant species reducing water surface and bitumen-water interfacial tensions. Reduction in surface and interfacial tensions promotes clay-water and bitumen-water wettability. As a result, NaOH additive promotes liberation of bitumen from oil sands matrix; however, it promotes silt-clay size particles dispersion and slows down coalescence and aeration of bitumen droplets, which harms overall efficiency of oil sands plants. Also, CHWE process causes accumulation of Na^+ in recycle process water, which detrimentally effects bitumen extraction and promotes production of toxic mature fine tailings. Existing mature fine tailings inventory is exceeding 10^9 m^3 and its production rate is exponentially increasing as bitumen production capacity increases. At our laboratory, bitumen extraction process is being studied by using lime (CaO) as additive replacing NaOH of the CHWE process. Use of CaO as an extraction process additive eliminates Na^+ accumulation in recycle water, reduces surfactant activities of water soluble naphthenic acids, suppresses silt-clay size particles dispersion in the extraction process slurry, reduces mature fine tailings production, promotes bitumen extraction efficiency and increases the kinetics of bitumen droplets coalescence and aeration processes. Furthermore, tailings disposal processes, such as production of nonsegregating tailings, whole tailings treatment, and mature fine tailings dewatering processes were studied, also using CaO additive at different dosages. Experimental data will be presented by focusing on practicality, integration to the existing plants, capital and operating cost reduction perspectives.

Key Words: oil sands, bitumen extraction, oil sands tailings, mature fine tailings, process affected water

1 BACKGROUND

The Northern Alberta, Canada oil sands resources presents world's one of the vast hydrocarbon deposits, which extend over 77,000 km^2 , distributed in three principle regions: Athabasca, Cold Lake and Peace River. The estimated crude bitumen in-place volume and ultimate potentials for recovery are $270 \times 10^9 \text{ m}^3$ (1.6×10^{12} bbl) and $50 \times 10^9 \text{ m}^3$ (300×10^9 bbl), respectively (Precht and Rokosh, 1998). The Athabasca, McMurray deposits are surface mineable, where the overburden thickness is less than 75 m with in-place bitumen volume of about $24 \times 10^9 \text{ m}^3$ (144×10^9 bbl). In deeper formations, where the crude bitumen is not mobile in the reservoir, thermal energy application is required for the recovery of the bitumen.

In Alberta, bitumen is produced by surface mining followed by ore-water slurry-based extraction processes at over 1.3×10^6 bbl/d capacity. Production capacity is predicted to grow as the existing plant capacities are increased and new plants become operational.

Some versions of Clark Hot Water Extraction (CHWE) process of 1930s are used at all oil sands plants, which uses caustic NaOH as extraction process additive (Clark, 1939; Clark and Pasternack, 1932). All bitumen production plants are permitted to operate with zero discharge policy, by which the process water recovered from oil sands tailings are recycled. This operating practice causes

accumulation of Na^+ concentration in process affected water. Use of NaOH as an extraction process additive and increase in Na^+ concentration in process water cause problems for both bitumen extraction and tailings disposal processes. CHWE process disperses silt-clay size particles in extraction process slurry, which promotes production of toxic mature fluid fine tailings (FFT).

Mature FFT is composed of about 33% solids (84% water by volume), over 98% of which are finer than $< 45 \mu\text{m}$ size particles (~ 325 mesh) and dewaterers with very slow rates; because of which existing mature FFT inventory reached over 10^9 m^3 over the five decades. Existing toxic mature FFT stands as a serious environmental liability for both oil industry and all level of governments.

In summary, use of CHWE process, more specifically use of NaOH as an extraction process additive, is the source of environmental and long terms sustainability problems associated with the operations of oil sands plants. Two major attempts were made by the oil industry to overcome these problems:

- (i) development of non-additive extraction processes to reduce or suppress dispersion of silt-clay size ($< 45 \mu\text{m}$) particles in the extraction process slurry, by which extraction plant produces tailings material with improved geotechnical characteristics, reduces MFT

- production and suppresses Na^+ accumulation in process water (Jeeravipoolvarn et al, 2017); and,
- (ii) produce Composite (or Consolidated) Tailings (CT) by treating the blend of cyclone underflow and existing MFT with gypsum ($CaSO_4$) additive to prevent segregation of fines from sand particles as depicted in Figure 1.

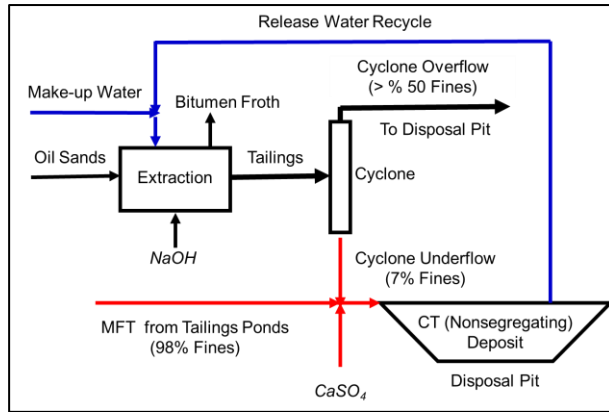


Figure 1. Schematics of CT production process.

After decades of commercial experience, implementations of these bitumen extraction and CT production technologies were discontinued. Non-additive, low temperature bitumen extraction process was implemented at two oil sands plants; however, it failed to provide acceptable bitumen extraction efficiency, which was gradually shifted to CHWE process of 1930s by using pH adjusting additives, such as sodium citrate and $NaOH$.

In fact, commercial implementation of the CT production process couldn't provide long term solution reduce the MFT inventory, since additional MFT is produced from the Cyclone Overflow tailings. CT process couldn't improve the energy efficiency of the oil sands plants because of the discharge of warm tailings into the tailings ponds. Continuous accumulation of Ca^{2+} and SO_4^{2-} ions detrimentally affects recycled release water chemistry, potentially promotes scaling in process vessels and pipes, and may cause H_2S emissions from the tailings ponds by anaerobic reduction of SO_4^{2-} by the residual bitumen in the tailings.

Performance of CT production process is also harmed by steady increase in process water Na^+ concentration, which increases the sodium adsorption ratio (SAR) in the tailings slurry (Miller et al, 2010; Dawson et al. 1999):

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}} \quad (1)$$

where the soluble cation concentrations are in me/L units. When SAR values of oil sands ore-water slurries exceeds about 7, Na^+ occupies adsorption sites on the clay, resulting in dispersion of the clay size particles. SAR values of most the oil sands tailings materials are greater than 20; therefore, $CaSO_4$ could not perform as an additive to prevent segregation of fines from sand particles by increasing yield stress of the fines-water matrix.

To reduce MFT inventory, oil sands players also spent sincere effort to develop novel technologies, such as TRO (tailings reduction operations), atmospheric drying, in-line thickening, coke-capping, centrifuging, pressure filtering; however, field trails of none of these processes has generated robust confidence for their full scale commercial implementations

In summary, oil industry needs novel bitumen extraction, tailings disposal and MFT dewatering processes to improve bitumen extraction efficiency, process water chemistry and long-term sustainability of oil sands plants in simple and cost-effective manners.

2 USE OF LIME AS ADDITIVES FOR BITUMEN EXTRACTION AND TAILINGS DISPOSAL PROCESSES

Our philosophy to reduce environmental impacts and to improve long-term sustainability of oil sands plant is based on the development and adaptation of following operating principles:

- reduce-suppress silt-clay size particles in the extraction process slurry;
- dispose oil sands tailings material as a non-segregating tailings material;
- convert *Na-Clay* to *Ca-Clay* before the implementation of any MFT dewatering technology;
- reduce-eliminate increase in Na^+ concentration in process affected water.

To achieve these fundamental process objectives, our research findings show that the following processes, all based on the use of CaO as additives, could have great impacts on profitability, reduction of environmental impacts and long-term sustainability of oil sands plants:

- (i) use CaO as an extraction process additive to reduce or suppress dispersion of silt-clay size ($< 45 \mu m$, -325 mesh) particles in the extraction process slurry;
- (ii) treat the whole tailings discharged from extraction plant before cyclones, or direct deposition of the whole tailings into the tailings ponds;
- (iii) dispose the tailings as a nonsegregating tailings (NST) material; and,
- (iv) treat MFT with CaO before the implementation of any commercially available or novel dewatering processes.

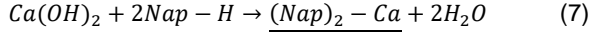
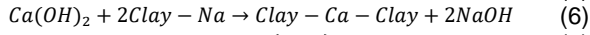
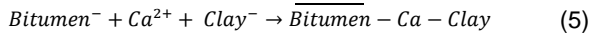
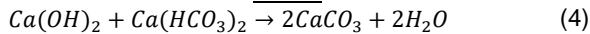
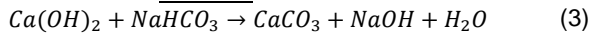
In the following sections further details of these processes, all based on the use of CaO as additives at different dosages, will be presented

2.1 Benefits offered by CaO Chemistry

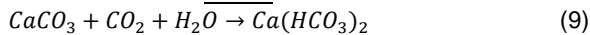
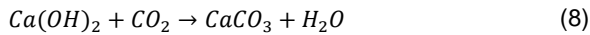
Our research findings suggest these process principles and objectives could be accomplished using lime (CaO) as additives at different dosages for bitumen extraction, tailings disposal and MFT dewatering processes.

The need for the use of CaO as additives for oil sands operations evolves from the unique characteristics of CaO chemistry; increases pH of the oil sands ore-water slurry

and provides Ca^{2+} ions for the following parallel and consecutive chemical reactions could take place between the species contained in oil sands ore-water slurry:



The excess CaO (Ca(OH)_2 in aqueous systems) presents in the ore-water slurry would react with the atmospheric CO_2 by the following reactions:



Also, the excess CaO presents in the recycled process water would be consumed for softening of bicarbonate hardness of the newly imported fresh water by the chemical reaction shown in Equation (4).

Bitumen extraction and tailings disposal tests using CaO additive showed that, based on the dosage of CaO additive, the chemical equilibrium attained in oil sands ore-water slurries at operating temperatures at atmospheric pressure favors certain physical-chemical processes to happen. These physical-chemical processes benefit performance of bitumen extraction, tailings disposal and/or MFT dewatering processes, and provide great advantages for the profitability, reduction of environmental impacts and long-term sustainability of oil sands plants.

2.2 Use of CaO as Bitumen Extraction Process Additive

Our early research studies showed that existing environmental impact and long-term sustainability problems of oil sands plants could significantly be reduced or minimized by using CaO (Ca(OH)_2 in aqueous systems) as an extraction process additive replacing NaOH of the CHWE process (Ozum & Scott, 2010; Babadagli et al. 2008).

Bitumen extraction process involves three fundamental processes taking place in the extraction slurry, as depicted in Figure 2:

- (i) bitumen liberation from oil sands ore matrix;
- (ii) coalescence of liberated bitumen droplets to form larger droplets; and,
- (iii) aeration of bitumen droplets with air.

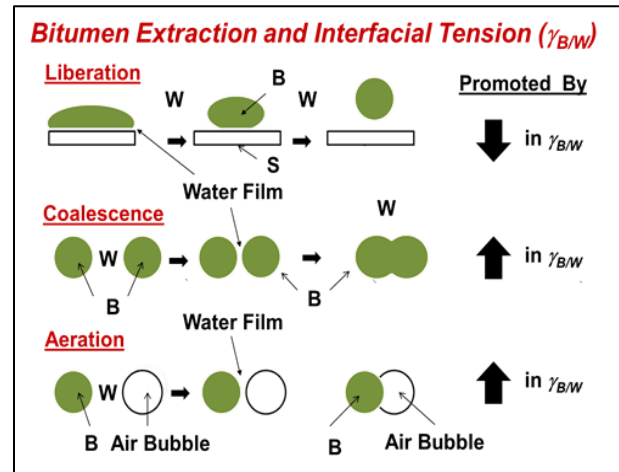


Figure 2. Role of bitumen-water IFT on the efficiency of bitumen extraction (Ozum et al. 2014a).

To achieve high bitumen extraction efficiency, improvements made in bitumen liberation process must be coupled with the improvements made in bitumen coalescence and aeration processes (Ozum et al. 2014a and 2014b; Ozum et al. 2012).

When NaOH is used as an additive, as in the CHWE process, it activates water soluble naphthenic acids, produces surfactant species and reduces water surface tension, γ_W , and bitumen-water interfacial tension (IFT), $\gamma_{B/W}$ (Moschopedis et al. 1977; Speight and Moschopedis, 1977/78). Reduction of γ_W promotes swelling of clay size particles (mostly kaolinite) in the extraction process slurry (of high Na^+ concentrations).

Dispersion of silt-clay size particles in extraction process slurry causes production of oil sands tailings with poor settling and consolidation properties and promotes mature fine tailings production. Reduction of $\gamma_{B/W}$ promotes bitumen liberation process; however, it suppresses bitumen coalescence and bitumen aeration processes in the extraction process slurry by increasing attractions between bitumen droplets and process water, by promoting the hydrophobic characteristics of the bitumen droplets surfaces (Liu et al. 2005; Pan et al. 2012; Pan and Yoon 2010).

As a result, CHWE process needs longer retention times, or larger process vessels for the formation of bitumen rich extraction froth, which increases capital and operating costs of the extraction plants.

To compare the performance NaOH and CaO as extraction process additives, COSIA requested from NAIT-NARCOSS to perform third-party verification tests (COSIA, 2014). These tests were made on a normal grade ore delivered from Shell Canada Ltd., at 50°C slurry temperature by using a Denver Flotation apparatus (800 rpm disperser rotating speed). Bitumen extraction efficiencies and process water chemistry for the first three Lock Cycle results using NaOH and CaO additives are presented in Tables 1 and Table 2.

Tailings from the batch extraction tests were settled in jars and pH measurements were made immediately. After seven days of settling, the release water was removed and analyzed for basic water chemistry. Images of the released

water samples are presented in Figure 3; which shows that NaOH additive promotes the dispersion of silt-clay size particles in extraction process slurry, while the CaO additive suppresses dispersion of these particles (Ozum et al. 2014a).

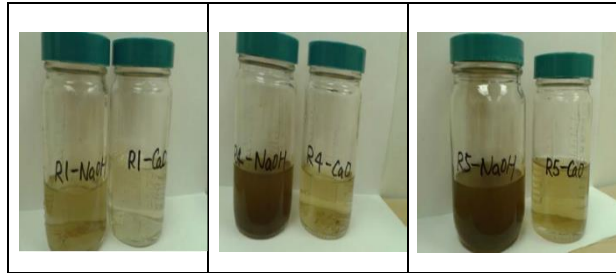


Figure 3. Images of release water from the 1st, 4th and 5th Lock Cycle tests (Ozum et al. 2014a).

When CaO is added into extraction process slurry, all chemical reactions expressed in Equation 2 to Equation 7 would take place. Test results suggest that, when the extraction process slurry pH is maintained in the range of 8.0 to 8.4, the chemical equilibrium attained in the extraction process slurry, it increases bitumen extraction efficiency and suppresses silt-clay size particles dispersion and improved geotechnical characteristics of the tailings effluent. Ion exchange reactions between Ca^{2+} and Na-Clay (Equation 6) also contributes suppression of silt-clay size particle in the extraction process slurry. These reactions are coupled with the reactions between bicarbonates and Ca(OH)_2 (chemical reactions expressed in Equation 2 and Equation 3), which reduces earth alkali bicarbonates concentration in process slurry and reduces scaling in the process vessels and pipes.

Use of CaO as an extraction process additive promotes bitumen liberation process similar reasons of the CHWE process; however, Ca^{2+} ions provided by CaO addition suppresses naphthenic acids activity and causes increase in γ_W and $\gamma_{B/W}$; which suppresses silt-clay size particles dispersion and promotes the kinetics of bitumen droplets coalescence and bitumen aeration processes in the extraction process slurry. As a result, smaller vessels would be needed in the extraction plants, which would reduce capital costs of new plants and increases and increase ore-water slurry processing capacity of the existing plants.

Use of CaO as an extraction process replacing NaOH of the CHWE process also suppresses Na^+ accumulation in process affected water, which provides great advantage for the efficiency of bitumen extraction, tailings disposal and MFT dewatering processes, therefore reduces operating costs and improves for long term sustainability of oil sands plants.

Furthermore, when CaO is used as additive to maintain ore-water slurry in the range of 8.0 – 8.4, Ca^{2+} does not binds negatively charged bitumen and clay together and suppresses bitumen extraction efficiency as claimed based on zeta potential measurements of ore-water lures using CaCl_2 additive (Masliyeh et al. 2004). Slurry pH and presence of bicarbonates make differences on the

reactions of Ca^{2+} with the species in ore-water slurries (Hall and Tollefson, 1982).

Also, use of CaO as an extraction process additive doesn't promote Ca^{2+} incorporation in bitumen phase either. Soluble Ca^{2+} measured in bitumen samples produced by extracting bitumen by NaOH and CaO additives are better correlated by pH of the process slurry than the dosages of NaOH or CaO used in the extraction process, as depicted in Figure 4.

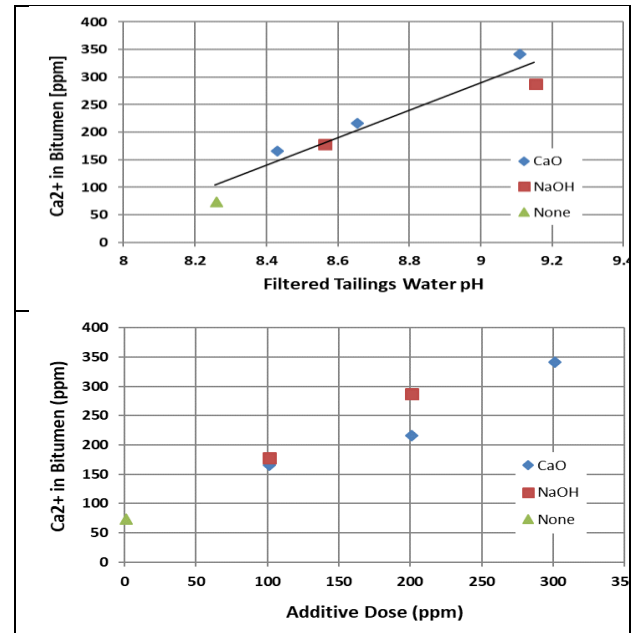


Figure 4. Dependence of Bitumen Ca^{2+} content on extraction process slurry pH and dosages of NaOH and CaO additives.

In summary, use of CHWE extraction process of 1930s, which uses NaOH as an extraction process additive is the source of environmental and long-term sustainability problems associated with the operations of oil sands plants. Steady increase in process water Na^+ concentration make plant operations more difficult in the years to come. High Na^+ concentration in process water suppresses bitumen extraction process efficiency, reduces nonsegregating tailings production efficiency, causes steady increase in MFT production and suppresses efficiency of MFT dewater process for the reclamation of the existing MFT ponds. Our research findings conclude that, solutions for all of these problems should start by focusing on the extraction process, at where oil sands tailing is produced in the first place.

2.3 Production of Nonsegregating Tailings using CaO

Effect of Ca^{2+} ions on drilling muds (clay type material) and use of calcium-based additives such as CaCl_2 and CaO to improve coagulation of clay size particle sand settling characteristics was studied for decades (Rogers, 1953; Speight and Moschopedis, 1980). The concept of depositing oil sands tailings as a nonsegregating tailings material, also called Composite (or Consolidated) Tailings

(CT), was developed at the University of Alberta and implemented firstly at Suncor's plant in 1990s (Caughill et al. 1993); process schematics of which is depicted in Figure 1.

As new oil sands plants didn't have access to low cost excess energy offered by the bitumen upgrading plans, thickening of Cyclone Overflow using thickeners, and recycling the thickener overflow as warm as possible to the extraction plant became almost a standard process design practice.

Shell Canada and Canadian Natural Resources Ltd. (CNRL) interested in production of nonsegregating tailings (NST) from the blend of Cyclone Underflow (about 59%-63% solids, 3%-7% fines) and Thickener Underflow (about 35%-40% solids; over 50% fines) and/or MFT (about 34% solids, over 98% fines), and using CaO as an additive; process schematics of which is shown in Figure 5.

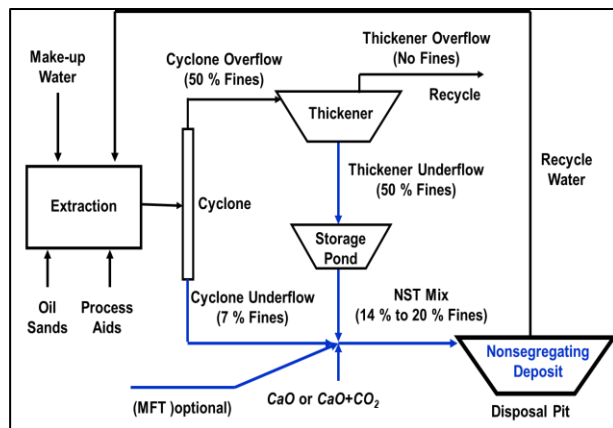


Figure 5. NST reduction using CaO (Scott et al. 2007).

At our laboratory, NST production tests using CaO and CaO & CO₂ additives were performed on Albian Sands (Shell Canada) Muskeg River Mine tailings materials, which produced when the extraction plant was operating with both non-additive and sodium citrate additive modes. Results of these studies were summarized in seven reports and submitted to Shell Canada Ltd., CNRL and Alberta Energy Research Institute (Scott et al. 2007; Apex Engineering Inc. 2004-2005).

Test results demonstration that NST at 59% solids content and SFR (sand-to-fines ratio) of 4 and 5 could be produced by using CaO additive at 0.6 kg-CaO/m³-NST dosages. It was observed that when a low shearing is imposed on NST, it promoted segregation and shifted segregation boundary to higher solids contents. As an example, static segregation boundaries of NST without any additive were at 59% and 61% solids contents for SFR of 4 and 5; while low shear segregation boundaries were 67% and 69% solids for SFR of 4 and 5. By using CaO at 0.6 kg/m³-NST dosages, static segregation boundaries were reduced to 53% and 54%, and low shear segregation boundaries to 57% and 58% solids contents for SFR of 4 and 5.

It was experimentally observed that segregation boundaries of NST produced from CHWE process MFT were at lower solids contents compared to that of the NST

produced from non-additive extraction process MFT, as shown in Figure 6. For example, segregation boundaries of NST with SFR of 4, produced from CHWE and non-additive extraction processes MFT, using CaO as additive at 0.6 kg-CaO/m³-NST dosages, were at about 48% and 54% solids contents respectively. These findings indicate that CHWE process disperses silt-clay size particles more than non-additive extraction process, and produces tailings with poor geotechnical properties, which promotes MFT production. However, dispersed clay size particles in CHWE process tailings reacts with Ca²⁺ introduced by CaO addition and produce yield stress in fines-water matrix and prevent segregation, much better than non-additive extraction process tailings.

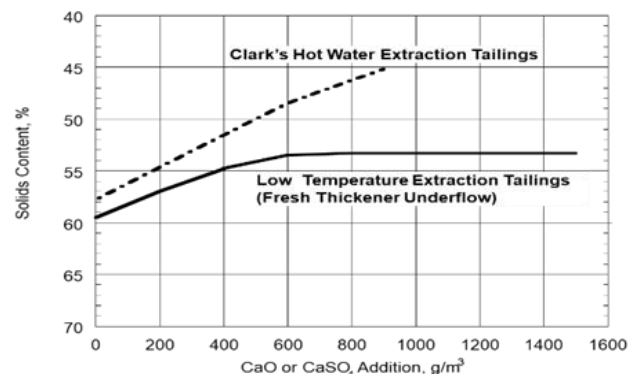


Figure 6. NST with SFR of 4 segregation boundaries using MFT from CHWE and non-additive extraction processes using CaO at 0.6 kg/m³-NST dosages.

These findings suggest that use of CaO as additives in bitumen extraction and/or whole tailing treatment processes could allow oil sands plants to consume larger volumes of the existing MFT (produced by CHWE process) to produce NST. The main challenge to consume more existing MFT for NST production is to maintain high solids contents, at about 40% solids, in Thickener Underflow tailings. This would require the use of high performance thickeners and the use of CaO as additives in extraction process and/or in whole tailings treatment before the cyclones.

It was experimentally observed that NST production using CaO additive reduces Na⁺ concentration in process affected water; most likely by capturing clay particles surrounded with water layer of high Na⁺ content by coagulation of clay particles with Ca²⁺. Adsorption of sodium ions on the newly formed CaCO₃ crystal surfaces (by chemical reactions of Equations 3 and 4) could also cause reduction of Na⁺ in process affected water. For example, NST produced from the Albian Sands Muskeg River Mine tailings material by CaO additive at 0.6 to 0.8 kg/m³-NST dosages, when the plant was operating with non-additive extraction process mode, Na⁺ concentration was reduced from about 130 to 110 mg/L. It was also observed that process water Na⁺ concentration was reduced from 625 to 515 mg/L by NST production from Syncrude Canada Ltd.'s Aurora Mine tailings material, also using CaO at 0.6 to 0.8 kg/m³-NST dosages.

Steady increase in process water Na^+ concentration detrimentally affects performance of NST production, because of increase in SAR in the process water. Recent NST production tests made at our laboratory on selected oil sands tailings samples showed that, about 50% to 120% more CaO dosages are needed to produce NST compared to that of the dosages required about over a decade ago.

In summary, disposal of oil sands tailings effluent as NST material reduces-eliminates the steady increase in the existing MFT inventory. Use of CaO as additive to produce NST provides additional advantages; improves process water chemistry by reducing bicarbonates (reduces scaling in process vessels and pipes) and Na^+ concentration in process water. Our research findings suggest that NST production using CaO additive offers great advantages to oil sands tailings disposal practices, especially when it could be implemented in coupled with the use of CaO as additives in bitumen extraction and whole tailings treatment processes.

2.4 Whole Tailings Treatment with CaO

Over four decades, treatment of the whole tailings with CaO , CaO & polymeric flocculants or CaO & CO_2 , has been considered to reduce oil sands tailings disposal operating costs and to minimize the environmental impacts of oil sands plants (Ozum et al. 2004; Hamza et al. 1996; Kessick 1983; Lane 1983). Advantages of treating the whole tailings with lime are that it coagulates clay size particles, improves settling characteristics of tailings material and Cyclone Overflow tailings in thickeners, promotes fines captured in the sands by producing nonsegregating tailings material and releases alkali $NaOH$ into the recyclable process water, by the ion exchange reactions between the Na -Clay and Ca^{2+} (Equation 6).

Our research was focused on the whole tailings treatment with CaO before cyclones and optionally removing the residual bitumen trapped in the whole tailings by flotation process (Romaniuk et al. 2015). It was observed that treatment of MFT with CaO at about 13 mmol- $Ca(OH)_2$ /kg-NST dosages destabilizes bitumen-in-water emulsions, by which bitumen removal from MFT could be made by the flotation process. It is expected that treatment of the whole tailings with CaO at about 1.0 to 1.5 kg- CaO /m³-tailings could promote removal of residual bitumen from the whole tailings before its deposition as is or after production of NST, process schematics of which is presented Figure 7. Whole tailings treatment with CaO and recycling the Cyclone Overflow to the extraction process would reduce the use of $NaOH$ in the extraction process; which would provide additional process advantages as discussed in Sections 2-1 to 2-3.

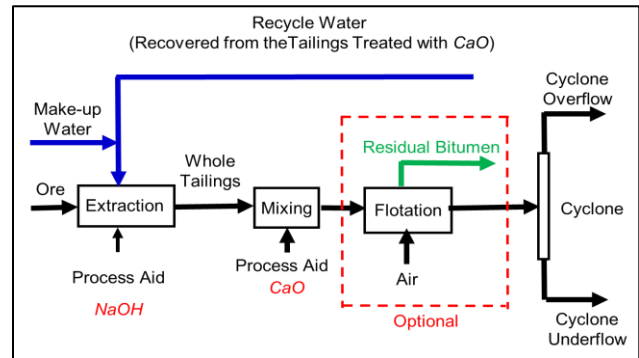


Figure 7. Whole tailings treatment with CaO before Cyclones.

In a recent study at our laboratory, a tailings material composed of 43% solids with 73% fines (SFR of about 0.37) and 0.34% residual bitumen was treated with CaO at and over 1,000 ppm (mass of whole tailings) dosages. This tailings material was stable like MFT (33% solids with over 98% fines); however, the composition of the material suggested that it represents a typical thickened cyclone underflow tailings material. Since sand contained in the whole tailings is not reactive, treatment of this material with CaO could provide information on the treatment of the whole tailings with CaO .

Dispersed and non-disperse hydrometer tests were made on -325-mesh sieve (<45 μ m) fraction of the tailings material by using a typical process affected water using the process water the tailings material. The results of the hydrometer test are provided in Figure 8.

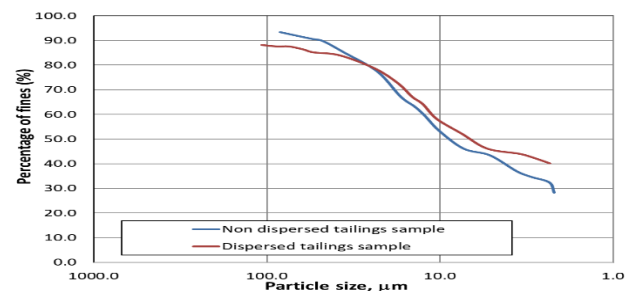


Figure 8. Dispersed and non-dispersed hydrometer tests results (tailings material of 43% with 73% fines).

The results in Figure 8 show that the distribution of fine particles was almost similar in both dispersed and non-dispersed tailings samples. That indicates that the use of $NaOH$ as an extraction process additive promotes dispersion of silt-clay size clay size particles in the extraction process slurry.

An attempt was made to perform a non-dispersive hydrometer tests on the tailing material treated with CaO at 1,000 g- CaO /kg-tailings (1,000 ppm on mass of tailings) dosage. A 51.49 g of -325 mesh solids of the tailings material treated with CaO at 1,000 g- CaO /kg-tailings dosage and process water was used in this test. Phase separation was observed within an hour of the tests, as

shown in Figure 9, and hydrometer test could not be made. Another test was conducted with less solids, 40.07g -325 mesh solids, and nevertheless, phase separation happened immediately. Similar observations were perceived for the samples treated with CaO at over 1,000 ppm (1,000 mg-CaO/kg-tailings by mass) dosages.

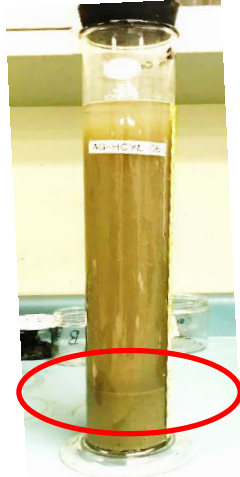


Figure 9. Phase separation of tailings sample treated with 1,000 ppm of CaO.

Experience gained from these hydrometer tests indicates that treatment of the whole tailings with CaO would improve settling characteristics of the whole tailings by facilitating the coagulation-flocculation of silt-clay size particles.

2.5 MFT Dewatering with CaO Additive

Our research findings on treating different oil sands tailings materials with CaO suggest that any MFT dewatering process, including centrifuging and pressure filtering processes, should be implemented after treating the MFT with CaO in the first place (Tate et al. 2017). Our research is focused on in-situ treatment of MFT with CaO followed by capping with sand or NST. Our research is also focused on two stage dewatering of MFT ponds; treating the water layer with CaO at about 0.5 to 1.0 kg-CaO/ton-water dosages and recycling it to the extraction plant, followed by treating the MFT layer with CaO at or over 1,0 kg-CaO/ton-MFT dosage and blending it with overburden soils. Further research of these MFT dewatering options are planned for the future of our research programs.

3 CONCLUSIONS

Existing environmental and long-term sustainability challenges of the oil sands plants could be alleviated by using CaO as additives for bitumen extraction, NST production, whole tailings treatment and MFT dewatering processes. Experience gained from commercial operations and research studies could be used for the design, commission and execution of field trials successfully before commercial implementation of these processes.

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5 TABLES

Table 1. Comparison of bitumen extraction efficiency using NaOH and CaO additives (Ozum et al, 2014a).

Lock cycle	Primary Froth				Secondary froth				Total	
	Recovery		S/B		Recovery		S/B		Recovery	
	Additive		Additive		Additive		Additive		Additive	
	NaOH (%)	CaO (%)	NaOH (-)	CaO (-)	NaOH (%)	CaO (%)	NaOH (-)	CaO (-)	NaOH (%)	CaO (%)
1	84.6	89.7	0.21	0.28	7.3	6.2	0.82	0.88	94.5	99.9
2	80.2	89.3	0.25	0.25	7.5	6.1	0.84	0.88	91.9	99.5
3	86.4	87.3	0.19	0.18	6.2	8	0.92	0.8	98.3	99.5

S/B is solids to bitumen ratio

Table 2. Comparison of process affected water chemistry using NaOH and CaO additives (Ozum et al. 2014a).

Water sample	Alkalinity, mg CaCO ₃ /L				Anions, mg/L				Cations, mg/L			
	Total		HCO ₃		Cl		SO ₄ ²⁻		Na ⁺		Ca ²⁺	
	Additive		Additive		Additive		Additive		Additive		Additive	
	NaOH	CaO	NaOH	CaO	NaOH	CaO	NaOH	CaO	NaOH	CaO	NaOH	CaO
APW	394	394	450	450	175	175	93	93	299	299	13.3	13.3
Lock cycle 1	480	371	539	414	175	185	97	106	334	305	3.1	4.7
Lock cycle 2	488	350	537	393	183	187	108	113	366	311	1.9	3.2
Lock cycle 3	521	371	568	412	187	197	115	115	398	357	2.3	3.8

APW: Artificial Process Water