A Novel Technique for Removing Finely Dispersed Particles from Tailings

W. Ware*, N. Ashcraft** and D. Soane*

*Soane Energy LLC, Cambridge, MA, USA, bware@soaneenergy.com
**Soane Mining LLC, Cambridge, MA, USA, nashcraft@soanemining.com

ABSTRACT

Traditional oil, gas, and mining industries rely heavily on the use of water as a means to aid in the recovery of natural resources. Often times these activities, either through mechanical shear or chemical additives, enhance the colloidal suspension of well dispersed, fine materials such as clay, ore, fine sand, and silt. Re-use of the resulting produced water can be difficult unless the suspended solid material is quickly and efficiently removed. A new water treatment technology, ATA™, has been developed that is capable of rapidly separating clays and other fine particulates from waste streams. The process immediately liberates clear water for reuse and aggregates the suspended solids making them well suited for dewatering and disposal. Applications in traditional oil and gas as well as mining markets offer benefits including efficient use of water resources and rapid reclamation of disturbed land.

Keywords: tailings disposal, wastewater treatment, ATA, oil sands, mining, polymers, reclamation, phosphate

1 BACKGROUND

Naturally occurring ores are heterogeneous mixtures of hydrophobic organic molecules and solid inorganic matter. Once the desired extractant (e.g. hydrocarbon or mineral) has been removed, the resulting slurry is known as tailings and generally consists of water with a high degree of finely dispersed clay and other suspended solids in aqueous form together with large particle inorganic solids (e.g. quartz sand). In many cases during processing, colloidal particles, such as clay and mineral fines[1], are formed in the aqueous phase often due to the introduction of mechanical shear associated with the extraction process. In addition to mechanical shear, alkali water and surfactant additives are sometimes added during processing, creating conditions suitable for stabilizing colloidal suspensions.

A common method for disposal of the resulting tailings is to store them in large tailings ponds to allow the solid material to settle out from the water. Often with highly dispersed and well-suspended fines material, it takes years or decades for the solids to settle enough to enable re-use of the water. In addition, there typically exists a layer of loosely packed clay fines that retains moisture. This material will remain a liquid with very low strength for decades and in some cases centuries. Unless treated, this material is not suitable for reclamation to the original landscape.

As a consequence of the fine particulates that retain water, operations often time need to construct large settling areas with long rehabilitation times prior to closure. In many cases, tailings impoundments represent the largest environmental liabilities associated with mining projects both during operation and decommissioning [1]. Ways to mitigate the size and reclamation costs of tailings ponds can provide significant benefits to both the industry and the environment.

The Canadian Athabasca oil sands and the United States phosphate mining industries have operations with large tailing footprints. These markets have been identified as ones that could benefit from new tailings technology.

1.1 Canadian Oil Sands Tailings

The Canadian oil sands contain the third largest oil reserves in the world. Mining operations currently account for about 55% of the oil produced from oil sands. Daily production of oils from the mining operations is roughly 780,000 barrels per day. For every barrel of oil produced, approximately 10 barrels of tailings is produced. While roughly 80-85% of the water in the tailings is re-used, the majority of the fine material settles in the ponds as mature fine tailings (MFT). Once the MFT settles to the bottom of the ponds, it remains as a viscous fluid, at 30-35% solids, for decades. The tailings ponds operations are vast, spanning more than 70 km^2, and will hold as much as 1 billion m^3 of MFT by 2014 [2].

The oil sands tailings ponds have been under public scrutiny for a number of reasons. Primarily, the oil sands oil has become and increasingly larger part of the worlds oil supply and, as a consequence, tailings ponds represent an increasing environmental liability without a clear strategy to rehabilitate the landscape.

New regulatory requirements have been implemented in 2009 that call for the controlled regulation of tailings handling and storage. The regulatory efforts are aimed at minimizing the long term storage of fluid tailings (MFT) by forming strict guidelines on solidifying the fluid tailings each year. Although it is still early in the regulatory cycle, to date, no operator has demonstrated the ability to be compliant. Efforts within the industry to colaborrate on

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[1] Fines are typically defined at particles <75μm in diameter (<44μm in oil sands mining). Coarse material is anything larger.

new tailings technology has recently begun with the aim to speed the introduction of potential solutions.

1.2 United States Phosphate Mining

Phosphate mining is a major industry with over 150 million tons of ore mined throughout the world annually. United States phosphate mining totals around 30 million tons with a majority occurring in central Florida. During phosphate beneficiation, significant quantities of waste clay and sand are generated. The approximate ratio of the extracted ore is 1:1:1 of phosphate to clay to sand. Thus, around 10 million tons of waste clay and sand must be disposed of annually in the U.S. Complicating matters is that the clay waste exists as a dilute slurry, or tailings, at approximately 1-5% solids. Separating out the clay into a high-solids-content, stable mass is difficult and costly, so the current practice of tailings disposal is to store the clay slurry in large tailings ponds [3].

For a typical phosphate mine, around 40% of the area of a mine ends up as tailings ponds, and estimates are that approximately 5,000 acres (20 km^2) of land is annually turned into tailings ponds in central Florida. It can often take decades for the tailings ponds to settle to a point where reclamation can begin, however even then the areas can only be used for very limited applications due to poor stability. Significant pressure exists to reduce or eliminate phosphate tailings, with a recent example being a lawsuit by environmental groups that shut down operations at a major Florida phosphate mine for over a year [4]. Additionally, domestic phosphate mining faces other regulatory and permitting issues due to tailings ponds, while other global phosphate operations suffer from lack of water availability.

2 TECHNOLOGY

A novel technique for tailings treatment has been developed that is capable of rapidly separating clays and other fine particulates from water. The technology, termed ATA (for Anchor-Tether-Activator) process, comprises three basic components: an Anchor particle, a Tether polymer and an Activator polymer. The tailings stream is first split into a fines stream and coarse stream either mechanically, via a hydrocyclone, or by other means. The fines stream is dosed with an Activator polymer, altering surface properties and causing the suspended clay fines to aggregate. The coarse sand serves as the Anchor particle and is coated with a monolayer of Tether polymer. The Tether-bearing Anchor particles exhibit a strong affinity to the Activated clay fines in the tailings. When the two treated streams are recombined, the Tether-bearing Anchor particles self-assemble with the aggregated clay fines in the Activated tailings, forming robust complexes that quickly settle.

Two output streams emerge from the ATA process: a clarified water stream that can be reused in the extraction process, and dewatered solids that possess sufficient mechanical integrity for reclamation. Benefits of the ATA process include: rapid dewatering of tailings, reduction in tailings ponds size, reduced energy consumption due to the recycle water retaining a substantial amount of sensible heat, and solid stream suitable for rapid reclamation.

2.1 How It Works

The key to the ATA technology is the interaction between the Anchor-Tether complex and the Activated fines. The ATA process, shown in Figure 1 below, comprises three components: 1) an Activator polymer that is added to the fine tailings stream; 2) a Tether polymer that has a high affinity for the Activator; and 3) an Anchor particle that is coated with the Tether polymer. First, the Activator is added to the fine tailings causing the fines to aggregate together (Fig.1, Step A). Simultaneously, the Tether polymer is added to the coarse particles, coating the particles with a monolayer and changing their surface behavior (Fig. 1, Step B). When the two streams are combined (Fig. 1, Step C), the Activated fines spontaneously bind to the Tether-Anchor complex creating solid clusters. These clusters can be separated from the water via sedimentation or filtration. If any of the three ATA components (Anchor, Tether, or Activator) is left out, the solids do not settle out to form a stable, non-segregating complex with good drainage properties.

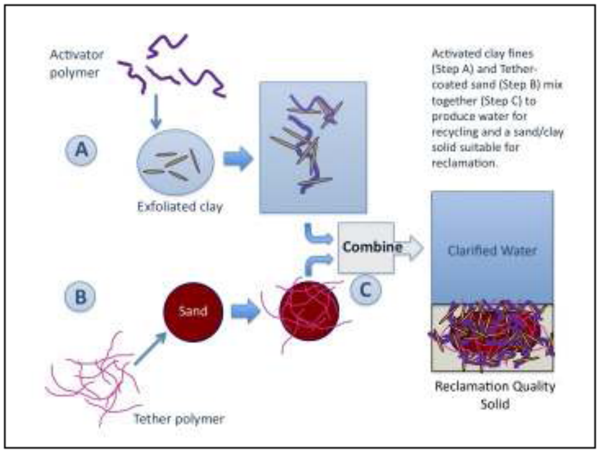

Figure 1. Schematic of the ATA mechanism

The resulting solids have a core/shell type morphology, with the fines material adhering to the surface of each individual coarse particle. This allows the solids to behave as an agglomerate of large particles, rather than as a mixture of fine and coarse particles. The benefits of the ATA architecture can been seen when comparing mixtures of similar material, prepared via the ATA process, and compared with traditional tailings treatments used in industry.

2.2 Comparison with Traditional Tailings Methodologies

Traditional methods to minimize tailings storage volumes and to reduce reclamation time have incorporated a variety of techniques. Approaches can be separated roughly into mixed stream approaches (having coarse and fines streams deposited simultaneously) or separated stream approaches, treating the coarse and fines streams individually and disposing of each separately. Major benefits from a combined stream approach is that the coarse fraction can enhance the strength properties of the resulting solids by acting as a scaffold to create grain to grain interaction while also promoting improved drainage.

Since the coarse fraction often times does not pose disposal issues, a separated stream approach allows for the fines stream to be targeted, which sometimes represents a small fraction of the entire waste stream.

One method to manage tailings used in the Canadian oil sands region is called NST, non-segregating tailings. It involves taking the fines fraction of the tailings and dewatering (or thickening) it with the use of traditional flocculants. Once thickened, the fines are then recombined with the coarse to fines ratio (CFR) of 4 or higher to produce a liquid slurry. The slurry is then pumped to a settling area where the NST is allowed to consolidate and solidify.

In Figure 2, solids were prepared with Canadian Athabasca oil sands tailings in two methods. The sample on the left, labeled "ATA Prep", was prepared as indicated in the discussion above, using a CFR of 4.0 by weight and allowed to gravity dewater to a solids level, 65%, by weight. The sample on the right in Figure 2, "Trad. Prep", was prepared using a traditional wastewater treatment polymer (high molecular weight anionic polyacrylamide) to flocculate the fines stream and decant the clarified water. The dewatered fines were mixed with the appropriate level of coarse to generate the same CFR of 4.0 and solids content of 65%. The latter treatment is known in the Canadian oil sands industry as non-segregating tailings or NST.

It is evident that the materials, although prepared with the same components of tailings material, have distinctly different properties. Typical ATA solids at 65% solids have a vane shear strength of 1000 Pa or higher* [5]. The NST mix on the right has shear strength of only 30 Pa.

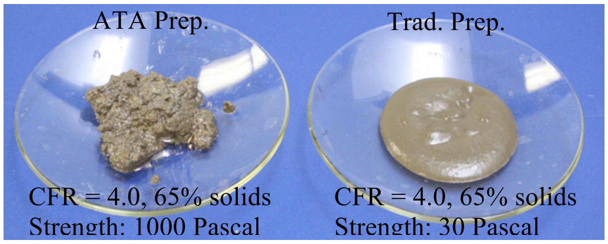

Figure 2. Canadian oil sands tailings prepared via the ATA method compared to NST. The ATA sample has a 33 fold increase in strength.

It is evident from the picture that the ATA solids prepared are rigid and stand on their own, while the NST mixture remains a liquid. Behavior of the ATA solids provides evidence that tailings material using this process can provide alternatives to traditional methodologies to mitigate the challenges posed by increased regulation and environmental concerns.

2.3 Filterability of ATA Prepared Solids

Often it is desirable to produce a solid cake of fine tailings material rather than in a slurry. Solid cake allows for maximum water removal for re-use as well as the ability to have material that is useful for immediate reclamation with high strength.

Because of its unique core/shell morphology, ATA solids are remarkably permeable to water which is evident in its high hydraulic conductivity values and leads them to be readily filterable. Filterability is essential to some proposed dewatering mechanisms for ATA solids. The resistance to filtration (r) is a measure of the ability of a filtrate to pass through a filter medium such as a bed of solids. To determine the r value, the filtration rate is measured experimentally and the inverse of the filtration rate is plotted against the volume of filtrate. The linear portion of this plot can be described by the equation [6]:

$$\frac{t}{V} = \frac{\mu r \omega}{2PA^2} V + \frac{\mu r L_m}{PA}$$

where t is filtration time (s); V is the filtrate volume (m^3); μ is the viscosity of the filtrate (Pa s); ω is the mass of the solids cake per unit filtrate volume (kg/m^3); r is the specific resistance of the filter cake (m/kg); P is the pressure on the top of the filter cake (Pa); A is the filter area (m^2); and L_m is the theoretical thickness of the filter medium. In this type of plot, the slope, b, and intercept, a, are:

$$a = \frac{\mu r L_m}{PA} \qquad b = \frac{\mu r \omega}{2PA^2}$$

At a constant pressure, resistance to filtration (r) can be calculated as:

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* The vane shear test consists of inserting a four-bladed vane in the end of an undisturbed tube sample or remolded sample and rotating it at a constant rate to determine the torque required to cause a cylindrical surface to be sheared by the vane. This torque is then converted to a unit shearing resistance of the cylindrical surface area. (ASTM D 4648)

$$r = \frac{2PA^2}{\mu\omega} b$$

Resistance to filtration for various tailings preparations were measured using samples obtained from Canadian oil sands tailings and compared to reported literature values, see Table 1.

Sample Description	r-value, m/kg
Mature Fine Tailings, MFT	$> 1x10^{13}$
Flocculated fines (no coarse)	$3x10^{10}$
NST, CFR 4.5*	$1x10^{9}$ - $1x10^{10}$
ATA Solids, CFR 4	$1x10^{6}$ - $1x10^{7}$

Table 1: Resistance to filtration (r-value) for oil sands tailings samples.

The results of the filtration study can be interpreted as a reflection of the relative amount of fines available to plug the pores of the filter matrix of the solid. MFT is unadulterated fines material, has the largest proportion of fines of the materials tested, and thus has the highest r-value. In the flocculated fines sample, high molecular weight polymer is used to capture fines material, and thus increase the fines relatives size and reduce the amount of free floating fines, resulting in much lower r-values than MFT. The NST sample is prepared first by flocculating the fines material, followed by introducing the coarse fraction. The additional coarse material both reduces the relative amount of available fines, and also allowing for larger pore sizes in the matrix. However, the fines and coarse factions are still unassociated and smaller aggregates tend to migrate though the coarse fraction. In contrast, the ATA solids aggregate the fines material on the surface of the coarse material. This essentially eliminates the influence of "free" fines by capturing them all on the surface of the larger diameter coarse. Not only does this increase the particle size of the material, but also eliminates the fines ability to block the pore openings, therefore, reducing the resistance to filtration even further.

These results obtained are consistent with Wakeman's findings that filterability is inversely proportional to the square of the particle size and explains the significant increase in resistance to fines content in the samples tested [7].

Filtration of oil sands tailings has been considered in the past [6]. However, to date, commercial implementation has not been achieved due to the difficulty in filtration of the fines heavy tailings streams. Implementation of the ATA process could significantly impact the commercial viability of filtration as a process for tailings.

3 CONCLUSIONS

Some of the he properties of ATA solids produced from mine tailings have been demonstrated here, including: high permeability, increased strength, and good filterability. Other attributes afforded by the ATA process, but not shown due to space constraints, include rapid and clear water liberation, fast consolidation of the ATA solids, and a process that is robust to process fluctuations.

A mine tailings treatment strategy employing an ATA process has the potential to eliminate the need for tailings ponds, thereby reducing a large environmental liability. In addition, where the extraction process is done at elevated temperature, fast separation of the solids from the water allow for the heat energy to be recovered, therefore saving energy and reducing green house gas emissions.

Finally, the ATA process had the potential to dramatically reduce the overall mining footprint. For both Canadian oil sands and the U.S. phosphate industries, the tailings ponds occupy roughly 40% of the mine footprint. By eliminating the tailings ponds, mine sites can significantly reduce construction costs and the level of disturbed area.

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