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Processing of tailings in Canadian oil sands industry①

J. Masliyah
(Department of Chemical and Materials Engineering, University of Alberta,
Edmonton Alberta, Canada, T6G 2G6)

[Abstract] Vast amounts of tailings are produced daily in bitumen extraction from the Athabasca oil sands. The coarse sand from the tailings stream is used to build dykes around the containment basin. The run-off slurry arrives at the water's edge in the tailings pond at a solids concentration of about 3%～8% by mass. Settling of the solids takes place "relatively fast", over several days, creating a "free water zone" that contains little solids. When the fine mineral solids concentration has reached about 15% by mass, the suspension develops non-Newtonian properties. After 2～3 years, the suspension concentration reaches a value of about 30% by mass at which the settling rate becomes extremely slow. Methods to handle the already created tailings ponds and new approaches to eliminate the creation of new ones will be discussed both from the industrial and fundamental prospective.

[Key words] oil sands; tailing; bitumen extraction
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1 INTRODUCTION

Oil sands are also known as tar sands and bituminous sands. They are unconsolidated sand deposits that are impregnated with high molar mass viscous petroleum, normally referred to as bitumen. Oil sands are found throughout the world, usually in the same geographical location as conventional petroleum. The largest deposit in the world is in the Athabasca area in the northeast part of the province of Alberta[1, 2]. The total estimate of bitumen in place in Alberta is 1.3 trillion barrels. The average overburden thickness in the Athabasca area is 25 m with a bitumen saturation of about 10% by mass. The near surface oil sands deposits in the Fort McMurray area have made it possible for the deposit to be recovered using surface mining techniques. However, the fraction of the surface mineable oil sands is rather small, about 10%～15% of the total deposits. Suncor Energy Inc. and Syncrude Canada Ltd. operate commercial surface mining plants for bitumen recovery from the oil sands. Production of bitumen from surface mining by Syncrude and Suncor is about 330 000 bbl/day, which is equivalent to approximately 15% of Canada's conventional oil needs.

2 CHARACTERISTICS OF ATHABASCA OIL SANDS

Typical oil sands consist of a mixture of sand grains, water and bitumen. In the Athabasca deposit, the sand is water-wet[3]. The water-wet sand grains characteristic of the Athabasca deposit is very important as it allows for water-based bitumen extraction methods. However, some deposits in other locations (e.g., Utah, USA deposits) lack the water-wet surface characteristics and therefore, the sand grains are oil-wet. Consequently, for such deposits, a solvent-based extraction method is preferable.

3 EXTRACTION PROCESS: CLACK WATER EXTRACTION(CWE)

Although there are a number of processes for bitumen extraction from oil sands, the Clark Water Extraction (CWE) process, operating at 50～80 ℃ with caustic addition, is used. A general flow diagram of oil sand mining to bitumen upgrading is shown in Fig. 1. Each box in Fig. 1 identifies a unit plant operation. Basically, oil sands are mined and transported to the extraction plant. The bitumen is liberated from the sand grains, either during its transit in a hydrotransport pipeline or in a rotating drum (tumbler) at the extraction plant. The liberated aerated-bitumen is subsequently separated from the sand water slurry in gravity separation vessels and flotation cells. The aerated bitumen floats to the top of the separation vessel to form a bitumen froth which is then de-aerated using steam. The de-aerated bitumen is then diluted with naphtha to reduce its viscosity. Scroll and disc type centrifuges are then used to remove most of the water and solids from the diluted bitumen.

The solvent (naphtha) is then removed using diluent recovery towers. The recovered naphtha is recycled and re-used with fresh de-aerated bitumen. The solvent-free bitumen that contains some solids residual is then sent to upgrading. The solids and water from the gravity separation vessel are fed to tailings ponds.

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4 TAILINGS DISPOSAL

The tailings from the separation vessel and flotation cells (Extraction box of Fig. 1) are combined to form the final tailings slurry stream. They are mainly solids, with a particle size range of 0.1 to 300 μm, and water with small residual quantities of bitumen. One can think of the final tailings stream as a warm aqueous suspension of sand, silt, clay, residual bitumen, salts, surfactants and naphtha at a pH between 8 and 9.

The final tailings stream is pumped to large tailings ponds, where the coarse solids settle out very rapidly to form dykes and beaches. Much of the fines and residual bitumen are carried in the run-off slurry that flows over the already formed beach. The run-off slurry stream arrives at the water's edge in the tailings pond at a solids concentration of about 3% ~ 8% by mass. Settling of the solids takes place "relatively fast", over several days, creating a "free water zone" that contains little solids (see Fig. 2). Below the free water zone, solids settling continues to take place within the fine tails zone. However, after the initial rapid settling during the first few days, when the fine mineral solids concentration has reached a value of about 15% by mass, the suspension develops non-Newtonian properties and has the consistency of yogurt. After 2~ 3 years, when the suspension solids concentration reaches the level of 30% by mass, it is normally referred to as "mature fine tails" (MFT). It has very high viscosity with high yield stress. Further, de-watering occurs very slowly and it takes several centuries for the MFT to reach the consistency of soft soils[4].

The inventories of the densified fines suspensions have been accumulating during the last several

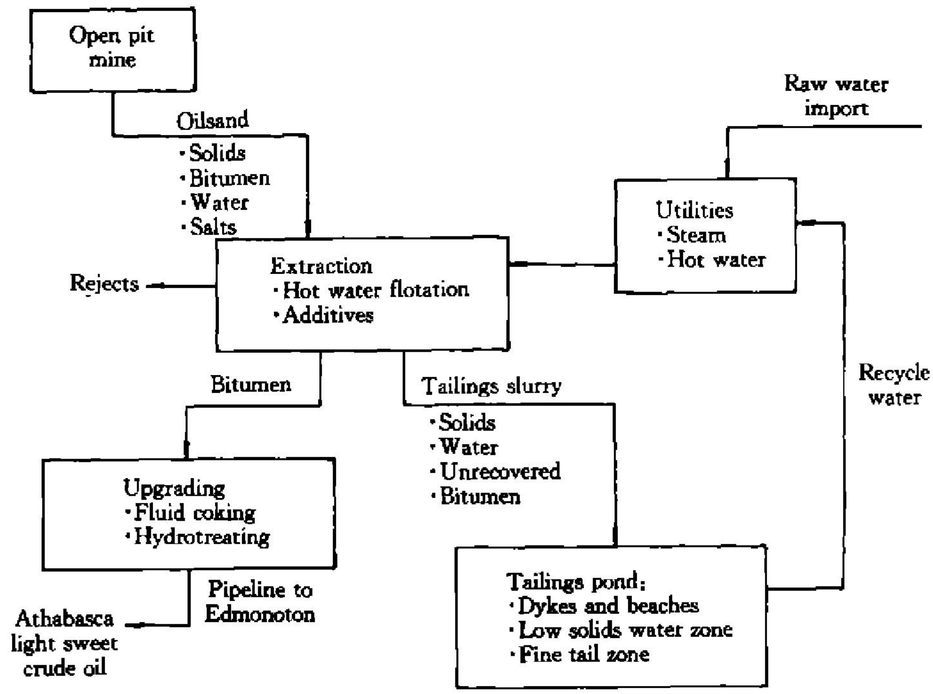

Fig. 1 Schematic of oil sands bitumen recovery process

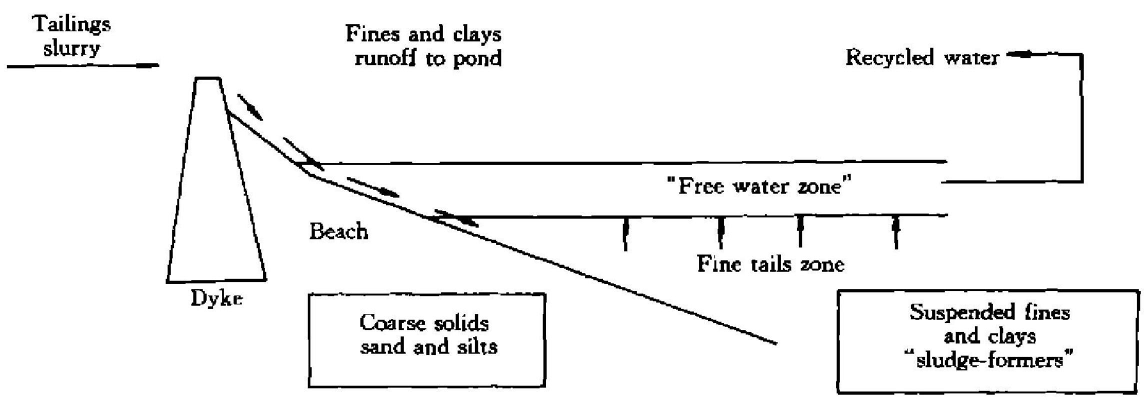

Fig. 2 Tailings pond in oil sands operation

decades. Fig. 3 shows the fine tails volume change with time for Syncrude's plant. Clearly, the confined volumes are very large and continue to increase. In addition to the slow settling solids contained in the fine tails, the water in the fine tails contains a large number of organic compounds, such as naphthenic acids and sulphonates which are derived from the bitumen during the extraction process. The naphthenic acids are responsible for the water toxicity. As well, the water contains a large number of electrolyte species, such as Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+} and Na^+. In brief, the fine tails are highly toxic. Fine tails management poses a challenge to environmentalists, scientists and engineers.

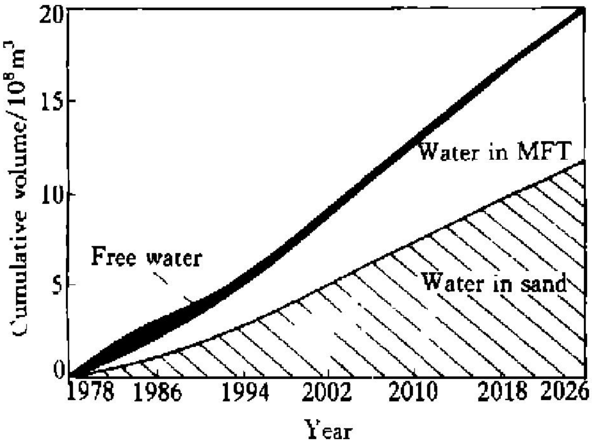

Fig. 3 Cumulative volume of tails produced by Syncrude plant[5]

Major efforts are presently being made to reclaim the fine tailing ponds using new emerging technologies, namely, consolidated tailings technology and paste technology.

4.1 Treatment of fine tails with calcium sulfate (gypsum)

The addition of divalent ions can lead to aggregation of fines due to the collapse of the electric double layer and the decrease of surface charge. A pictorial view of the role of water chemistry on fines aggregation is shown in Fig. 4.

From the point of making recycled water available in a relatively short time, the use of gypsum as a source for divalent ions is very encouraging and it forms the key component in a consolidated tailings process that is being considered by Suncor and Syncrude to treat fine tails already produced and in future operations. Over the last several years, a large number of tests were conducted to investigate the effects of combining mature fine tails (MFT) with coarse solids in the presence of Ca^{2+} on the settling and consolidation characteristics of the final "tails". As was pointed out earlier, once the fine tails settle to a level of about 30% by mass (to produce mature fine tails, MFT), the settling or the consolidating process becomes very slow.

This is simply because the MFT develops a yield stress at the higher solids concentration. In other words, stress or a load has to be applied to the MFT before it can consolidate any further. This situation is similar to a sponge that has its own solids inter-linkage and voids. It will only compress when a load is applied to it. The addition of Ca^{2+} tends to aggregate the fines (clays) and the addition of the coarse solids acts as the "load" on the aggregated clays or fines. The combination of calcium addition and coarse solids enhances clear water generation and sediment consolidation.

The process of MFT and coarse solids addition is referred to as composite tailings (CT) by Syncrude, consolidated tailings (CT) by Suncor, or non-segregating tailings (NST). The term "non-segregating tailings" simply means that when MFT is added to coarse solids, the solids do not settle out of the MFT. The coarse solids become entrapped within the MFT structure and the fines, together with the coarse solids, settle as one unit. Conversely, segregating tailings would mean that, upon the addition of the coarse solids to the MFT, the coarse solids will settle out of the MFT, leading to a settled consolidated coarse solids sediment with MFT at the top of the coarse solids layer. The MFT would consolidate as if the coarse solids were not added to begin with.

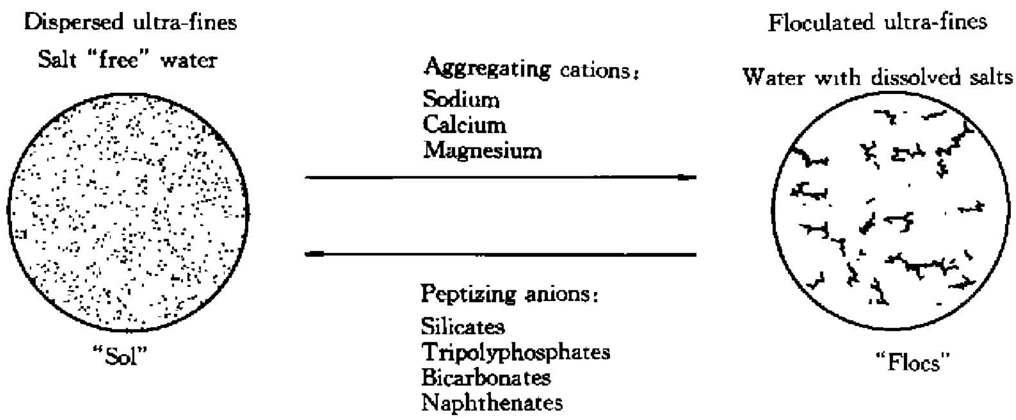

Fig. 4 Effect of water chemistry on ultra-fines aggregation

Lord[①] indicated that, at the appropriate Ca^{2+} dosage, non-segregation characteristics can be obtained only when the final slurry obtained from solids addition to the MFT has a given percent of fines in the solids. Fig. 5 shows the regions of segregating and non-segregating slurries. For example, a slurry containing 62% total solids and 25% fines(< 44 μm) in the solids, the slurry is of the non-segregating type. Here all the solids settle and consolidate as one unit, thereby producing quick water release and high solids content in the consolidated sediment. However, a slurry containing say 45% and less than 20% fines in the solids would not have a non-segregating characteristic. In order for the non-segregating tailings concept to be effective, it becomes necessary to combine high solids stream with the MFT in order to produce a non-segregating slurry. To that end, the flow chart shown in Fig. 6 becomes appropriate in a commercial operation. The combined tails stream with solids content of about 50% by mass is first fed to a hydrocyclone. The overflow stream contains little coarse solids and it is further processed to recover any bitumen in the stream. The underflow stream from the hydrocyclone has most of the coarse solids of the feed stream and it contains about 72% by mass of solids. This stream is combined with MFT (that is pumped out of the tailing basins) together with gypsum. The final slurry stream contains 62% solids by mass and is pumped to a settling basin. Clarified water ready for recycle is formed within a few days. After 30 days, a consolidated sediment having about 82% solids by mass is formed. The sediment is fairly consolidated and acts as "solid earth". The use of this technology helps to reduce the volume of the present tailing ponds.

4.2 Paste technology

A new technology is emerging from efforts made by the oil sands operators for the disposal of fine tails

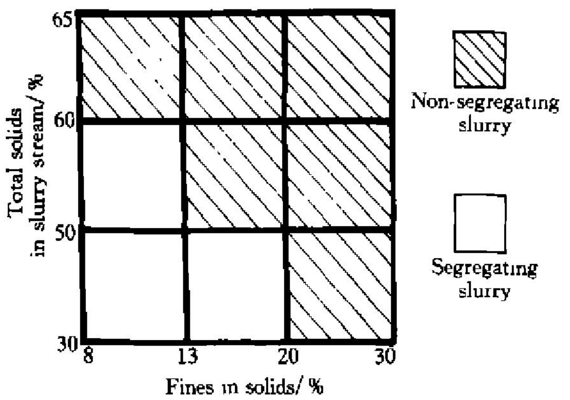

Fig. 5 Regions of segregation for a slurry (Courtesy of Ted Lord, Syncrude)

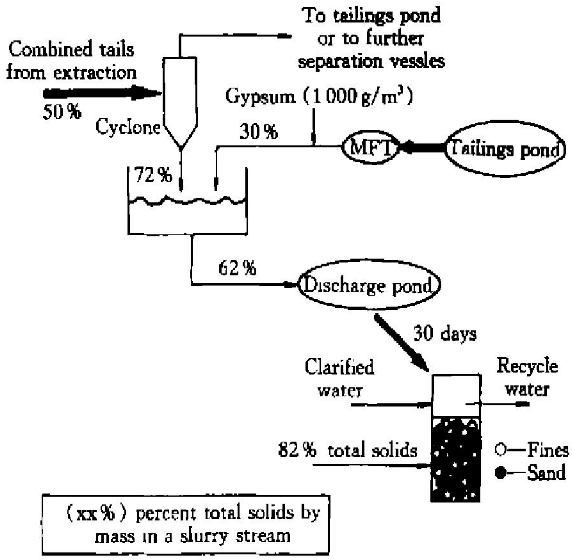

Fig. 6 Process flow for non-segregating tailings: production of recycle water and fine tails consolidation (Courtesy of Ted Lord, Syncrude)

from oil sand processing using what is known as paste technology. Although paste technology does not address a remedy for existing mature fine tails, it offers a possible solution for treating fine tails arising from present and future oil sand processing.

Through studies conducted by Cymerman and Lord during 1996-1999, it was established that high molecular mass, medium charge anionic co-polymers of acrylamide and acrylates can lead to some flocculation of the fine tails derived from the extraction streams, e.g. tailing streams from the centrifuges and flotation cells. At a pH of about 8.5, for example Percol 727 (manufactured by Ciba Specialty Chemicals) was found to be very effective in flocculating the fine tails streams whereby producing fast settling flocs but with a turbid supernatant water layer containing about 1.5% solids by mass. Fig. 7 shows results obtained by Cymerman et al[6] for the settling rates of the flocculated fine solids under different polymer dosage. Clearly, Percol 727 gives the highest settling rate for the flocs at a concentration of 15 mg/L. The ability of the above mentioned flocculants to produce a clear overflow stream and a high solids content underflow stream is dependent on the ratio of

$$\frac{\text{Fines}}{\text{Fines+ Water}}$$

and on the fine tails pH.

4.3 Fundamental research on paste technology

Polyelectrolyte mediated interactions are of fundamental importance and have many practical implica-

① Lord T. Private communications. Syncrude Canada Ltd. (1998)

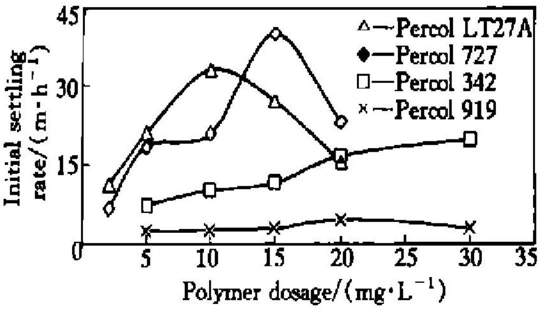

Fig. 7 Variation of initial settling velocity of fine solids flocs with polymer dosage (Courtesy of George Cymerman, Syncrude Canada Ltd., Cymerman et al(1999))

tions. In industrial applications, polyelectrolyte mediated interactions are important in many flocculation and stabilization processes, for instance, polyelectrolyte assisted dewatering, flocculation of fine oil sand tails, flocculation of coal tailings, colloidal stabilization and destabilization, etc. In such situations, the ionic macromolecules are used to tune surface interactions, which are strongly dependent upon various parameters such as adsorbed layer conformation and surface coverage. For instance, low surface coverage with loops and tails extending far from the surfaces can give rise to long range attractive bridging force which promotes the flocculation process. Conversely, high surface coverage and osmotically stretched adsorbed layers can give long range electro-steric repulsive force leading to stabilization of systems. Several surface force measurements established the effects of both low and high polyelectrolyte adsorption densities on surface interactions.

We have measured forces between two mica surfaces in an aqueous solution containing 3 mmol/L $MgCl_2$ and 10×10^{-6} PAA at pH= 8.0~ 9.0 using the interferometric Surface Forces Apparatus. The results are shown in Fig. 8. Schematics show the loops and tails of adsorbed polymer chains interacting with surface sites (denoted by A) as well as the adsorbed layer structure at close distance of separation (denoted by B). A long range attraction is present at distances below 500 Å The surfaces can be approached up to about 23 Å from mica-mica contact. The obtained force profile clearly suggests adsorption of PAA, and this adsorption is sufficient to alter the mica-mica surface interactions. In contrast, the attractive force regime vanishes and the overall forces become repulsive when the PAA concentration is increased from 10×10^{-6} to 50×10^{-6}, as shown in Fig. 8. These results illustrate very clearly as to why the settling rates are concentration dependent as was shown on Fig. 7. Such fundamental study assists to a very large extend in the decision making on what polyelectrolytes to use

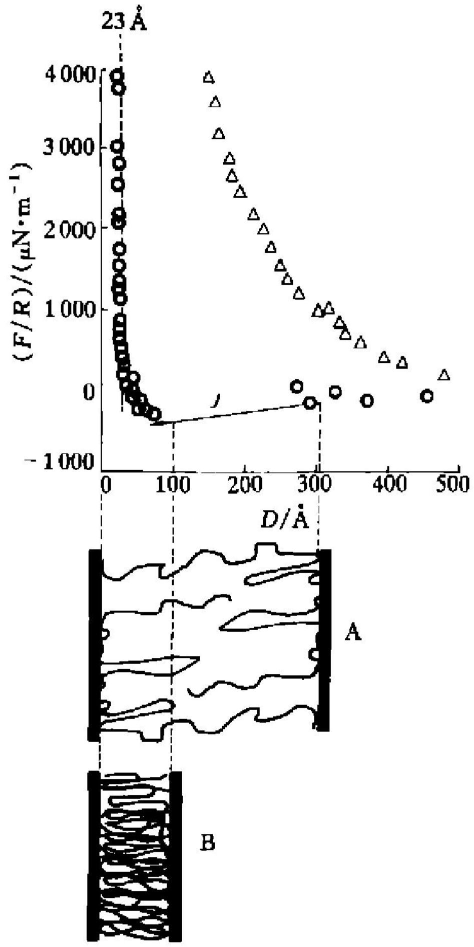

Fig. 8 Normalized interaction forces (F/R) as a function of distance (D) measured between mica surfaces across 3 mmol/L $MgCl_2$ salt solution at pH 8.0~ 9.0 in presence of polyelectrolyte, PAA (Abraham et al. Submitted for publication, 2001)
○—10×10^{-6} PAA; △—50×10^{-6} PAA

in the paste technology.

Research efforts are continuing to improve water utilization and to ensure complete water recycle.

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