PETROLEUM SOCIETY
CANADIAN INSTITUTE OF MINING, METALLURGY & PETROLEUM

PAPER 2008-097

CANADIAN INTERNATIONAL
PETROLEUM CONFERENCE

Water Use in Bitumen Production: Tailings Management in Surface Mined Oil Sands

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This paper is to be presented at the Canadian International Petroleum Conference/SPE Gas Technology Symposium 2008 Joint Conference (the Petroleum Society's 59th Annual Technical Meeting), Calgary, Alberta, Canada, 17-19 June 2008. Discussion of this paper is invited and may be presented at the meeting if filed in writing with the technical program chairman prior to the conclusion of the meeting. This paper and any discussion filed will be considered for publication in Petroleum Society journals. Publication rights are reserved. This is a pre-print and subject to correction.

Abstract

Approximately 12 barrels of water are used for the production of each barrel of bitumen in surface mined oil sands operations. Typically, about 70% of this water is recycled, leaving a net trade of about 4 barrels of water per barrel of bitumen production. This water is tied up in the pore spaces of the mineral sand, silt, and clay left after the bitumen is extracted from the oil sands. The sand component of the mineral tailings is a relatively straightforward reclamation problem due to the relative ease with which strength can be developed in the sand tailings. The silt and clay component which forms the fluid fine tailings, or mature fine tailings, is usually contained behind large dikes and at 30 to 50% solids, even after 40 years, this material does not have enough strength to support the overburden or soil horizon replacement required for reclamation. Currently the lowest cost reclamation option is the long term storage of the mature fine tailings under a water cap in an end pit lake. This so-called wet landscape reclamation has several unknown long term monitoring liabilities, aside from the difficulties inherent in the creation of an artificial lake above the mature fine tailings. Some of the tailings management options which would lead to a dry stackable tailings naturally also significantly decrease the barrels of water lost with each barrel of bitumen production. These options are discussed along with an analysis of their impact on recycle water quality and quantity.

Introduction

Tailings management in surface mined oil sands is a very complex endeavor (1). In order to appreciate the impact of various tailings management options, it is possible to apply several simplifying assumptions. In this discussion, the tailings management options and their impact on recycle water chemistry will necessarily have to be simplified, and where possible, the shortcomings of these simplifications will be noted.

In general, there are three oil sands tailings streams. These are the coarse tailings from the primary bitumen separation step, the fine tailings from the secondary and/or tertiary bitumen recovery step, and the froth treatment tailings. Solvent addition to the bitumen froth reduces the viscosity and allows for the removal of the froth minerals. The resulting froth treatment tailings are particularly important because of the environmental impact of the residual solvent or diluent. In terms of their contribution to the total tailings volume, however, they represent a relatively minor stream(2,3). .

Surface mined oil sands convention defines sand as the mineral fraction greater than 44 microns and the fines as the mineral fraction less than 44 microns. The coarse tailings are predominantly made up of the sand fraction, and the fine tailings are predominantly made up of fines. It has been demonstrated that it is the clay fraction, as a size and mineral that defines the tailings properties, and in particular the tailings volume and water holding capacity. For comparison purposes, however, one can discuss the fines fraction, with the underlying assumption that the clay to fines ratio is 0.5.

Results and Discussion

Figure 1 shows a bar graph with the tailings stream volumes associated with a conventional tailings management strategy, common until the mid 90's with the coarse tailings used to contain the fluid fine tailings. For the purposes of this, and the following examples, the froth treatment tailings have simply been added to the coarse and fine tailings volumes. In this example, we have assumed an average coarse sand solids content of about 80%. In reality, the coarse sand is used for dike construction to contain the fluid fine tailings , and would have components with relatively low solids content (sand below the water line) and with relatively high solids content (sand or beach above water). For simplicity, this complexity is hidden in the average expressed in Figure 1. The fluid fines is assumed to densify to an average solids content of 35%. These assumptions are typical of those found in many oil sands planning submissions.

Figure 1 shows that for each volume of bitumen produced, over four volumes of water are lost to the pore spaces in the sand and in the fluid fine (at 35% solids, mature fine) tailings. The slow settling rate of the fluid fine tailings and the accumulation of the resulting mature fine tailings, results in the requirement for large tailings and recycle water containment areas. Tailings management is essentially about water management, and any tailings technology or process that changes the tailings solids content will also reduce the amount of water lost per barrel of bitumen production.

Prior to 1989, the best available technology to deal with the accumulated mature fine tailings was to transfer it from the recycle water/tailings pond into the mined out area and cover it with a layer of water. This so-called wet landscape reclamation proposed to create an artificial lake over several million cubic meters of accumulated mature fine tailings.

The Fine Tailings Fundamentals Consortium, created in 1989 to investigate alternatives to the wet landscape reclamation, led to the development of several tailings management options, and in the years since its conclusion, has prompted the industry to develop many other tailings dewatering strategies(4). Most significant of these options is the consolidated tailings treatment process commercialized by Suncor in 1994 (5). The following sections briefly discuss, on a conceptual level, several tailings management alternatives to wet landscape reclamation.

Consolidated, Composite, or Non-Segregating Tailings

A simple way to consider the consolidated tailings process is that it is a method by which the mature fine tailings can replace the water found in the sand tailings. The volume of water previously occupying the sand pore spaces is then available for reuse in the extraction process. This is achieved by developing enough strength in the mature or fluid fine tailings so that the mixture can support a sand content from 3 to 5 times the fines content in the mix(6,7). The presence of the sand results in consolidation of the mixture, resulting in a consolidated mix in excess of 80% solids. At this point, the tailings will have enough strength to support a sand cap, and ultimately can be reclaimed with replacement of the overburden and the original soil horizons.

There are many additive options that can achieve the required strength change in the mature, or fluid fine tailings so that it can support the sand fraction. Suncor has implemented this process using gypsum as the additive to manipulate the fluid fine tailings strength (8). Other process aid options include carbon dioxide, lime, acid and lime, and polymers. Tailings management options known as composite tailings, or non-segregating tailings are simply alternative names for the same basic process, with perhaps some modification to the sand to fines ratio, solids content, or chemical additive used. The impact on the recycle water chemistry will be a function of the choice of additives.

Figure 2 shows the water recycle volume consequences of a typical implementation strategy for the consolidated tailings (CT) process, following the template in Figure 1. This shows that if it were possible to implement the CT process on all of the available fluid fine tailings, the net water lost to tailings per volume of bitumen production would be reduced from four to three. It could be possible to implement the CT process to deal with the accumulated mature fine tailings, or to create an MFT analogue with a thickener on the fluid fine tailings stream, and thereby prevent accumulation of the MFT in the first place.

The advantage of the CT process is that initially, the CT mixture is an easily transported, pumpable slurry. This advantage is at the same time its greatest drawback since until it has consolidated and developed significant strength, the mixture will still require fluid containment. Since the fluid containment is often constructed from the sand component of the tailings, the balance of sand availability for dike construction and the sand requirement for CT production is often at odds.

In the case where CT is produced using accumulated MFT, the sand component usually is sourced directly from the extraction operation. This direct coupling of the tailings management to the extraction process can cause control problems for the tailings process since extraction operations will always take precedence. For a CT/NST process that proposes to create an MFT analogue from a thickener underflow, there would be two of the three CT requirements closely coupled to the extraction process, making tailings process control even more challenging.

Sand Dewatering

Dewatering of the sand component can be achieved to varying degrees depending upon the proposed technology. Options might include high density cycloning, sand screws, or direct filtration (9-11). If the sand solids content can be increased to 90% by weight, then implementation of this option, regardless of the methodology would also result in a reduction in the barrels of water per barrel of bitumen by approximately 25%.

MFT Drying/Dewatering

Depending upon the available area, it could be possible to simply dry the MFT in order to create a solid substrate for reclamation (12). Figure 3 shows the significant difference in drying with and without a lime/gypsum (calcium hydroxide/calcium sulphate) additive. The accompanying micrograph shows how the additive disrupts the continuity of the bitumen film, thereby increasing the evaporation rate for the treated MFT drying samples. Implementation of an MFT drying process would require a significant area, along with the capability of depositing relatively thin lifts of treated MFT at intervals corresponding to the evaporation rate. Small pilot scale testing of this concept at Suncor has been successful and is continuing in 2008. It was found that enough strength has to be imparted to the MFT to enable it to maintain a slope. This is to ensure that rainfall will run off and not impede the evaporative dewatering. The run-off water chemistry is shown in Table 1, and in can be noted that the dried MFT samples result in a run off water that has lower dissolved solids compared to the original pore water. This is due to the less permeable nature of the treated and dried MFT. Polymers can be used to create some strength in the MFT mixture, and they will not have the impact on water chemistry that an inorganic additive would have. Of note, however, is the relatively low pH of the gypsum and lime treated MFT compared to the ru off water from the untreated or polymer MFT's.

Table 1 shows that the polymer treated dry MFT has a significantly greater propensity to re-adsorb any rainfall. The resulting effect on the long term properties of a dried MFT deposit created with a polymer are not known.

MFT dewatering, as opposed to drying, on the other hand, could significantly improve the water use and tailings volume management since the water would not be lost to evaporation, but retained for recycle in the extraction process. Although it has been demonstrated that MFT can be successfully dewatered using centrifugation, further work to define the optimum conditions has yet to be carried out. The optimum will most likely be at a particle size less than 44 micron that would allow for efficient cycloning and stacking of the coarse tailings, and at the same time reduce the volume of the fine tailings stream that would need to be centrifuged.

Water Chemistry Implications of the Tailings Management Options

The oil sands extraction process requires an elevated temperature, mechanical energy, and the appropriate water chemistry in order to achieve the high recoveries mandated by the current regulations. Although there is some debate as to the level of dissolved salts or total divalent ions that might impact the extraction process, there is no debate that at some point an increase in either or both will reduce recovery of bitumen. With the current policy of zero discharge of water to the environment, the extraction recycle water chemistry will inevitably increase to equal the dissolved ions in the connate water from the ore, diluted by the make up water. When one adds the impact of process aids, either for extraction, or to create the various dry tailings options, the total dissolved ions, and therefore the likelihood of an impact on extraction goes up proportionally (13-16).

For many ions, there can be charge exchange or other chemical and biological processes occurring which can alter the water chemistry. These processes are further complicated by separation of various water streams in the complex water and tailings management in a typical oil sands mining, extraction, and upgrading operation. If one looks at the operation as a whole, however, one can still quickly assess the broad water chemistry aspects of any of the dry stackable tailings options. In the simple example shown in Figure 1, the ratio of make up water to connate water is approximately 8 to 1. If we consider the chloride ion which does not undergo any chemical or physical processes which would remove it from the water supply, we can easily calculate that for a connate water with 2000ppm Cl, we would, over time have a recycle water Cl concentration of 250ppm.

Table 2 shows the relative reduction in make up water required for the series of tailings management options discussed earlier. Note that these are a function of the fines (clay) content in the ore. The last column shows the relative increase in Cl content for a given tailings treatment option. In general, the creation of a dry stackable tailings would require a reduction in the water lost to produce a barrel of bitumen from about four to about two. For an oil sands with 10% bitumen and 5% connate water, decreasing the amount of make up water required will increase the ionic strength by the same proportion. Any increase in ionic strength would be further magnified for operations which use process aids that alter the water chemistry.

Summary

One can appreciate from the previous discussion that optimizing water recycle volumes degrades water quality, possibly to the point where bitumen extraction is not feasible. Clearly, this would require water treatment of some sort to remove ions that are interfering with the extraction process. Although many technologies are available, most are expensive and not necessarily completely proven in the hydrocarbon-contaminated oil sands processing water. Basically, two approaches are available for controlling water quality in the extraction process. One is to treat the ionic components in the water to preserve an appropriate extraction process water quality while maintaining zero liquid discharge. The other is to treat the organic components in the water to remove toxicity, and then to discharge a certain volume of water back to the river, making it up with fresh water. Such a scheme would increase the ionic load on the river only negligibly, but would allow the extraction process to maintain a suitable chemistry that would not only make the extraction process indefinitely sustainable, but would also facilitate final site reclamation

No discharge criteria exist for oil sands process water, and the current zero discharge policy adopted by the operating companies technically precludes the option of discharging even detoxified process water. As a result, even treated water is unlikely to be acceptable for discharge to the river. The argument that if the water is good enough for the river, it should be good enough for the extraction process, is a difficult one to overcome. At the end, however, the discharge of water to the river has to be weighed against the long-term consequences of landfilling with materials that contain large volumes of salt removed from process water, and on the multiplied difficulty of managing reclamation water chemistry after mine closure. Notwithstanding the potential case for discharge of non-toxic water to the river in order to maintain a reasonable ionic strength in the recycled process water, this option would remove the natural surfactants that accumulate in the recycle water along with the inorganic ions. The importance of these in maintaining extraction recovery should not be underestimated.

There are water quality advantages to a steady, relatively small discharge to the river, both for the extraction process, as well as for the final reclamation water chemistry, and the resulting environmental impact at reclamation. Clearly more research is needed to fully understand these options. Ultimately, however, it will not necessarily be technological arguments, but public opinion that determine the optimal water use strategy in oil sands development.

Significant improvements in water utilization have occurred in the last several years in surface mined oil sands bitumen extraction, most notably with the implementation of the CT process. A major driving force in the use of water for extraction is the efficiency with which materials can be transported in a slurry form. As the costs of handling tailings in the conventional manner becomes clearer, further improvements will be made which will in turn reduce water storage requirements. These improvements will likely take the form of mine face sand rejection, and/or more aggressive chemical treatment of the tailings, along with combination of the fines and clays with the sand to allow for continuous reclamation behind the mining operation. Development of sand filtering or stacking technologies will further improve tailings properties and further reduce the amount of water required per unit of bitumen. At the same time, these technologies will minimize the land disturbance and resource sterilization that sometimes accompanies the use of large-scale tailings/water containment and recycle storage.

Meanwhile, strategies to minimize fresh water consumption will drive water chemistries to the point where extraction recovery is impaired. This will require treatment, either to remove toxicity due to organic contaminants and allow for discharge to the river, or to remove inorganic ions as a landfill solid while maintaining all of the water on the site (zero liquid discharge). Since the organic contaminants responsible for toxicity are also responsible for improving recovery, there is merit in removing inorganic ions and keeping the water on-site. However, these same organic constituents interfere with most of the processes that remove ions from the water. Although the future of tailings management is moving steadily towards dry landscape reclamation as opposed to the water capping of many millions of cubic meters of MFT, this trend will also inevitably lead to some consideration of water treatment to maintain appropriate extraction water chemistry.

Acknowledgement

The authors would like to thank PERD, the panel for energy research and development for financial support.

Nomenclature

MFT	=	Mature Fine Tailings
TFT	=	Thickened Fine Tailings
NST	=	Non-Segregating Tailings
CT	=	Consolidated or Composite Tailings
t/h	=	tonnes per hour

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Sample	Water absorbed in 40kg water rain test	Cl in pore water before drying	Cl in run off water	Ca in pore water before drying	Ca in run off water	pH in pore water before drying	pH in run off water
MFT Control	12.0	333	224	15	2	8.33	9.79
MFT 300g/t polymer	13.9	333	337	15	14	8.33	9.75
MFT 0.25%Lime and 0.25% Gypsum	11.0	333	263	261	91	10.94	8.15

TABLE 1. Run off water chemistry and run off water volumes for the treated and untreated MFT. All concentrations are in mg/L. The run off water test used 39.8kg of water in a simulated rainfall experiment.

		Treatment results		
Tailings Treatment	Ore Type	Volume water lost per volume bitumen produced	% saved water	relative chloride ion concentration
No Treatment	15% Fines	4.5		1.0
No Treatment	10% Fines	3.7		1.0
No Treatment	5% Fines	2.9		1.0
CT	15% Fines	3.1	40%	1.5
CT	10% Fines	2.9	32%	1.3
CT	5% Fines	2.7	20%	1.1
Sand Filtration	15% Fines	4.1	21%	1.1
Sand Filtration	10% Fines	3.1	26%	1.2
Sand Filtration	5% Fines	2.2	35%	1.3
Both	15% Fines	3.0	40%	1.5
Both	10% Fines	2.5	42%	1.5
Both	5% Fines	1.9	45%	1.6
MFT dewatering	15% Fines	2.1	54%	2.2
MFT dewatering	10% Fines	2.0	45%	1.8
MFT dewatering	5% Fines	2.0	30%	1.4

TABLE 2. Comparison of various tailings treatment options with initial conditions 35% mineral MFT, 80% mineral coarse tailings, 80% mineral CT, 80% mineral dried MFT, and 90% mineral filtered coarse tailings.

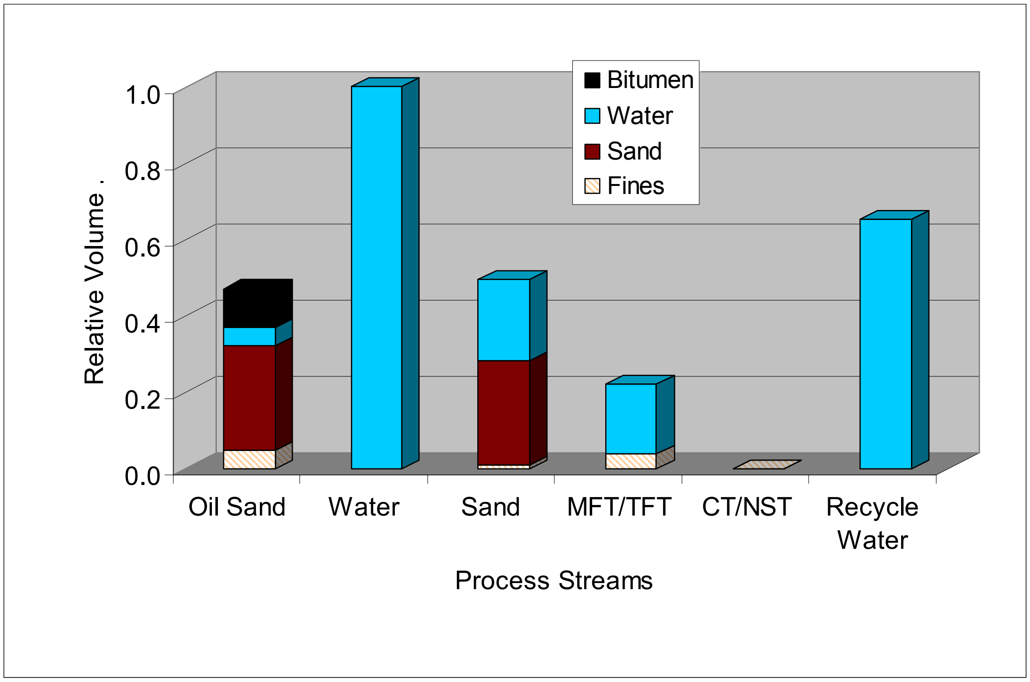

FIGURE 1. Relative volumes for a conventional tailings management strategy which accumulates mature fine tailings. This process requires 4 volumes of make up water for every volume of bitumen produced.

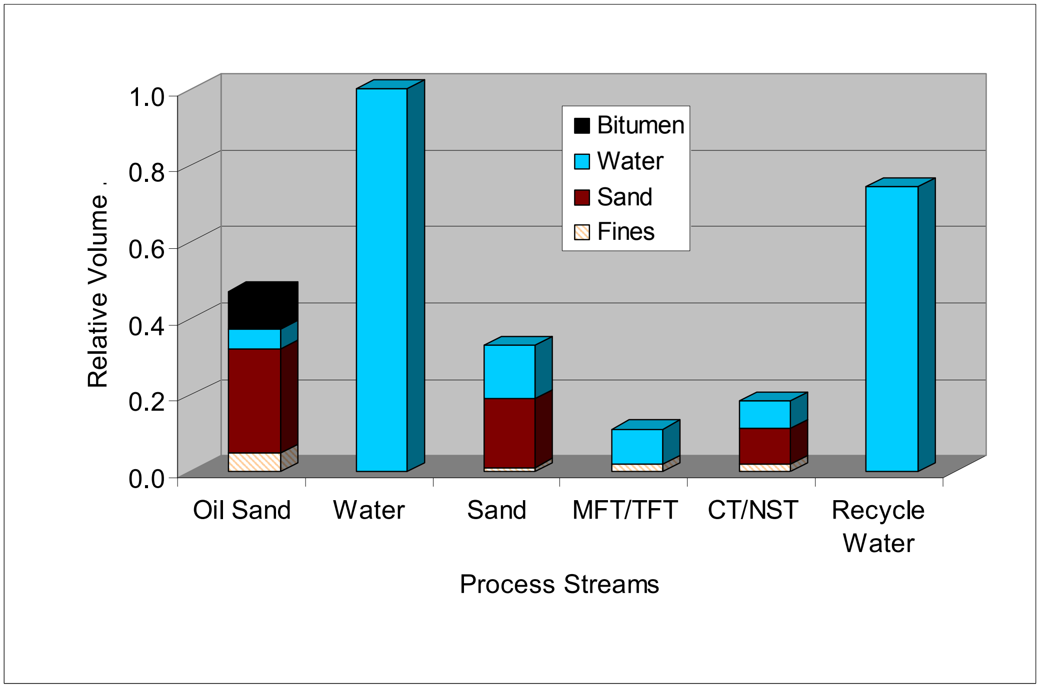

FIGURE 2. Relative volumes for a CT/NST process which would use 50% of the MFT/TT volume. This process requires 3 volumes of make up water for every volume of bitumen produced.

FIGURE 3. Untreated MFT (left) and a gypsum/lime treated MFT (right). Under the same conditions, the treated MFT has dried considerably faster.