Title : The effect of flocculant on the sedimentation and consolidation of fine tailings

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The effect of flocculant on the sedimentation and consolidation of fine tailings.

Bachelor Thesis Paper
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Abstract
Mixing fine mine tailings with flocculant is a method for water retention and accelerated sedimentation in the oil sand industry. One of the known effects of adding flocculants to soil is the resulting porous structure, which leads to fast dewatering but could possibly have a lower final compaction. The objective of this paper is to study the consolidation effect of adding the flocculant, compared with the natural tailings, to figure out the structural difference in final compaction state. In this paper, a river clay is studied instead of fine mine tailings, to avoid the effect of location distinct chemicals. Column studies were performed in which sedimentation and consolidation of the clay mixture, with and without flocculant were examined. CT-scans of the columns after 26 days of consolidation were carried out to evaluate the effects of the flocculant. The results lead to a consistent conclusion: final consolidation of the natural clay is significant lower volume, compared with flocculant mixture. Further research in the reliability and density relation of the CT-scans is recommended.

1. Introduction
Tar sands (also known as oil sands) are loose sands with clay, water and most important bitumen. Bitumen is more viscous than heavy oil, and it will not flow until heated or diluted. Due to higher oil prices, the tar sands are only recently counted as part of the world’s oil reserves. The tar sands reserves (economical recoverable resources) are good for a third of the world reserves and will be of increasing importance. The biggest reserves are located in Alberta, where the tar sands are almost at the surface in a few huge deposits (Government of Alberta, 2008).

There are 2 common extraction processes: Strip mining or in situ techniques which make the oil less viscous. Both extraction processes use besides chemicals and energy, a lot of water. Beside the high processing cost, the major technical problems mining tar sands are the mine tailings (processing waste), which are hard to treat and reclaim. The ratio of water used and oil extracted is between 2 and 4.5. This is the reason for treating the mine tailings with an economical interest to redeem the water (National Energy Board of Canada, 2006). The tailings are first treated in various ways to win back the majority of the water, where after it is deposited in a tailings pond. In the tailings pond the segregation of the particles starts immediately. In the tar sand industry commonly accepted division of the layers respectively is: on top water, thin fine tailings (TFT), mature fine tailings (MFT) and on
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the bottom sand. The MFT tailings are especially problematic because the consolidation can take decades before the area is reclaimable. The characteristics of the fine tailings are high water and clay content, with a few chemicals. This mixture makes it hard to extract water from tailings (M. Mamer and P. Eng., 2010).

After sedimentation in the tailings pond, the tailings are deposited with a dip, for water retention and layered to obtain optimal shrinkage. Adding flocculant is useful for a faster sedimentation rate of the particles. The desired effects are a higher separation speed of the solids and water. This effect can be achieved with the flocculant, which binds the clay particles together and forms a rough porous structure (Munoz et al, 2010). The consolidation of the tailings consists of two stages: first sedimentation of the particles and later compaction. Known is that the sedimentation rate is much higher with flocculant added, but the compaction rate could be lower, leading to an unwanted lower final consolidation. The objective of the research is to study the long term consolidation, which is unfortunately limited by the 6 weeks period for the thesis. This paper presents water consolidation and evaporation rates of the clay mixture, with and without flocculant. The optimal mixing properties of the flocculant are determined. Atterberg limits, particle size distribution and water content is specified of the studied clay. Additional CT-scans of 26 days consolidated columns are carried out to study the effects of the flocculant. The objective is to study the effect of flocculant, possibly waste increasing instead of reducing.

2. Basic Physical properties

In this paper normal clay is used, because mine-tailings contain various amounts of oil and chemical residuals, which will make the laboratory results distinct for the origin. The material is a river clay of the company Ve-Ka (fluβton-10000), the basic physical properties are given in table 1. The clay is commonly used for sculpting and pottery. The flocculant is supplied by a client and the properties are unfortunately confidential.

A hydrometer test is performed according to British standards (BS 1377, 1990) to obtain the particle size distribution. This shows a slightly finer material then most mine tailings, such as Albertan tailings (Yao et al, 2012). The flocculation effect is assumed, in this paper, to be comparable. With the fall-cone test, using British standards (BS 1377, 1990), the liquid limit and the undrained shear strength are determined. Making the assumption that the undrained shear strength of the plastic limit is 100x stronger then the liquid limit (Skempton and Northey, 1953), will give the plastic limit with the fall cone test as well. For the clay mixture high water content is used, this is to overcome the friction in the cylinders, which are used in the laboratory test. The bulk density is determined as well.

<table>
<thead>
<tr>
<th>Index</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%) (Mw/Ms)</td>
<td>250</td>
</tr>
<tr>
<td>Solid content (%)(Ms/Mt)</td>
<td>29</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>55</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>22</td>
</tr>
<tr>
<td>Fines content (&lt;44 µm) (%)</td>
<td>90</td>
</tr>
<tr>
<td>Solid content (&gt;44 µm) (%)</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1, Basic physical properties of the clay used in the laboratory test.
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3. Mixing Properties

The sensitive mixing operation of the flocculant, is done with the following equipment: 600mL graduated cylinder, rectangular stirring rod (25x60 mm), 200 ml of clay mixture and 1 g of flocculent solution per kg solid.

The Desired effect of adding the flocculant to fine tailings is a high sedimentation speed. The flocculant causes the clay to from flocs, which settle faster due to a larger apparent aggregate size. The structure of the sedimented clay flocs is more permeable allowing for fast dewatering. Test done before, have shown that the mixing properties are really important for this desired effects (Munoz et al, 2010). This is discussed at the end of this section.

![Graph](image-url)

Figure 1. Initial sedimentation speed of different mixing procedures. Note: the measurements of 200 & 300 rpm have no significant difference. The surface is a little bit rough and slightly dipped. This makes an error in reading of 1 mm possible, which is 0.5 volumetric %.

Measurements after a few days lead to the conclusion that initial settling rate is indicative for longer term (two days) settling. Figure 1 clearly demonstrates that for optimal flocculation of the clay a low mixing speed is needed.
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The left column in figure 2 shows that a rough structure is formed after the clay has settled, while the right column, which is mixed at 300 rpm, shows a much finer structure. These observations are consistent on micro scale, shown on microscopic photos in previous research (Munoz et al, 2010). The curve of 100 rpm shown in figure 1 is explained through a certain optimum in this mixing process. First the formation of the flocs is the dominant process, which creates the desired structure. After a while the flocs start to break and the structure breaks. This is an irreversible process (Keys and Hogg, 1979), what explains this optimum in mixing time. The conclusion is that the mixing speed of 200 and 300 rpm is too high with the current equipment. 60 Seconds at 100 rpm is the optimal mixing condition. Note: the definite optimum is probably not reached in figure 1.

4. Laboratory test set up

The flocculant solution is mixed with 4 g dry flocculant per liter demi-water. Accidental deviations in the volume in clay mixture lead to unintended much lower initial sedimentation speed. The mixing time and speed is discussed in the previous section.

One two liter cylinder was filled with clay only (referred as clay column/cylinder), and in the other the clay is mixed with the flocculant (referred as flocculant column/cylinder) in small batches of 200 ml. This test is set up with the optimal mixing conditions, which were already specified in this paper. Besides these two cylinders, a cylinder with 2l of demi water was set up (figure 4). The top of these three cylinders is covered, with an inlet for the air-pump and outlet for the air.
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Figure 4, Laboratory test for the consolidation curves, just after the set up.

The weight, height of the water and clay mixture, humidity and temperature is measured every day.

5. Consolidation curves

The effects, which condition the consolidation rates, are sedimentation of the particles and self-weight compaction of the structure. The sedimentation will play an important role for the first period of settlement. This first period is expected to be much shorter for the flocculant cylinder, while the fine particles of the clay cylinder will settle much slower. The next phase is compaction of the structure, which is a slower process. Enhanced atmospheric drying is used, in the form of air pumps, to reduce the evaporation time. In reality the top water can flow off. Possible was to simulate this with manual extraction but that is subjected to human interaction. Interpreting the data would be harder; decided is to use enhanced drying only. This is discussed in the next section.
Figure 5, Consolidation curves of the clay and flocculant column.

Figure 5 shows a much lower sedimentation rate of the clay column, in contrast with the flocculant column. After approximately 10 days the particles in the flocculant column have fully settled and the self-weight consolidation becomes the dominant process. At the moment the top dried out (flocculant column 26 days, clay column 21 days) the compaction increases the whole consolidation curve. In the last days the clay cylinder shows a much faster consolidation rate compared with the flocculant cylinder. This tendency leads to the expectation of a higher final consolidation of the natural clay.

6. Enhanced atmospheric drying

Although the subject of this paper was not enhanced drying, more a tool to simulate the consolidation process, the results were notable. The unexpected findings are explained in this section.
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It’s clear from figure 6 that there is consistent difference in the evaporation rates of the cylinders. Although a recording of the humidity shows a good correlation between the overall evaporation, the mutual difference is harder to explain. The important evaporation factors (humidity, temperature, contact area etc.) are the same for the cylinders. The dissimilarity of ions in the surface water shouldn’t make a significant difference, as shown by Raoult’s law: \( P = X P^* \) (for ideal solutions), one of the thermodynamics basic rules. However the flocculant can be a surfactant, and reduce the evaporation rates. Another difference could be the airflow, which consists of the amount of air pumped and the placement of the inlet. The pumps used are potentially unreliable fishbowl air pumps, the capacity is shown in table 2.

<table>
<thead>
<tr>
<th>cylinder</th>
<th>flow (g/min)</th>
<th>Inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay</td>
<td>0.041</td>
<td>Halfway to middle</td>
</tr>
<tr>
<td>flocculant</td>
<td>0.056</td>
<td>Halfway to middle</td>
</tr>
<tr>
<td>demi water</td>
<td>0.039</td>
<td>Middle</td>
</tr>
</tbody>
</table>

Table 2, Capacity and inlet location of the air pumps

The discontinuity on the 13\(^{th}\) day was due testing air-pumps. Persistent discontinuity started on 23\(^{th}\) day, caused by drying of the top water, the clay column got an edge effect. This effect is sticking of clay at the plastic cylinder, which leads to a higher contact area and evaporation rate.

The only possible conclusion is that the inlet in the middle is an important advantage for the airflow. The mutual difference between the flocculant and the clay cylinder is the higher pump capacity, maybe reduced by the flocculant if it reacts as surfactant. This explains the consistent dissimilarity in the measured evaporation rates.

7. CT-scan of the samples
For the understanding of the consolidation process, density profiles of the samples will be helpful. Taking it apart in the laboratory is accurate but destructive and time consuming. There is a research done where x-rays are used to obtain density profiles of self-weight consolidation of soils (Been and Sills, 1981). The soils used in that experiment had a lower void ratio. Consolidation during the experiment resulted in increasing consolidation in depth.

The device is a Siemens CT-scanner with a maximum resolution of 0.3 mm. The CT-scan uses x-rays in a circulating device to obtain tomographic images, a relative density 2-d image. Multiple slices in following order give a 3-d figure. These circulating density measurements are good for round objects. Our cylindrical samples however couldn’t be scanned sideways because of the loose material. Scanning straight up can lead to small errors, because the circulating density measurements of the x-rays don’t go through a constant length of the sample. This can result in artifacts like cross lines. In the clay cylinder (below) the cross lines are slightly seen. In the rougher structure of the flocculant cylinder the cross lines aren’t clearly notable. The sample is expected to be horizontally homogenous (except edge effects), because consolidation is powered by gravitational (vertical) force. With this strong assumption, calculating different vertical cross sections (figure 9), gives a measure for the reliability of the CT-scan. Although some differences can be found due to small water pockets, at the clay column this effect is minimal.

CT-scan after 26 days. The top of the clay cylinder dried out already 2,5 days, the flocculant cylinder a few hours. Left: Figure 7, the clay column. Middle: Figure 8, the flocculant column. (white is high density) Right: figure 9, Five different cross-sections with four different shots of the clay column. The Cyan colored line is a cross section near the edge.

In the figure 9 the curves are comparable in density and follow the same curve. In the middle (approximately 11 cm ) is the average 1360,7 with a standard deviation of 6.8. The standard deviation is in the whole cylinder between 18,7 and 3,6. The conclusion is that the CT-scan shows a fairly accurate cross section of the sample. The cylinders were of almost the same height and
comparable density, which will lead to approximately same measurement error. Comparing the CT-scan density of the two columns, should be fairly accurate.

CT-scan after 26 days. The top of the clay cylinder dried out already 2,5 days, the flocculant cylinder a few hours. Figure 10, Average density plots of clay and flocculant column.

For a sample with water on top, is an increasing density expected due to self-weight consolidation and particle sedimentation. When the top water is evaporated, the top of the sample starts to consolidate faster due to water extraction. These logical effects are shown in previous researches, respectively (Been and Sills, 1981) and (Yao, et al, 2012). These effects are clearly shown in the clay sample. However these effects aren’t that clearly shown in the flocculant density plot, but the global trends are as expected.

In figure 10 the density profile of the flocculant cylinder forms a rough line, due to the porous water pockets, which is visible in the two dimensional section. A smooth line is formed by the clay column, which doesn’t have these water pockets. The most important outcome of this test is the slightly, but consistent, higher density of the clay column at the bottom of the cylinder. In other words: after a period of 27 days the overall higher density of the flocculant column (sediment zone) is overtaken by the clay column at the bottom zone, where the highest consolidation will be found. This is a strong indication/tendency for the where the final consolidation state will evolve too.

Limitations of the experiments

1. The firm looking fishbowl air-pump can have a staggering difference in capacity (0.039-0.056 g/min in this test). Control of the pumps is necessary before use. Placing the inlet on the same place is necessary for equivalent air flow, which effects the evaporation
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2. The clay is slightly finer than the Albertan tailings, which can result in slightly different consolidation effects.

Conclusions

1. Mixing the tailings with flocculant with clay, will lead to a higher final volume. Three indications support this conclusion:

- The formed structure with the flocculant is more porous, which will result in a lower density.
- Consolidation curve of the clay column shows a tendency which finally leads to a lower volume than the flocculant column.
- CT-scans indicated a higher density at the bottom of the clay column.

Flocculant addition should be reconsidered because slower compaction leads to an increased waste volume.

2. CT-scans showed valuable additional information about the consolidation process. Relative density curves can be obtained multiple times, without destroying the sample.

3. The mixing properties of flocculant are highly important for sedimentation rates. The optimum in mixing time is completely explained by an irreversible process of floc breakage (Keys and Hogg, 1979), after floc forming. Mixing procedure should be a focus if flocculants are used in industry.

Recommendations for further work

1. The reliability of the CT-scans, for straight up columns, can be further tested, by example with a known homogeneous clay. This gives a possibility to study the effects of cross-lines and errors on such form. With literature study the real density plots could be approximated, a valuable addition in studying the consolidation process.

2. Extracting top water from the clay and flocculant cylinder would be an interesting test, simulating the reality. This would give a different compaction rate and can be compared with the consolidation rates of this study

Reference


BS 1377: 1990 British standard institution, part 2.


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Mamer, M., Eng, P. 2010 Oil sands tailings technology; understanding the impact of reclamation. Suncor energy inc. (a major company in reclamation of the tailings in Alberta).

UNDERSTANDING THE IMPACT TO RECLAMATION


