CGS.ca GeoVirtual 2020 September 14-16
Resilience and Innovation

Evaluation of oil sands tailings using ultrasonic pulse velocity method

Hirlatu Yose Peruga & Paul Simms
Department of Civil and Environmental Engineering – Carleton University, Ottawa, Ontario, Canada
Giovanni Cascante
Department of Civil and Environmental Engineering – University of Waterloo, Waterloo, Ontario, Canada

ABSTRACT
The Alberta oil sands mining and extraction processes in Northern Alberta, Canada, produce a tremendous amount of volumes of tailings which are comprised of water, sand, fine clay particles, chemicals, and bitumen at the pH typically ranging from 8 to 9. The disposal of this mixture in the tailings pond is one of the main reasons, causing gravity segregation to occur. During this process, the stable suspension also known as fluid fine tailings (FFT), is formed, which requires many years to consolidate. Thus, land reclamation becomes a huge environmental issue. Therefore, having a proper understanding of the transformation occurs in density and structuration of mine tailings may be important for the operators in Alberta's oil sands industry to better plan the operation of deposition in the tailings ponds such that reclamation can be done when these ponds are no longer in use. This paper reports on the initial results of an experimental program designed to closely monitor the changes in density and structure of the FFT in 10 days using ultrasonic waves. The experiments include not only the evaluation of wave velocities (compressional and shear) but also the changes in wave attenuation as a function of time.

RÉSUMÉ
Les processus d'extraction et d'extraction des sables bitumineux de l'Alberta dans le nord de l'Alberta, au Canada, produisent une quantité considérable de volumes de résidus composés d'eau, de sable, de fines particules d'argile, de produits chimiques et de bitume à un pH généralement compris entre 8 et 9. L'élimination de ce mélange dans le bassin de résidus est l'une des principales raisons, entraînant une ségrégation par gravité. Au cours de ce processus, la suspension stable également connue sous le nom de résidus fins fluides (FFT), est formée, ce qui nécessite de nombreuses années pour se consolider. Ainsi, la remise en état des terres devient un énorme problème environnemental. Par conséquent, une bonne compréhension de la transformation se produit dans la densité et la structuration des résidus miniers peut être importante pour les exploitants de l'industrie des sables bitumineux de l'Alberta afin de mieux planifier l'opération de dépôt dans les bassins de résidus de sorte que la remise en état puisse être effectuée lorsque ces bassins ne sont pas plus longtemps en service. Cet article rend compte des premiers résultats d'un programme expérimental conçu pour surveiller de près les changements de densité et de structure de la FFT en 10 jours à l'aide d'ondes ultrasonores. Les expériences comprennent non seulement l'évaluation des vitesses des vagues (compression et cisaillement) mais aussi les changements d'atténuation des ondes en fonction du temps.

1 INTRODUCTION

Oil sands are composed of series of quartz sand, surrounded by a layer of water and clay, and then covered with a heavy oil, known as bitumen. In Alberta, oil sands accounted 97% of Canada's 171 billion barrels of proven oil, making Canada the world third-largest proven oil reserve (Natural Resources Canada, 2020). In 2014, the production of the oil sands was estimated to be 2.2 million barrels of bitumen per days (Natural Resources Canada, 2020). The deposition of the proven oil reserve are located in three different areas: Athabasca, Peace River, and Cold Lake. Among all three locations, Athabasca has the largest deposit of the reserve oil and the only area in which is shallowed enough to allow surface mining techniques.

The extraction process of bitumen is usually done through surface mining techniques which generate a huge amount of volume of tailings after the bitumen has been extracted, the oil sands tailings naturally consist of a mixture of water, sand, fine clay particles, silt, other hydrocarbon, and residual bitumen (Beiger and Sego, 2008). These mixtures are then transported and deposited in the basin, known as tailings pond, where it allows the tailings to gradually settle to achieve approximate 30% (w/w) solid content, also known as fluid fine tailings (FFT) during the deposition (Siddique et al., 2014; Thompson et al., 2017). The biggest challenge faced by the oil sands industry in tailings management is that FFT requires many years to reach full consolidation. This is due to the FFT consists of various densities of water, sand, silt and clay and some of components such as silt and clay require many year to consolidate, resulting in the increase volume of FFT and the incline number of tailings ponds are eventually caused a significant impact on the environment (Nicolaisen, 2015)

The Clark Hot Water Extraction Process (CHWP) is a method currently used in extracting the bitumen and it was initially developed by Karl Clark in 1920, involving mixing hot water with oil sands to separate oil sands into layers (Shaw, 1996). In this suspension, sand with the densest solid settle to the bottom and water with the least dense floating to the top, separating the bitumen. As a result, bitumen can be extracted through the floatation process. Once it is extracted, the extracted bitumen is upgraded into synthetic crude oil (SCO) and it can then be refined into products such as gasoline, fuel oil, ethylene and propylene (Institute for Oil Sands Innovation, 2016).

Many regulations have been implemented to minimize the environmental footprint and concern associated with the reclamation of tailings ponds. In 2016, the Alberta Energy Regulator (AER) implemented a new regulation in order to reduce the accumulation of the tailings by reclaiming 10 years after the end of the mine exploration. (Alberta Energy Regulator, 2018). In order to successfully comply with the new regulations, tailings require to go through an efficient dewatering treatment technology to enhance the rate of FFT dewatering that can alter the petro physical properties of the oil sands. Even though many technologies have been demonstrated to improve the settling rate of oil sands tailings, an on-site fast measurement is still needed to identify the tailings properties and their settling rate characteristics when modifications are required. Understanding the properties of the tailings in a function of time can lead to optimization of settling rate and it can also significantly minimize the environmental impacts from the oil sand mines. Numerous studies have been conducted using ultrasonic pulse velocity (UPV) test to evaluate the ultrasonic properties of cemented tailings backfill (CTB).

As the depth of mining continue to increase, the UPV of CTB significantly affected by the underground high temperature. The UPV values of CTB also increase with temperature and age due to the improvement of internal structure of CTB (wenbin & al., 2019).

The development of solid stiffness in CTB can occur during self-weight, consolidation, self-desiccation and evaporation of water (Ercikdi & al., 2013). During the evaporation of water, particles are pulled together under the capillary forces, causing the stiffness to increase, resulting in the increase of UPV (Ercikdi & al., 2013).In addition, the UPV measurements can also affected by the sample size. The sample length increased will cause an increased in void ratio or micro cracks, resulting a decrease in UPV measurements (Ercikdi & al., 2013).

Although numerous studies have been done using UPV method to determine the geotechnical of CTB, there are still no studies conducted on the utilization of UPV technique to evaluate the oil sands tailings. However, the UPV measurements of CTB could be used to apply in tailings as well. Thus, the main purpose of this study is to the use of UPV method as a non-destructive technique and prospective on-site application as well as laboratory scale equipment for oil sands tailings in order to make a rapid evaluation of change in density, strength and structuration. These fast measurement would eventually help to analyze the settling rate of the tailings and would directly help the operators to better plan the deposition of the oil sands tailings in the tailings ponds.

2 MATERIALS AND METHODS

2.1 Preparation of Oil Sands Tailings

For this experiment, the oil sands tailings sample were obtained from the tailings ponds in Northern Alberta, Canada and was delivered to Carleton University, Ottawa, Canada. The tailings were then shipped to the NDT lab in the University of Waterloo for ultrasonic testing. The oil sands tailings used for this experiment has a solid content of 30.6% (W/W).

In the preparation of the oil sands tailings, a polymer A3338 is the flocculants used to condition the FFT. 2 grams of polymer A3338 was placed on the weighing paper. 498 mL of deionized water was poured into a 1000 mL glass beaker with 2 gram of polymer A3338. The jar tester was initially set up to 200 RPM to stir the flocculants and deionized water in the beaker together for 5 minutes. After 5 minutes, the speed was reduced to 125 RPM and continued stirring for the following 55 minutes. Then they were mixed with a hand blender for 10 seconds and left for maturation for 1 hour.

To condition the tailings, 300 mL of FFT was poured into an empty bucket. Using the 600 PPM dose, 180 mL of polymer stock solution was transferred into another beaker. The overhead stirrer was set up to 250 RPM to stir the FFT. The 180 mL of polymer stock solution was then poured in the bucket and was mixed with the FFT for 20 seconds. After 20 seconds, the FFT was flocculated.

2.2 3D – Testing Prototype

The 3D – testing prototype for this experiment consists of a cylinder and transducers holder were designed using AutoCAD software and printed with the 3D – printer. The 3D – cylinder was designed to store the FFT for the ultrasonic testing and is comprised of three separate cylinders with 200 mm in height and with a diameter of 110 mm each. In each cylinder, there is columns' plates, embedded aluminum flat bars, membranes and bender element, which is illustrated in Figure 1. Each of these has their own purpose in the ultrasonic testing: the cylinder's plates and membranes were used to conduct compressional and shear wave testing, respectively, aluminum flat bars were used for both compressional and shear waves and bender element was for consolidation testing purpose. In addition, each cylinder is divided into three section: bottom, middle and top. This implies that there will be in total of three compressional and shear wave measurements in each cylinder.

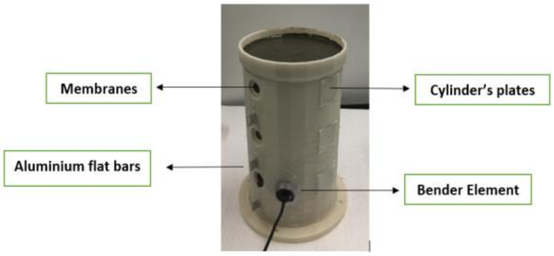


Figure 1. The 3D-cylinder attached on the base

In addition, the picture illustrated in Figure 2 shows the 3D – holder. The main purpose of designing the 3D-holder is to obtain consistent measurements. They were designed to stabilize both compressional and shear transducers and put them in place while conducting ultrasonic testing on the aluminum flat bars.

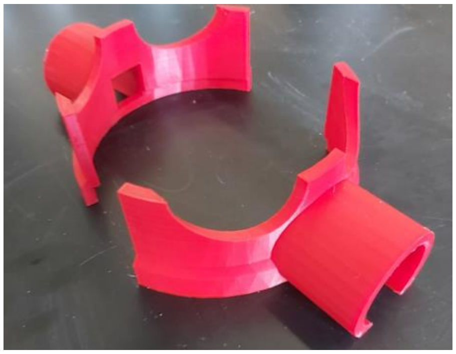


Figure 2. The 3D – holders for both compressional and shear transducers

2.3 The Pulse Velocity Method

The UPV method is used in this study to monitor the transformation of density and structuration of the oil sands tailings. The test instrument used in this research involve sending an electrical pulse from the wave generator and piezo driver and it was then converted into mechanical wave by the piezoelectric transducer. The mechanical wave was then transmitted into the specimen (transmitter transducer) and detecting the arrival of the pulse (receiver transducer) and measuring the first arrival time of both compressional and shear wave. The equipment was also connected to the amplifier to amplify and filter the signals.

The pulse velocity method for both compressional and shear test was performed on the 3D-cylinder. The time of flight was read from the data recorded with the oscilloscope. Moreover, the arrival time was determined from the moment the transmitter transducer emits the pulse into the specimen to the time when the receiver transducer receives the pulse. To obtain more accurate pulse velocity result, the time arrival must be subtracted with the time delay introduced by the ultrasonic equipment. The 54 kHz compressional transducers were used to obtain the P-wave results, the 50 kHz shear transducers were used to obtain the S-wave measurements and the bender element was used for consolidation test.

2.4 Calibration of Ultrasonic Transducers

The ultrasonic transducer plays a significant role in evaluating the internal conditions of the medium being tested. Therefore, the initial step in the ultrasonic testing is the calibration of ultrasonic transducers. The calibration is essential to ensure consistency in the measurements are being met prior to ultrasonic testing by evaluating the delay time. In this experiment, conventional methods such as reference standard bars and face to face procedures were used to calibrate the ultrasonic transducers to determine the delay time. In addition, another calibration method was conducted in this research is water in order to see how the signals behave in water. This calibration will help to analyze the oil sands tailings which have a water content of 70% (w/w) later in the study.

In the conventional methods, the calibration was performed with ultrasonic couplant as a coupling agent. As mentioned previously, the conventional method for this experiment consist of face to face and reference standard bar procedure. For the face to face procedure, the calibration was basically performed by placing both transducers together to obtain the delay time introduced from the instrumentation. Moreover, the calibration test performed on the standards reference bars were made from steel (6 bars) and PVC (4 bars) vary in dimensions, shown in Figure 3.

Another calibration test was performed in water. This procedure was done by pouring the water in the 3D – cylinder and the compressional test was obtained from the 3D – cylinder's plates by placing the compressional transducers on them. Both the results for the conventional methods and water are presented in the results sections.

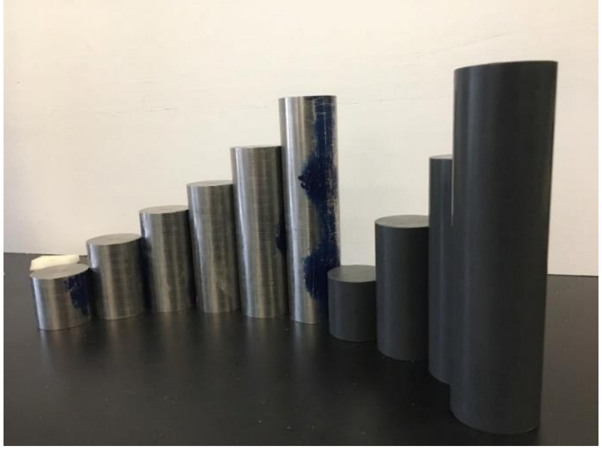


Figure 3. Standard calibration reference steel and PVC bars

3 EXPERIMENTAL RESULTS AND ANALYSIS

3.1 The calibration of ultrasonic transducer using reference standard bars and face to face

The Calibration time of flight were plotted against corresponding length, shown in Figure 4 and 5. The velocities of each material for both compressional and shear test were calculated using the trend line, the results were shown in Table 1. The calculated velocities were compared with typical velocities (Dakota Ultrasonics, nd) and the percentage of error were obtained. The calculated velocities are pretty closed to the typical velocities.

The time signal was obtained from face to face procedure, shown in Figure 6. The time delay which was caused by the ultrasonic instrumentation was determined to be 0.03 μs from the time signal.

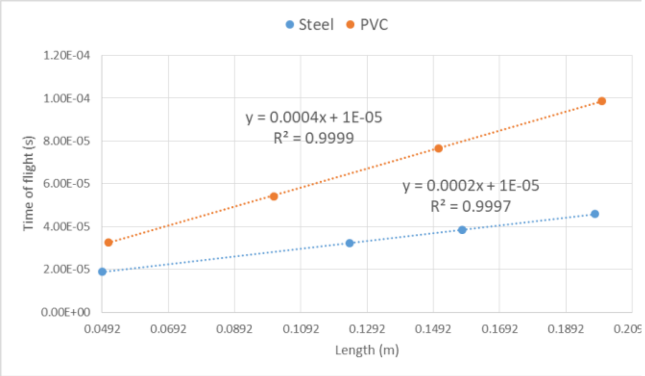


Figure 4. Calibration results obtained from the steel and PVC using 54 kHz P-transducers

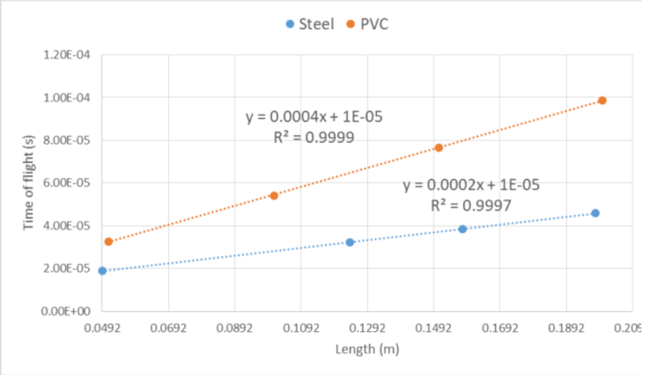


Figure 5. Calibration results obtained from the steel and PVC using 50 kHz S-transducers

Table 1: Calculated velocities, typical velocities and percent of error for steel and PVC bars obtained from both compressional and shear test

Transducers	Materials	Vs (m/s)	Typical Vs (m/s)	Error (%)
Compressional	Steel	5000	5664	13.3
	PVC	2500	2388	4.5
Shear	Steel	3333	3240	2.8
	PVC	1111	1060	4.6

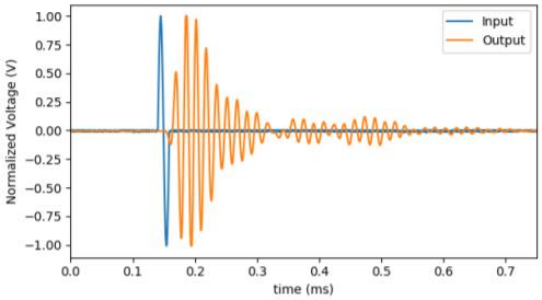


Figure 6. Schematic sketch of the face to face system

3.2 The calibration of ultrasonic transducer using water

The wave signals shown in Figure 7 was obtained by placing 54 kHz compressional transducers at each position of the column's plate and each test was done three times. The time of flight shown in the Table 2 was obtained after subtracting the first arrival time with the time delay. The pulse velocity of the water was then calculated by dividing the diameter of the cylinder (0.11 m) with the time of flight and it was found to be 1345.3 m/s. the calculated pulse velocity was then used to compare with the typical wave velocity of water which is found to be 1473 m/s (Dakota Ultrasonics, nd). The percentage of error was calculated to be 8.7 %.

Table 2: the velocities of water obtained from the compressional test with the 54 kHz transducers

Section	Channel	Time (s)	Time of flight (s)	Vs (m/s)
Bottom	01	7.98E - 05	7.95E - 05	1383
Middle	02	8.28E - 05	8.25E - 05	1333
Top	03	8.37E - 05	8.34E - 05	1318
	Average Velocity (m/s)			1345

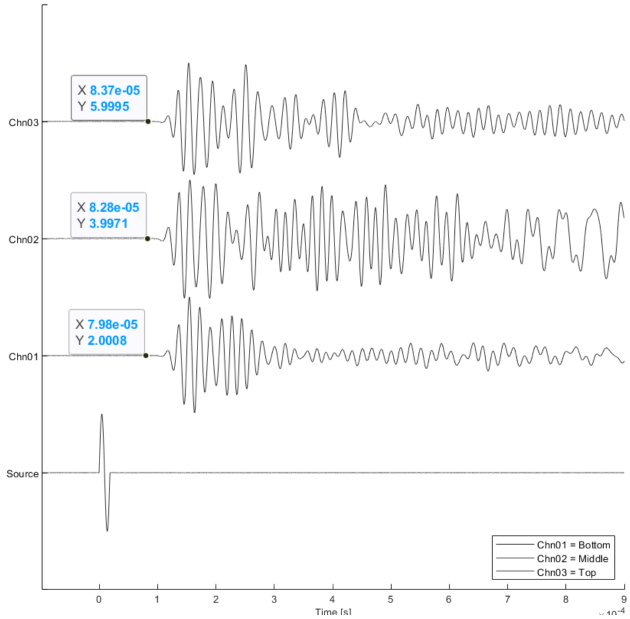


Figure 7. Typical wave signal of water obtained from the compressional test with 54 kHz transducers and selection point of the time arrival

3.3 Arrival time against time for FFT from compressional and shear test

From Figure 8, 9 and 10, the graphs show the arrival time from day 1 and day 10, in which the arrival time in day 1 is higher than the arrival time in day 10. Higher arrival time indicates lower velocity while lower arrival time indicates higher velocity. As mentioned previously, higher velocities indicate good quality of the sample, while lower velocities may indicate the presence of many voids or cracks in the sample. The low velocity in day 1 was possibly due to the FFTs was not as consolidate as day 10 and this implied the strength of FFTs was very weak in day 1 due to the dispersion of tailings particles.

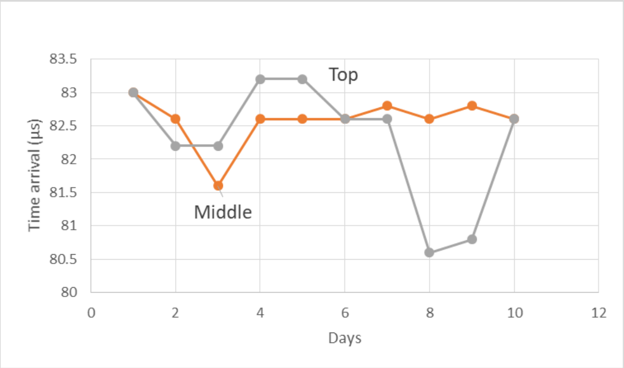


Figure 8. Time arrival varies in day of FFT obtained from the compressional tests on the column's plate in each section of the column

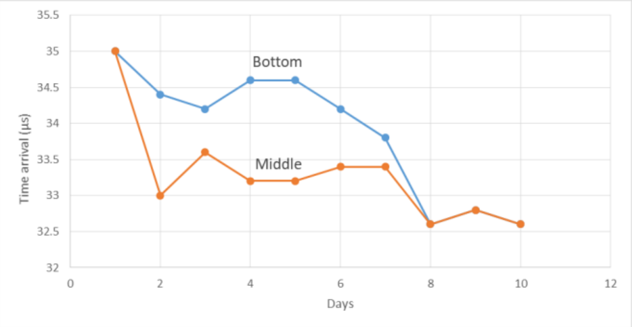


Figure 9. Time arrival varies in day of FFT obtained from the compressional tests at the aluminum plate in each section of the column

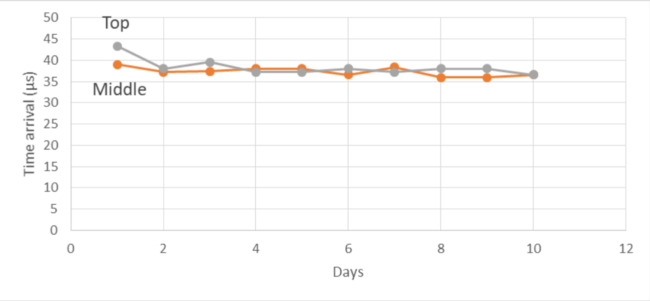
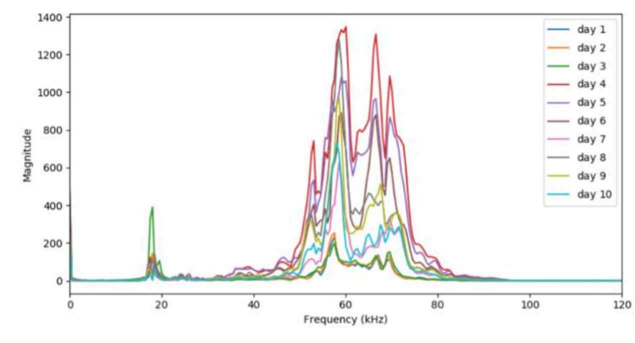


Figure 10. Time arrival varies in day of FFT obtained from the compressional tests at the aluminum plate in each section of the column

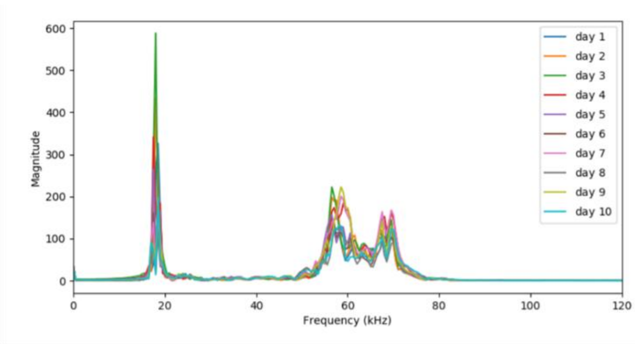
3.4 Wave attenuation vary with time

From Figure 11 and 12, the area under the curve from the two selected bandwidths ranging from 0 – 20 kHz and 40 – 80 kHz were determined. The area under the curve against days for each frequency graphs were plotted in order to analyze the changes in wave attenuation from day 1 to day 10, which were shown in Figure 13, 14, 15 and 16.

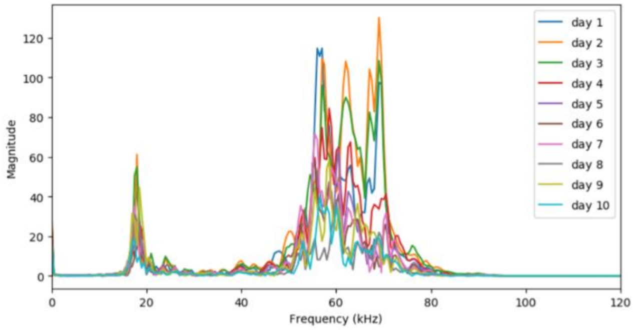
Both figure 13 and 15 show that there is a significant change in attenuation in day 3. This was assumed that there may have a huge change in properties such as strength, density and structuration of FFTs in day 3.



(1)

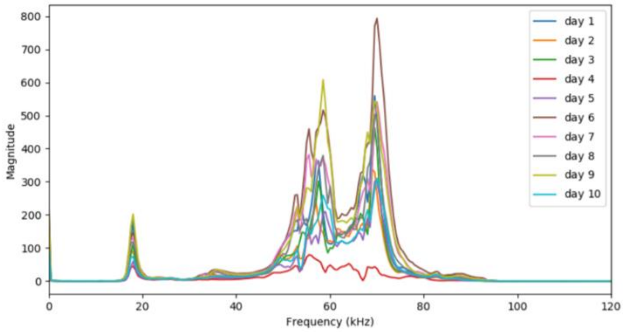


(2)

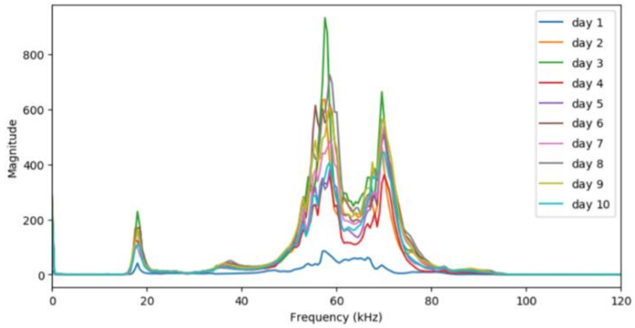


(3)

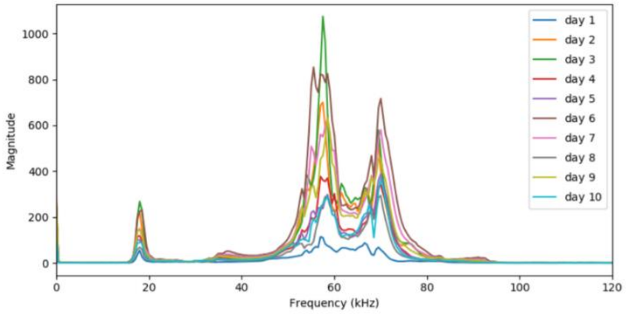
Figure 11. The Fourier spectrum obtained from the compressional test at each section of the cylinder's plate: (1) bottom, (2) middle and (3) top



(1)



(2)



(3)

Figure 12. The Fourier spectrum obtained from the compressional test at each section of the aluminum plate bar: (1) bottom, (2) middle and (3) top

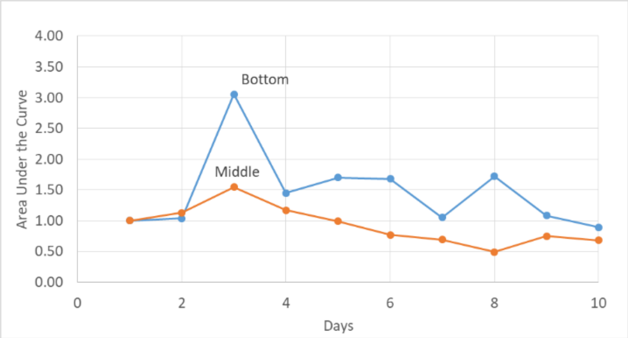


Figure 13. The spectral area of FFT obtained from the compressional test at each section of the cylinder's plate in the frequency bandwidth ranging from 0 – 20 kHz

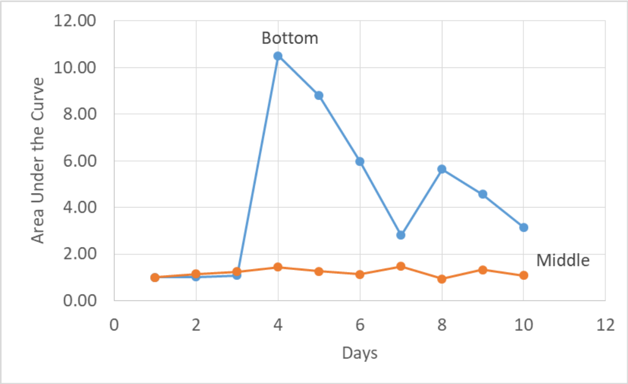


Figure 14. The spectral area of FFT obtained from the compressional test at each section of the cylinder's plate in the frequency bandwidth ranging from 40 – 80 kHz

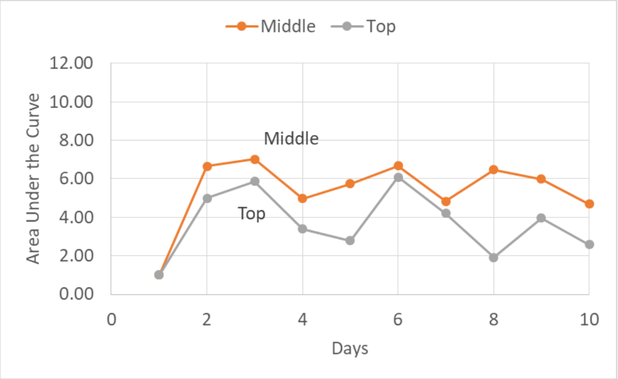


Figure 15. The spectral area of FFT obtained from the compressional test at each section of the aluminum plate bar in the frequency bandwidth ranging from 0 – 20 kHz

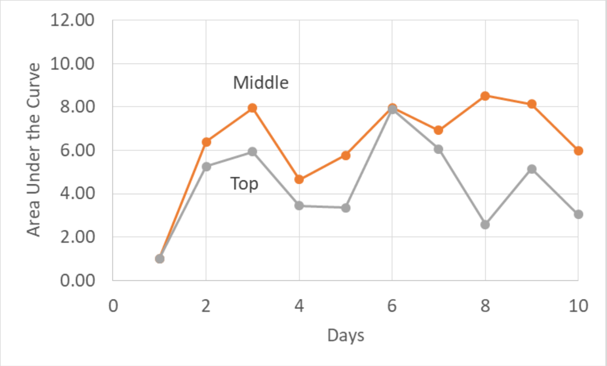


Figure 16. The spectral area of FFT obtained from the compressional test at each section of the aluminum plate bar in the frequency bandwidth ranging from 40 – 80 kHz

4 SUMMARY AND CONCLUSIONS

In this study, the UPV technique was used to evaluate the transformation of density and structuration of oil sands tailings. In spite of relatively easy application, several issues with UPV are presented in this paper. The pulse velocity method was used to conduct in the oil sands tailings to predict their strength. From the results there is a decrease in arrival time from day 1 to day 10. The decrease may be caused by most materials were completely consolidated on day 10. However, the pulse velocity results obtained from the FFT were pretty consistent and it was still not sensitive enough to predict the behavior of the oil sands tailings. Thus, a wave attenuation was another test used in this study. This test was employed in this research to analyze the quality of the FFT. In fact, wave attenuation can be more sensitive to damage than wave velocity and it can be used to evaluate the degradation or loss of material strength through the reduction in the wave amplitude (Ensminger and Bond, 2011). Moreover, the wave attenuation can also be used to evaluate the heterogeneities in different types of materials as scattering attenuation occurs when the wave propagates through medium and there is a presence of heterogeneities (Soham and Kumar, 2016). The results obtained from the wave attenuation test show that the frequency bandwidth ranging from 0 – 20 kHz has a better change in attenuation. From Figure 13 and 15, highest attenuation was occurred in day 3. This could be caused by most of the materials in FFT have been consolidated. However, it is difficult to interpret the cause of attenuation as the amplitude if the signals shows a large variation due to the current test setup was not reliable for assessing wave attenuation. To enhance the consistency in the wave attenuation test, the 3D – holders, shown in Figure 2, were designed for both compressional and shear transducers to place the transducers in place on the aluminum flat bars with the consistent force applied during each test.

5. REFERENCES

Alberta Energy Regulator. 2017. Directive 085. Retrieved April 2018 from the website: http://www.aer.ca/rules-andregulations/directives/directive-085.

Beier, N., and Sego, D. (2008). The oil sands tailings research facility. Geotech. News, 2008: 72–77

“Dakota Ultrasonics, (n.d). Retrieved from the website: http://dakotaultrasonics.com/reference/.

Ensminger, D., and Bond, L,. J. (2011). Ultrasonics: Fundamentals, Technologies, and Application: CRC Press.

Ercikdi, Bayram, et al. “Strength and Ultrasonic Properties of Cemented Paste Backfill.” *Ultrasonics*, Elsevier, 27 Apr. 2013.

Nicolaisen, J. (2015) Oil sands tailings management projects: low return, business critical “Oil Sands History and Development.” *Institute for Oil Sands Innovation*, 2016. Retrieved from the website: www.ualberta.ca/engineering/research/groups/oil-sands-innovation

R.C. Shaw, L.L. Schramm, and J. Czarnecki, Suspensions in the hot water flotation process for Canadian oil sands, in Suspensions: Fundamentals and Applications in the Petroleum Industry, Advances in Chemistry Series 251, L.L. Schramm, Ed., ACS, Washington, DC, USA, 1996.

Siddique, T., Kuznetsov, P., Kuznetsova, A., Li, C., Young, R., Arocena, J.M., Foght, J.M., (2014b) Microbially-accelerated consolidation of oil sands tailings. Pathway II: solidphase biogeochemistry. Front. Microbiol. 5 (Article 107).

Soham, B, and Kumar, A. “Http://Ljournal.ru/Wp Content/Uploads/2016/08/d-2016 154. Pdf.” *Determination of Seismic Wave Attenuation: A Review*, 6 June 2016, doi: 10.18411/d2016-154.

Thompson, D.K., Motta F.L., Soares J.B.P., (2017) Investigation on the flocculation of oil sands mature fine tailings with alkoxysilanes. Miner.Eng.111. 90-99

"What Are the Oil Sands?" *Natural Resources Canada*, 28 Feb. 2020. Retrieved from the website: www.nrcan.gc.ca/our-naturalresources/energy-sources-distribution/cleanfossil-fuels/crude-oil/what-are-oil-sands/18089.

Xu, Wenbin, et al. "Coupled Effect of Curing Temperature and Age on Compressive Behavior, Microstructure and Ultrasonic Properties of Cemented Tailings Backfill." *Construction and Building Materials*, Elsevier, 7 Dec. 2019.