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Case study: the impact of tailings properties on conveying system designs

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Abstract

Mine wastes, specifically tailings, are commonplace in mining operations and most mines dispose of their tailings wastes in wet impoundment structures. Consequently, the failure of wet impoundment structures is one of the most significant environmental liabilities for mining operations and recent failures have highlighted the perils of this type of tailings disposal strategy. Likewise, water scarcity continues to be a growing concern at many mines globally, specifically within arid regions. Risk mitigation priorities along with water resource conservations are steering the mining industry's waste management of tailings away from wet impoundment and towards dewatered tailings and dry stack disposal. The handling of dewatered tailings is most efficiently performed with the operation of automatic conveyance systems and the deposition of the tailings achieved by mobile conveyor stacking systems.

Lab testing and analysis have identified that mine waste tailings characteristics vary widely between mine samples due mostly to the ore's mineral composition, particle size distribution, and moisture content. Evaluating the mine site's tailings material samples for their conveyability and measuring their change in surcharge angle is the key to understanding how the tailings react at different moisture levels while being transported along the length of an overland conveyor. The results of the conveyability tests are used for the design and strategy for the material handling and waste disposal stacking systems.

This paper will present case studies of multiple tailings samples, from various mine sites, at specifically determined moisture levels. During the conveyor simulation tests, the samples were measured and recorded for the initial angle of repose, surcharge angle, and material density. This paper aims to demonstrate that there are often significant differences between tailings samples' physical and dynamic properties and how that relates to the parameters needed for accurate conveyor engineering design.

Keywords: *Tailings, conveyor, conveyability, waste, material handling, moisture levels, stacking, disposal, repose, surcharge angle, material density, conveyor tester, conveyor simulation*

1 Introduction

Worldwide demand for minerals and metals is constantly growing. Among most of the growing industries exists the socially responsible goal of reducing global carbon emissions, which will require a significant increase in the supply of the raw materials needed for carbon-reducing technologies. By the year 2050, global demand for these raw materials and minerals is estimated to grow as much as tenfold. Combined that increase with the problem of declining ore grades in many mines, equates to the need for larger ore throughputs to keep up with this growing demand. Consequently, there will be a significant increase in both water usage, for the mineral extraction processes, and mine wastes generated. One of the solutions is to extract and recycle the water from the tailings through thickening and filtration thereby reducing the need for freshwater. Dewatered tailings also come with the added benefit that stacking in terraced lifts reduces the overall area required for tailings disposal with a safer and easier-to-manage tailings disposal stack.

> *'A typical mine closure plan includes the rehabilitation of the TSF, which requires capping, covering, revegetation, and monitoring of the TSF to ensure it is safe and non-polluting. Discharging higher solids content tailings reduces the volume of tailings that must be*

> *deposited as well as allows for steeper beach angles; the size of the TSF is reduced as the density of the tailings increases. For filtered tailings, progressive reclamation of the TSF can begin while still in operation, which can further reduce closure costs.'* (England et al. 2020)

For mining operations with high tailings throughputs, material handling systems, specifically conveyor systems, will be required to transport and stack the dewatered tailings at its disposal site.

> *'There are two methods in common use for transport of the filtered tailings to the tailings storage facility. These are conveyors or trucks, and the equipment selection is a function of cost. Placement in the facility can be by a conveyor radial stacker system or trucks depending upon the application and the design criteria. Conveyor transport of tailings to the disposal site can be combined with placement by truck, so conveyor transport does not automatically result in placement by the radial stacker. The main issue associated with the placement of the filtered tailings by truck is usually trafficability. The filtered tailings are generally produced at or slightly above the optimum moisture content for compaction. This means that a construction/operating plan is required to avoid trafficability problems.'* (Davis 2011)

It is important to understand the dynamic nature of the site's dewatered tailings in order to design an effective and efficient conveying and stacking system (Figure 1).

(a) (b)

Figure 1 (a) Tailings tripper conveyor; (b) Tailings stacking conveyor with spreader conveyor (image source: FLSmidth Australia)

2 Belt conveyor sizing

The sizing of belt conveyors is an important engineering task in ensuring that the conveyor system will function seamlessly and operate efficiently. Refer to Table 1 for the necessary input parameters for accurate belt conveyor sizing.

Table 1 Belt conveyor sizing requirements

Conveyor geometry sizing	Belt cross-section sizing
Conveyor horizontal length (m)	Material throughput (mt/h)
Conveyor vertical lift/drop (m)	Material bulk density (t/m^3)
Maximum slope (deg)	Material angle of repose (deg)
Conveyor type	**Material surcharge angle** (deg)
Conveyor drive configuration	Idler angle (deg)
Conveyor tensioning system and configuration	Material characteristics
	• Material minerology
Belt speed (m/s)	• Material particle size distribution
	• Material moisture content (wt.%)

Conveyor geometry sizing is all about determining and designing the conveyor profile, take-up travel, curve geometry, power requirements, belt load, and conveyor component ratings (Figure 2). Whereas the input data for the cross-section is used to size the width of the conveyor belt. The conveyor belt speed variable is used for both sizing categories. A faster belt speed can reduce the belt width, while a slower belt speed can reduce the conveyor's power requirements. During the engineering design of the conveyor, the belt speed is adjusted to optimise a balance between the conveyor's capital and operational costs.

The following equations for calculating the cross-sectional area of the material sitting on a conveyor belt can be found in the Conveyor Equipment Manufacturers Association (CEMA 2007) manual for '*Belt Conveyors for Bulk Materials*', 6th edition, chapter four.

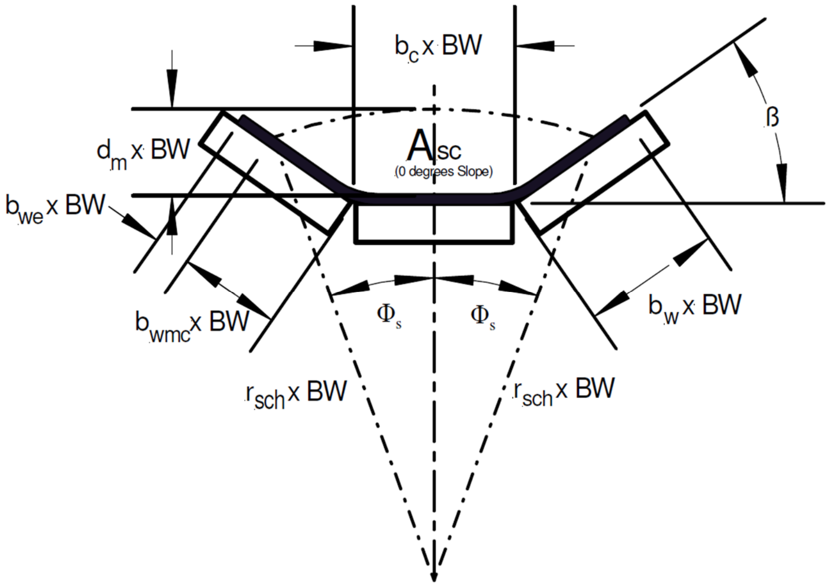

Figure 2 Conveyor belt cross-sectional area equation

Area of the trapezoid (Imperial):

$$A_b = \{0.375 \times BW + 0.25 + (0.2595 \times BW + 1.025) \times \cos\beta\} \times \{(0.2595 \times BW - 1.025) \times \sin\beta\}$$

Area of the circular segment (Imperial):

$$A_s = \left\{\frac{0.1855 \times BW + 0.125 + (0.2595 \times BW - 1.025) \times \cos\beta}{\sin(\phi_s)}\right\} \times \left\{\frac{\pi \times \phi_s}{180} - \frac{\sin(2\phi_s)}{2}\right\}$$

Total area (Imperial):

$$A_{sc}(ft^2) = \frac{A_b + A_s}{144}$$

Table 2 Conveyor belt cross-sectional area equation variables

A_{sc} (ft²) or (m²)	Total material cross-sectional area based on the surcharge angle w/circular top surface and a known edge distance
b_c	Ratio of upper surface of the belt above the centre roll $= \frac{0.375 \times BW + 0.25}{BW}$
b_w	Ratio of upper surface of the belt above the wing roll $= b_{we} + b_{wmc} = \frac{1 - b_c}{2}$
b_{we}	Ratio of upper surface belt edge above the wing roll $= \frac{(0.055 \times BW + 0.9)}{BW}$
b_{wmc}	Ratio of surface belt with material contact on the above wing roll
BW	Belt width
d_m (in) or (mm)	Maximum depth of the material profile
β (rad)	Idle troughing angle (degreed when using trig function, otherwise radians)
Φ_s (rad)	^{1} **Surcharge angle** (degreed when using trig function, otherwise radians)
Φ_r (rad)	^{2} Angle of repose (degreed when using trig function, otherwise radians)
r_{sch}	Ration of effective radius of the top surface of the material $= \frac{b_c \div}{\sin(\Phi_s)} + \frac{\cos(\beta) b_{wmc}}{\sin(\Phi_s)}$ based on the surcharge angle compared to BW

Note: The CEMA formulas are in Imperial units, convert as necessary for metric units.

1: The angle of surcharge of a material is the angle to the horizontal which the surface of the material assumes while the material is at rest on a moving conveyor belt. This angle usually is 5 degrees to 15 degrees less than the angle of repose, though in some materials it may be as much as 20 degrees less (CEMA 2007).

2: The angle of repose of a material is the natural angle formed by gravity discharge of the material and measured from a horizontal base (CEMA 2007).

> *'For capacity and equipment calculations, it is important to know the variation in bulk density in loose and packed states, the angle of repose and surcharge, and the particle size distribution of the conveyed material. Once again, these factors are greatly influenced by the moisture content of the conveyed material.'* (CEMA 2007)

The angle of repose and the surcharge angle are the material specific variables within the cross-sectional area equations. The angle of repose is influenced by the composition of the material, notably its particle size distribution (PSD), moisture content, and particle surface conditions. The surcharge angle is influenced by the energy introduced into the material through the speed of the belt, the conveyor slope, and mostly the movement of the belt through the belt sag then over the idler rolls. Because of the combined horizontal and vertical velocities this motion of the material is more like multiple ocean waves, with the same frequency, rather than just a vertical bump travelling through the material.

The material surcharge angle is in bold to highlight that with tailings this parameter can be unpredictable. Common wisdom would assume that for conveyable tailings the higher the moisture content the surcharge angles will decrease more rapidly. However, through the following case studies this assumption is not always correct.

3 Tailings sample testing

Basic material characterisation, mineralogical analyses, and dynamic surcharge angle testing are necessary to determine the mineralogical composition and physical properties of the tailings samples. The material characteristics are useful in understanding the size, type, and quantity of solids, as well as useful to help explain how ore and mineral extraction method variabilities affect the dewatering and conveyability processes.

3.1 Tailings characteristics

Quantitative mineralogy, including clay concentrations, are important factors that can affect the performance of the thickening and filtration circuit. Basic material characterisation and mineralogy consist of the following tests:

- **X-ray diffraction (XRD)**, shines X-rays onto a powdered sample which identifies and quantifies minerals present in the tailings stream. The outcome of the test is the bulk mineralogy of the sample in weight percent (wt%) of the minerals present.
- **Swelling clay analysis**, uses cation-exchange-capacity (CEC) to quantify the quantity of swelling clays present in the tailings. Results are given in (wt%) and combined with the XRD results for a balanced composition.
- **Particle size analysis**, a Malvern laser size analyser is used to measure the PSD of the slurry. This is an important measurement that affects dewatering and material handling equipment sizing. The results are specified as the percentage of the particles that are smaller than a certain size (wt% passing).
- **Total solids concentrations** (wt%), are measured by drying a slurry sample in an oven at 105°C for 24 hours. The mass of the wet sample is divided by the mass of the dried sample. Results are given in moisture percentage by weight (wt%). Samples are measured directly before and again directly after the conveyor simulation tests.

3.2 Surcharge angle testing

The tailings filter cake sample is run on a proprietary conveyor simulator. The tailings sample is loaded onto the conveyor simulator in such a way as to mimic a conveyor transfer point. The side skirt plates are removed, and the initial angle of repose is measured. The conveyor simulator is initiated, and the surcharge angle measurements are taken at designated simulated travel distance intervals. The test is run until the surcharge angle stabilises or at a simulated travel distance of 10 km.

4 Tailings surcharge angle case studies

Tailings from different mine sites with a variation of tailings cake preparations were tested on the conveyor tester to determine the surcharge angles of each sample.

4.1 Tailings surcharge angle case study #1

Two tailings samples were collected from the same mine site with each tailings sample divided into three different dewatering preparations. The target moisture levels were specified by the client. The samples are labelled as samples ‘A’ and ‘B’ and preparations as ‘1’ (filtered tailings), ‘2’ (melia tailings) and ‘3’ (cyclone underflow tailings). For example, ‘A1’ is Sample ‘A’ preparation type ‘1’. See Table 3 for the mineralogy of the samples. See Table 4 for the PSD of the samples. See Figure 3 for the results of the conveyor testing of the samples. See Figures 4 through 9 for the images taken before and after the conveyor simulation testing.

Table 3 Case study #1 tailings sample mineralogy

Sample	*Moisture (wt%)*	Quartz (%)	Plagioclase (%)	Muscovite (%)	Chlorite (%)	Kaolinite (%)	Talc (%)	Gypsum (%)	Pyrite (%)	Swelling Clays (CEC) (%)
A1	*22*	35.8	9.1	31.7	4.5	6.5	1.5	1.4	1.7	7.8
B1	*21*	36.4	9.9	32.2	4.4	5.6	1.2	1.7	2.4	5.8
A2	*19*	35.8	9.0	33.1	3.9	7.4	0.0	1.1	1.7	8.0
B2	*19*	36.4	9.2	33.5	4.5	5.2	1.4	1.6	2.2	6.0
A3	*17*	51.9	8.2	26.9	3.5	0.0	0.8	1.4	2.4	4.9
B3	*18*	49.2	10.0	27.2	3.4	0.0	1.9	1.6	2.6	4.1

Table 4 Case study #1 tailings sample PSD

Sample	*Moisture wt%*	P_{80} (µm)	P_{50} (µm)	P_{10} (µm)
A1	*22*	124	17.1	2.82
B1	*21*	105	17.8	3.18
A2	*19*	91.9	13.9	2.77
B2	*19*	81.1	14.9	3
A3	*17*	260	147	9.88
B3	*18*	242	130	13.4

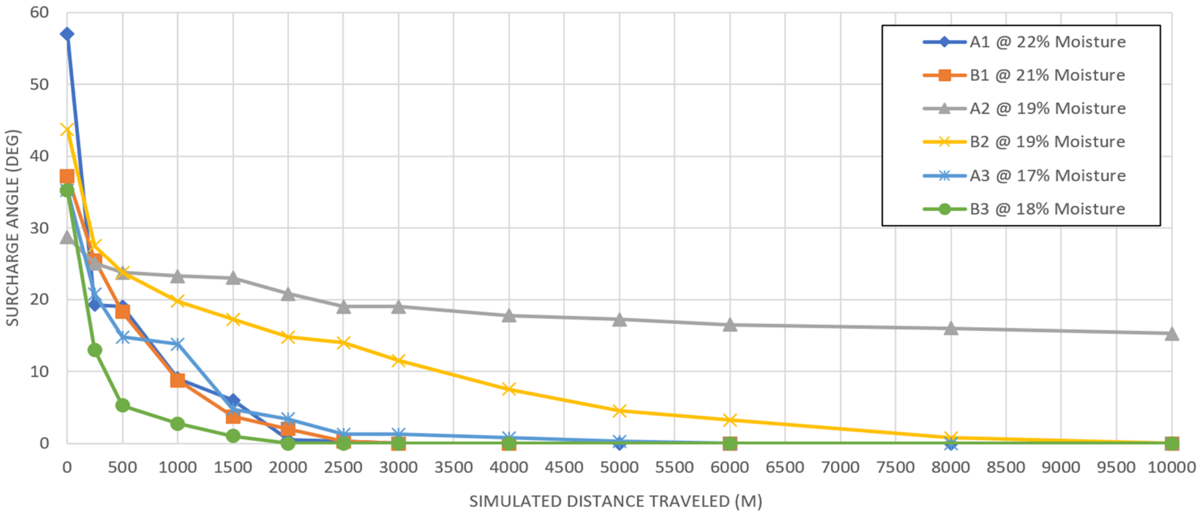

Figure 3 Case study #1 surcharge angle simulation graph

Figure 4 Sample A1 (22%) moisture before and after simulation (image source: FLSmidth USA)

Figure 5 Sample B1 (21%) moisture before and after simulation (image source: FLSmidth USA)

Figure 6 Sample A2 (19%) moisture before and after simulation (image source: FLSmidth USA)

Figure 7 Sample B2 (19%) moisture before and after simulation (image source: FLSmidth USA)

Figure 8 Sample A3 (17%) moisture before and after simulation (image source: FLSmidth USA)

Figure 9 Sample B3 (18%) moisture before and after simulation (image source: FLSmidth USA)

Within this case study of tailings samples from the same mine with similar mineralogy testing results, the PSD may have had a greater effect on the drop in the surcharge angle than the moisture content. While the sample preparation '3' (the cyclone underflow) has the lowest moisture content the particle sizes were much larger.

4.2 Tailings surcharge angle case study #2

Two tailings samples were collected from the same mine site with the same pressure filter dewatering preparation with different moisture content. The target moisture levels were specified by the client. The samples are labelled as samples 'C' and 'D' and preparation as '1' (pressure filter). See Table 5 for the mineralogy of the samples. See Table 6 for the PSD of the samples. See Figure 10 for the results of the conveyor testing of the samples. See Figures 11 and 12 for the images taken before and after the conveyor simulation testing.

Table 5 Case study #2 tailings sample mineralogy

Sample	***Moisture (wt%)***	**Quartz (%)**	**K-feldspar (%)**	**Plagioclase (%)**	**Muscovite (%)**	**Chlorite (%)**	**Kaolinite (%)**	**Calcite (%)**	**Alunite (%)**	**Pyrite (%)**	**Swelling Clays (CEC) (%)**
C1	*18*	42.4	3.5	0.0	28.3	0.0	16.1	0.0	2.8	1.9	5.0
D1	*26*	37.3	0.0	4.6	38.3	2.3	3.3	0.6	0.0	6.1	7.5

Table 6 Case study #2 tailings sample PSD

Sample	*Moisture wt%*	P_{80} (μm)	P_{50} (μm)	P_{10} (μm)
C1	*18*	91.6	15.7	3.07
D1	*26*	78.5	15.8	3.51

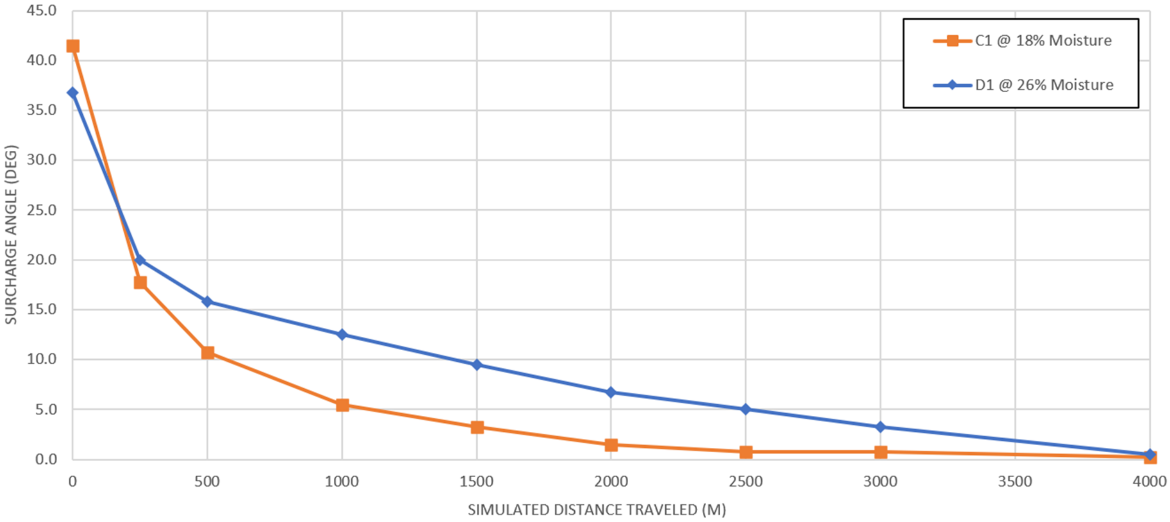

Figure 10 Case study #2 surcharge angle simulation graph

Figure 11 Sample C1 (18%) moisture before and after simulation (image source: FLSmidth USA)

Figure 12 Sample D1 (26%) moisture before and after simulation (image source: FLSmidth USA)

Within this case study of tailings samples from the same mine with similar PSD and some variability in the mineralogy testing results. With these samples, it may have been the difference in swelling clays that straightened the charted curve.

4.3 Tailings surcharge angle case study #3

Three tailings samples were collected from three different mine sites with the same pressure filter dewatering preparation. The moisture levels were specified by the client. The samples are labelled as samples ‘E’, ‘F’, and ‘G’ and preparation as ‘1’ (pressure filter). See Table 7 for the mineralogy of the samples. See Table 8 for the PSD of the samples. See Figure 13 for the results of the conveyor simulation testing of the samples. See Figures 14 through 16 for the images taken before and after the conveyor simulation testing.

Table 7 Case study #3 tailings sample mineralogy

Sample	*Moisture (wt%)*	Quartz (%)	K-feldspar (%)	Plagioclase (%)	Muscovite (%)	Chlorite (%)	Calcite (%)	Pyrite (%)	Dolomite (%)	Apatite (%)	Sphalerite (%)	Biotite (%)	Amphibole (%)	Pyrrhotite (%)	Swelling Clays (CEC) (%)
E1	*17*	57.5	14.3	1.2	7.6	3.2	4.7	1.5	2.1	0.0	1.1	0.0	0.0	0.0	6.7
F1	*18*	42.1	16.1	7.0	5.4	7.7	10.7	1.1	0.0	1.3	0.2	0.0	0.0	0.0	8.5
G1	*13*	17.5	4.5	22.6	0.0	5.3	55	0.8	0.2	0.0	0.0	5.8	33.8	1.4	2.5

Table 8 Case study #3 tailings sample PSD

Sample	*Moisture (wt%)*	P_{80} (µm)	P_{50} (µm)	P_{10} (µm)
E1	*17*	112	22.5	1.5
F1	*18*	71	8.4	1
G1	*13*	110	38	5

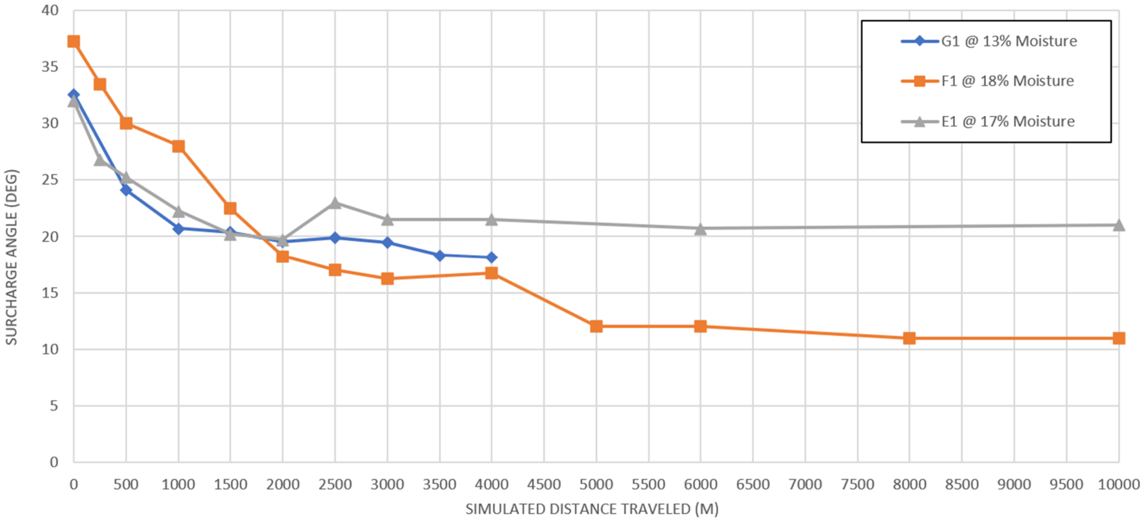

Figure 13 Case study #3 surcharge angle simulation graph

Figure 14 Sample E1 (17%) moisture before and after simulation (image source: FLSmidth USA)

Figure 15 Sample F1 (18%) moisture before and after simulation (image source: FLSmidth USA)

Figure 16 Sample G1 (13%) moisture before and after simulation (image source: FLSmidth USA)

Within this case study of tailings samples from different mines with similar moisture contents. The conveyor simulation tests showed some similar results in the measurements of the surcharge angles with the surcharge angle resting at between 10 and 15 degrees. Sample G1 had the largest variation from the other two with both the moisture content and the quantity of swelling clays measuring lower.

5 Conclusion

Each of the three case studies had one sample that had a target moisture content of 18% (wt%); sample B3 from case study #1, sample C1 from case study #2, and sample F1 from case study #3. The results of the conveyor simulator showed that there was a wide disparity in the material's surcharge angle. Where samples B3 and C1 had their surcharge angles flatten out after 2,000 m of simulated travel, sample F1 settled at about 12 degrees of surcharge angle at 5,000 m and held that angle through 10,000 m of simulated travel. In conveyor design the surcharge angle is an important input variable in correctly sizing a conveyor. Assuming that the surcharge angle will be less than five based on moisture content alone could result in oversizing the conveyor. The result of this is the approximated increase in capital costs of 3% to 5% and an approximated increase in operational costs of 2% to 3% for oversizing the conveyor by one belt width. Because the surcharge angle for tailings at this time is mostly unpredictable it is recommended that tailings sample test studies for material handling projects be executed during the pre-feasibility phases of projects to have the accurate design data for the project’s engineering phases.

References

CEMA 2007, *Belt Conveyors for Bulk Materials* (6th Edition, 2nd Printing ed.), Naples, Florida, United States of America: Conveyor Equipment Manufacturers Association, retrieved from cemanet.org.

Davis, M 2011, ‘Filtered dry stacked tailings – the fundamentals’, *Tailings and Mine Waste 2011,* Vancouver, BC.

England, L, Wisdom, T, Schoenbrunn, F, Chaponnel, J & Macnamara, L 2020, June 23, ‘Recent developments in FLSmidth dewatering technologies for tailings disposal to maximise water recovery’, *SYMPHOS 2019–5th International Symposium on Innovation & Technology in the Phosphate Industry,* available at: https://ssrn.com/abstract=3633783.