Inline flocculation: an update to fundamental considerations

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Abstract

Tailings management remains a significant challenge for the mining industry. Inline flocculation offers a promising solution, providing efficient and cost-effective thickening and dewatering of tailings. This paper will delve into recent advancements in inline flocculation, focusing on fundamental considerations that influence its effectiveness.

We will explore factors such as:

- *characterisation of tailings – the impact on dewatering capability and flocculant dosage with changing tailings types*

- *mechanics of slurry and polymer flows – determining the optimal mixing conditions for any application*

- *polymer injection – the influence of injector design on optimising the dewatering and dosage outcomes for inline flocculation*

- *conditioning and water release – the role of piping distance in dewatering outcomes if polymer injection has been performed correctly.*

By understanding these fundamental principles, mining operations can optimise their inline flocculation processes, leading to improved tailings thickening, reduced water consumption and enhanced environmental performance.

Keywords: *inline flocculation, chemical mixing, scale up*

1   Introduction

Inline flocculation of tailings for dewatering is used at commercial scale to dewater oil sands tailings. These tailings materials are characterised by high clay activity slurries with significant organic contents and have proven difficult to dewater effectively with other technologies. In spite of the successful application across this industry, there is little uptake of the technology in other areas of the mining paste industry, despite an initial introduction in the *Paste and Thickened Tailings Guide*, third edition (Wells et al. 2015) (hereafter referred to as the Paste chapter). This is due to two key issues:

1. Inline flocculation is a technically complex process to design and control, and the science is not well understood in the industry. While the potential exists for a properly designed system to produce dewatering results that meet or exceed those found in the current generation of thickeners and filter presses, the technology requires a detailed understanding of the science and engineering associated with chemical mixing.

2. Previous descriptions of the technology did not provide sufficient descriptions of the fundamentals. In the Paste chapter, the scientific and engineering description of the technology was at an early stage in development, and the authors were not able to fully explain the design and characterisation requirements to provide future practitioners with sufficient background to

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produce successful systems. Notable advances made since that time will allow for the design of systems that could produce similar performance for other tailings materials through an improved understanding of the fundamentals in design.

The technology was developed towards commercial application in the oil sands industry, with success due primarily to the availability of both large-scale funding and key subject matter experts to explore the science and engineering needed. This combination enabled various models and process design systems on a targeted but iterative method of investigation to be worked through. This allowed for inline flocculation to be integrated into various tailings processes at most of the oil sands operations in Northern Alberta Canada. It is used in inline dewatering, feed systems for centrifuges, and dewatering and chemical treatment for in-pit lake storage. Through this broad use and investigation, understanding of the fundamental science needed to design the process for specific tailings materials has improved, allowing systems to be designed and implemented outside of the specific oil sands applications. The advances in understanding can be broadly described as:

1. improvements in the base science and engineering fundamentals that control the dewatering process. Oil sands fine tailings are among the most difficult to dewater due to the particle size, clay activity and presence of organic matter. While the industry has been able to provide funding levels far beyond any other in the mining industry, the challenges of these tailings materials meant that the need to provide improved solutions was equally great. These difficult tailings required time and effort to develop robust systems and engineering to describe the designs, and with the decade that has passed since the original designs, the base science and engineering can be applied to the more trivial tailings materials. Systems based on this developed understanding are set to revolutionise the options available to the mining industry.

2. advances in polymer mixing. While measurements of turbulence provide some insight into the control and optimisation of polymer mixing, it is better to view the performance and design of these systems through chemical mixing theory.

3. understanding of the importance of shear regimes. Inline flocculation is a rapid process that needs to consider the flow and shear regimes throughout the system. As such, it requires higher degrees of engineering and design than traditional thickeners, where the design is less sensitive to shear regimes.

2   Tailings types and key material properties

Inline flocculation for tailings is used primarily either for dewatering or for increasing the strength of tailings to allow for improved stacking. The Paste chapter mentions that the dewatering capacity of the tailings is influenced by the tailings water chemistry and the sizes and activity of the clay minerals present. The article states that the methylene blue index can be qualitatively used to determine the chemical dose and rheology of the tailings but does not indicate the amount of dewatering or the dosage that should be expected.

A paper at the Paste 2024 conference (Kaminsky et al. 2024) outlines how the methylene blue index can be used to determine the weight percent solids after dewatering, depending on the water layer thickness in nanometres (nm) surrounding the clay. In Figure 1 the Kaminsky et al. (2024) approach is switched around to be a lookup table for benchmarking the dewatering performance of the dewatering technology. In oil sands work it has been found that the layer of water that can be removed is a function of the chemicals that are selected for flocculation, and the mixing of those chemicals. If the selection of chemicals and the mixing are optimised, 11 nm of remaining water should be observed. An average performing inline flocculation system would leave 15 nm of water remaining. The limit of a bench scale paddle mixer is around 16 nm of water remaining, indicating some of the limits associated with using the bench scale as a screening tool for a full-scale inline flocculation system. An inline flocculation process that has not be optimised for mixing or chemistry would be expected to result in remaining water layers greater than 20 nm. As an example, an average oil sands mature fine tailings (MFT) has a methylene blue index (MBI) of around 9 and dewaters to 50 wt% solids in current field inline flocculation systems, whereas an average thickener feed sample for oil

sands has an MBI of 4 and dewaters to 50 wt% solids in a thickener. The naive view would take the two results of 50 wt% solids as identical, but what would happen if the MFT feed was in a thickener and the thickener feed was in the inline system? In a thickener, MFT would only reach 30 wt% solids, but thickener feed in inline flocculation would reach 70 wt% solids.

The method outlined in the Wells et al. (2011) and demonstrated in Kaminsky et al. (2024) states that the dosage can also be factored using MBI to create a clay-based dose. What wasn't known during these initial papers was that dosage is influenced not only by the MBI but also by how efficiently the polymer is mixed into the tailings. If mixing is inefficient then > 20 nm of remaining water is observed, and very high doses are required. As mixing parameters are optimised, dewatering will often reach a plateau of good performance (11–15 nm) but further optimising the mixing parameters will result in further dose reductions.

An example from oil sands inline flocculation technology can illustrate this. Prior to the development of a sufficient understanding of mixing, inline flocculation on MFT needed a dose of 2,500–3,000 g/t on a clay basis to obtain any water release. As the understanding of chemical mixing application to flocculation advanced it was realised that very high doses of > 2,500 g/t of clay was indicative of a mixing problem. Designing a new injection system and ensuring turbulent mixing of the polymer and MFT reduced the dose to 1,800 g/t on a clay basis before further advances in injector design, changing how the polymer was injected, reduced it to 1,400 g/t on a clay basis. Optimal mixing on the bench scale can achieve 700 g/t on a clay basis for MFT, indicating there is still room for injector design optimisation. MFT has a pre-existing floc structure created by organic byproducts of the oil extraction process and this increases the chemical dose required to achieve optimal flocculation. When average mixing conditions are applied to oil sands thickener tailings a much lower dose of 400 g/t for optimal dewatering is achieved. Figure 2 outlines how both MBI and mixing influence the dosage on a solid basis for the inline flocculation. As an example of how to use the chart, MFT typically averages an MBI of 9 but can be as high as 14. At a constant dose on a clay basis of 1,400 g/t, the expected solids-based dose is 900 g/t for an MBI of 9 MFT and 1,400 g/t for an MBI of 14.

It is our expectation that inline flocculation outside of the oil sands should be able to achieve 11–15 nm of dewatering at a flocculant dose of ~400 g/t of clay. By measuring the MBI of the tailings, Figures 1 and 2 can be used to estimate the dewatering and chemical dose performance of an inline flocculation technology. If inline flocculation has been attempted and results were a higher dose or poorer dewatering performance than described here, it is likely due to unoptimised mixing parameters.
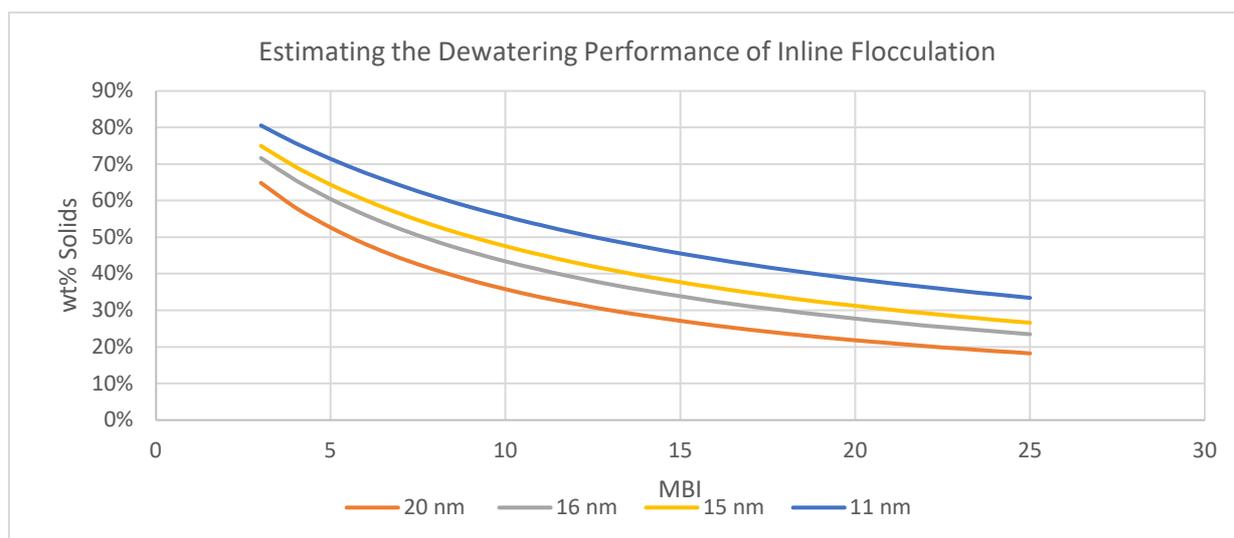

Figure 1   Effect of methylene blue index (MBI) on weight percent solids depending on the amount of water residual around the clay after flocculation. The lower the MBI, the higher the solids achievable after flocculation
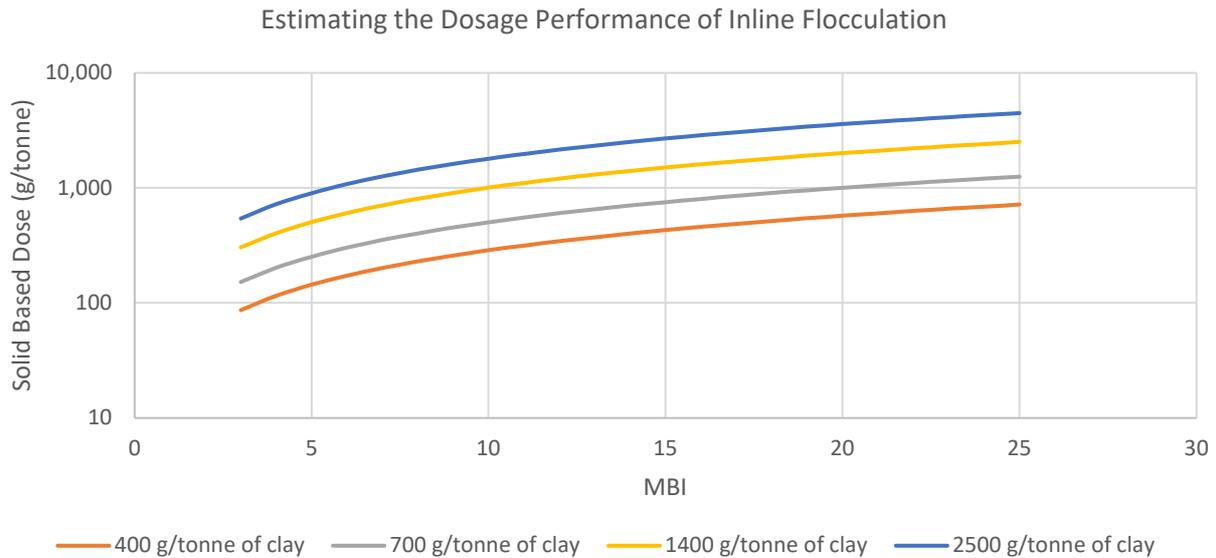
Estimating the Dosage Performance of Inline Flocculation

Figure 2 Influence of methylene blue index (MBI) on the solid-based dose depending on the level of clay-based dose that can be achieved based on optimisation of mixing and flocculant chemistry

3 Mechanics of slurry and polymer flows

In the Paste chapter the importance of increasing mixing energy and characterisation of the fluid flow are outlined. This needs to be taken in the context of the materials on which the process was designed. MFT, which is on average ~30% solids, ~10 Pa yield stress Bingham fluid. It needed to be at high flow rates (> 500 m³/hr in a 32.4 cm pipe or > 400 rpm in a laboratory paddle mixer) to achieve turbulent mixing. Due to the high level of clay in MFT the flocculant causes a rapid rise in the yield stress, resulting in the fluid in the pipe transitioning to laminar flow around two seconds after initial injection. To mimic the transition to laminar flow in the laboratory paddle mixer, the rpm had to be turned down to 100 or 50 rpm once the peak yield stress was observed, which denoted the completion of polymer dispersion. The peak yield stress can also be inferred using maximum torque on the paddle, or the maximum floc size using a focus beam reflectance measurement (FBRM) either inline or in the paddle mixer. A description of the equipment used for the torque technique is shown in Revington et al. (2017) and Aldaeef et al. (2022) gives a good literature review of this technique. The FBRM is a well-known technique, with De Clercq et al. (2003) and Swift et al. (2004) being the starting point for the use in oil sands inline flocculation.

It was observed that higher flow rates through the inline injector and higher initial rpms in a paddle mixer prior to peak yield stress led to better dewatering outcomes and lower flocculant doses. This can be observed in Figure 3 on the bottom left, with data from Diep et al. (2014), where laminar/transitional conditions below 450 m³/hr in a 30.48 cm pipe showed poor dewatering outcomes but a very rapid increase in water was observed above 500 m³/hr once in a fully developed turbulent flow. The data from the paddle mixer in Figure 3 in the top left, from Revington et al. (2017), shows the same pattern with increasing dewatering and lowering of dose up to 700 rpm, with a reversal observed at 900 rpm where the dose has increased and the dewatering has decreased.

It was found in Diep et al. (2017) that if MFT was diluted down to 10–20 wt% solids typical flow rates inline and typical rpms in the paddle mixer showed the same pattern as 900 rpm did for the undiluted MFT, they became detrimental to dewatering and increased the polymer dose. It was discovered that a variable called the 'Reynolds number over Reynolds number transition' (Re/Re$_T$) could collapse the low solids (< 20 wt%) and the high solids (> 30 wt%) MFT dewatering and dosage performance together. Equations 1 to 5 show how to create the Re/Re$_T$ term. First, we generate the Reynolds number by knowing the velocity, density, viscosity and pipe diameter of the system. Then the Hedstrom number is calculated by knowing the yield

stress, density and diameter of the pipe over the viscosity. The Hedstrom number will then allow us to select which of Equations 3, 4 or 5 we should use for calculating the Reynolds number over transition (Re$_T$).

Two other factors mentioned in the Paste chapter but not expanded upon are the benefits of adjusting the polymer percent solution, and the influence of shear on the degradation of flocs. While the Paste chapter outlines the potential benefits of changing the polymer percent solution to match viscosities of feed fluid, it is also worth calculating and varying the Re/Re$_T$ of the polymer at the point of injection. The influence of turbulence on floc build-up, and shear on floc breakdown, have implications for extending the inline flocculation methods developed for oil sands MFT to other substrates. On the left side of Figure 3, data from Diep & Weiss from the commercial inline flocculation system and from Revington et al. (2017), created using the paddle mixer, both show an increase in net water release (NWR) with increasing Re/Re$_T$ but the commercial inline system achieves close to 60 wt% water release whereas the paddle mixer appears to plateau at 30% water release and then decreases at 900 rpm. The much higher shear rate intensity to Re/Re$_T$ in the paddle mixer limits the maximum floc size that can be obtained. A similar risk exists for pilot systems below a 5.08 cm diameter, where the increase in Re/Re$_T$ will be slower than the increase in shear rate, reducing the obtainable maximum floc size.

$$Re = \frac{\rho u L}{\mu} \tag{1}$$

where:

Re = Reynolds number

ρ = density of the fluid

μ = velocity

L = ipe diameter

μ = dynamic viscosity.

$$He = \frac{(\rho d^2)\tau}{\mu^2} \tag{2}$$

where:

He = Hedstrom number

d = diameter of pipe

τ = yield stress of the fluid.

$$He < 1{,}700 = Re_T = \frac{2{,}100}{1 + 0.00000083 \times LOG\ He^{13}} \tag{3}$$

where:

Re_T = transitional Reynolds number.

$$He > 1{,}700 - < 100{,}000 = Re_T = 80 \times He^{0.4} \tag{4}$$

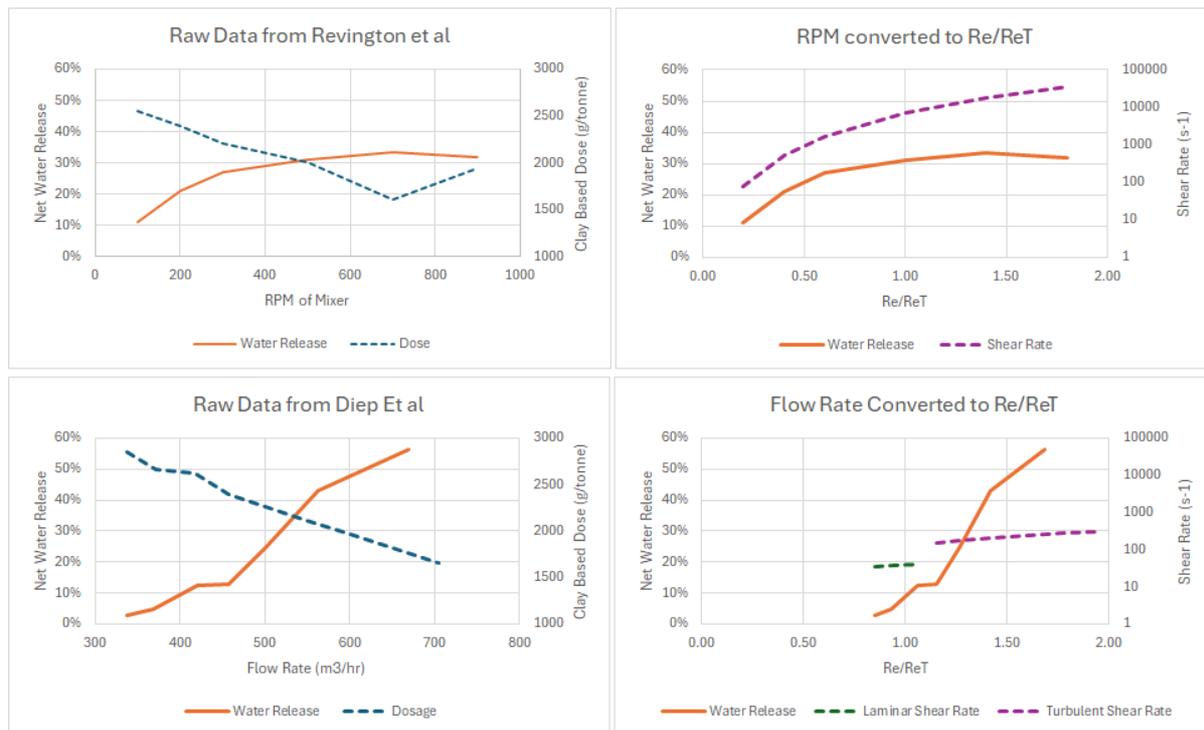$$He > 100{,}000 = Re_T = 25 \times He^{0.5} \tag{5}$$

Figure 3   Mature fine tailings paddle mixer from Revington et al. (2017). compared to a 30.48 cm line commercial facility from Diep et al. (2014), showing a pattern of increasing water release with an increasing Reynolds number, with the 30.48 cm line showing a much lower increase in shear rate

4   Polymer injection

In the Paste chapter, T-injection (a pipe fitting shaped like a T) and a design by Vrale & Jorden (1971) were outlined, with the latter being the successful injector for commercial MFT applications. This section presents a method adapted from Bourne (2003) and simplified using methods from the Handbook of Industrial Mixing (Paul et al. 2003) and Advances in Industrial Mixing (Kresta et al. 2015) that can be used to inform on inline injector design. When the Paste chapter was written it was thought that the Vrale & Jorden (1971) (VJ) injector could be directly used for other tailings substrates but, given the new knowledge, this may not be the case. The important consideration is that flocculation is a chemical reaction and must be considered as such. To determine the optimal design for dewatering, the extent to which mixing could be a problem for the substrate needs to be characterised. If there is a mixing problem, the type of mixing problem must be identified.

In the Paste chapter the term dispersion was outlined and defined as the mixing of the polymer and the tailings before the maximum floc size is reached. It was discovered that dispersion is a function of three mixing prefixes: macro-, micro- and meso-. Macromixing occurs on the scale of the reactor or a mixing facility. It sets the conditions of mass transfer through large-scale convection involving the entire volume of the reactor. Micromixing is characterised by diffusive mixing and deformation at the molecular level. Mesomixing (viscous diffusion) is usually lumped into macromixing and perceived through convective turbulence transport.

In a protocol developed by Bourne (2003), changes in the stirrer speed, feed rate, feed point position, number of feed points and viscosity of the solutions can be systematically varied to see if macromixing, mesomixing or micromixing timescales are important. In Figure 4 the Bourne (2003) protocol is adapted and simplified for use in a paddle mixer device such as the one outlined in Revington et al. (2017). More details on these methods and their use in the screening of chemicals are outlined in Sadighain et al. (2018). This simplified protocol can be used to evaluate how complex the polymer injection system needs to be.
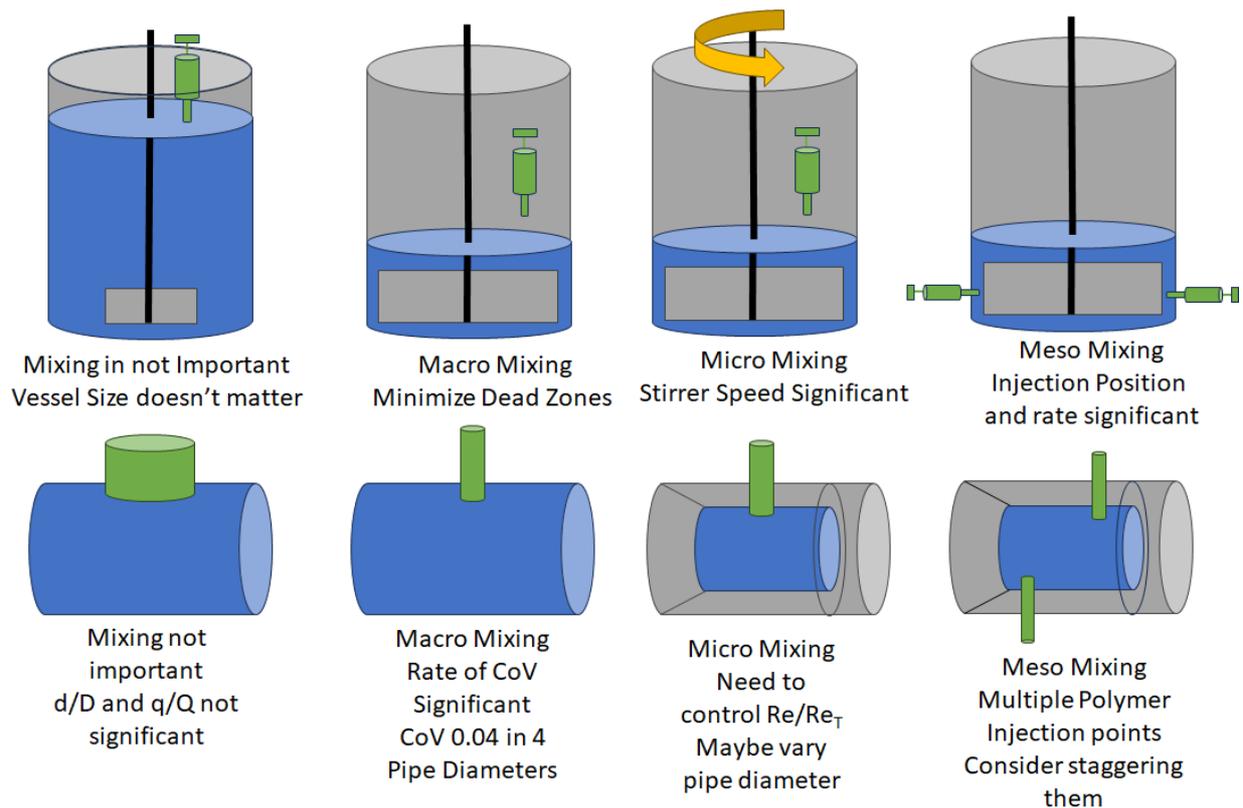
Figure 4   Using laboratory testing to determine whether a simple injector design or a complex injector design is needed for the application

The first test is to determine if there is a mixing problem. To accomplish this, the mixing rpm and polymer dose is kept constant but the volume of the tailings is varied. As an example, in oil sands the first flocculation experiments in the laboratory were based on paddle mixers used in waste water treatment, with a 1L-beaker and 700 mL of MFT and polymer injection from the top. This method did not lead to any dewatering outcomes with MFT. Dewatering was first observed when the vessel size was reduced to 400 mL and volume of the MFT was reduced to 300 mL. The key was getting all the MFT in contact with the mixer blades to minimise dead zones or caverns. If this experiment is attempted and there is no change in the dewatering or dosage outcome, it is likely that mixing isn't a significant factor and a simple T-injector could be used, with no attention paid to the flow rates or the size of the polymer injection pipe size. If mixing is significant then it means that the rate the polymer blends into the tailings feed is significant, so the diameter of the T-injector over the feed (d/Q) and the polymer flow over the feed flow (q/Q) both must be tuned to jet the polymer to the centre of the feed flow and optimise blending time. As an example in the oil sands work, it was found if the polymer was not rapidly blended into the tailings no dewatering was observed, which led to the use of the term coefficient of variation (CoV) from chapter 4 of the Handbook of Industrial Mixing (Paul et al. 2003). For MFT it was found that a CoV of 0.04 in four pipe diameters was the requirement, which means that all the polymer needed to be fully mixed in four pipe diameters from injection or in less than a second from injection.

The next test is to evaluate if micromixing needs to be factored into the injector design. This evaluation is accomplished in the paddle mixer by keeping the dosage range and volume of tailings the same while increasing and decreasing the rpms of the mixer. As already outlined in the top of Figure 3 (from Revington et al. 2017), MFT rpm was significant, with the highest water release and lowest dose being observed at 700 rpm, and higher stirrer speeds reducing water release and increasing the dose. As the bottom of Figure 3 (from Diep et al. 2014) illustrates, the commercial inline system with the VJ injector showed a similar response, increasing dewatering and decreasing dose with increases in Re/Re_T. For MFT this demonstrated that controlling the micromixing scale was also important.

The final test is to evaluate if mesomixing needs to be factored into the injector design. The simplest way to accomplish this is to keep the dosage range, rpms and volume of tailings the same and vary the rate of injection. In the initial MFT experiments the injection of the polymer was set at 50 mL/s and was thought to not be a significant factor. The consideration of the concepts of chemical mixing from the Bourne (2003) and Handbook of Industrial Mixing (Paul et al. 2003) led to the variation in the paddle mixer of the injection rate, number of injector points and their position, which together change the mesomixing time. Figure 5 shows an experiment with 300 rpm and the standard injection rate of 50 mL/s. The NWR was 30% with a clay-based dose of 2,400 g/t, while the same MFT at the same 300 rpm with an injection rate of 1 mL/s gave 35% NWR at a clay-based dose of 1,200 g/t. The VJ injector has eight polymer injection holes and was designed for the macromixing blending criteria of a CoV of 0.04. The number, size and position of the injection holes was not seen as significant so long as the polymer blended in within four pipe diameters. Once the significance of the paddle mixer results for mesomixing were understood, new injector designs were investigated. There is no direct way to translate mesomixing from the paddle mixer to the inline injector, but by varying the injector hole size, hole number and position around the VJ design, an optimised design was developed that halved the dosage and further increased the dewatering.
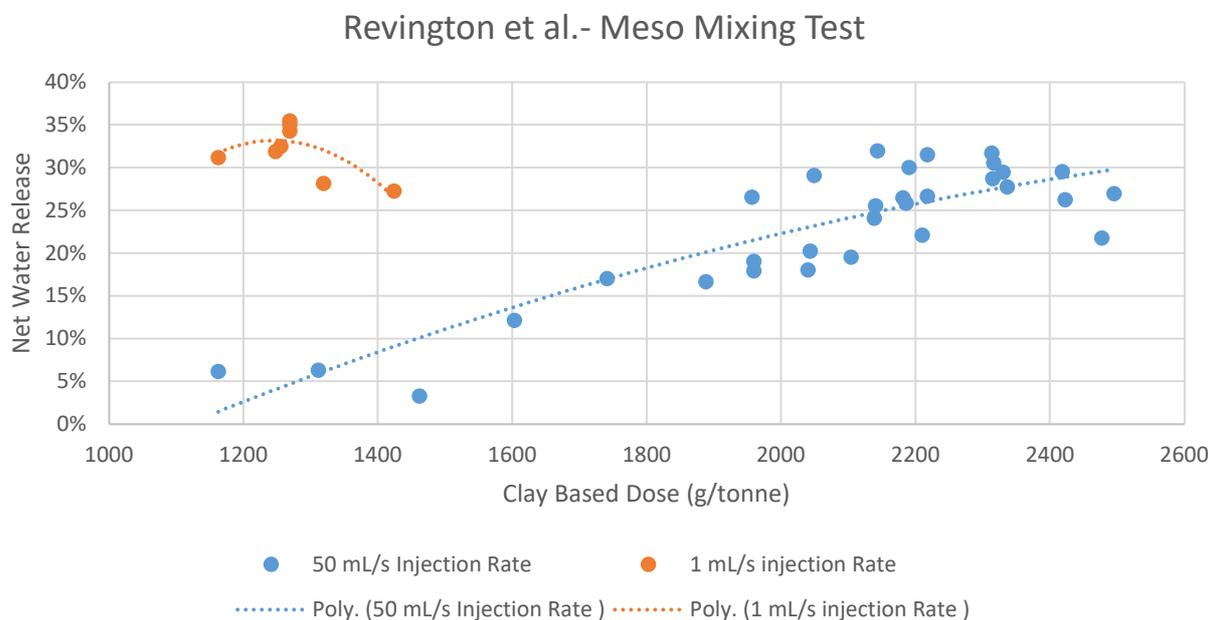

Figure 5 Using the same paddle mixing system outlined in Revington et al. (2017) in laminar mixing conditions of 300 rpm with different injection rates of 1 mL/s and 50 mL/s shows a shift up in water release and a shift down in dosage

In summary, the VJ injector design worked for MFT as mesomixing, micromixing and macromixing were all important factors, and it met the following criteria:

- blending criterion – CoV achieving a 0.04 in four pipe diameters
- turbulence criterion – achieving an Re/Re_T of > 1.2 at flow rates required for production
- injection criterion – multiple small polymer injector holes.

To determine the criteria and complexity of the injector required for other tailings, a simplified Bourne (2003) protocol as outlined in Figure 4 can be used. If just the macromixing test shows a dewatering or dose response, a blending criterion is needed. If a response is also seen in the micromixing test to change the rpm, then a turbulence criterion is required. If a response is also observed to the injection rate of the polymer, then the position, size and number of holes for the inline polymer injector will be significant, and an injection criterion will be required.

5   Conditioning and water release

In the Paste chapter, the approach with oil sands tailings was to split it into four separate processes: dispersion, floc rearrangement, floc breakdown/water release and overshear. As outlined in the previous section, dispersion or floc build-up was found experimentally to be dominated by chemical mixing phenomena, and the post-peak breakdown rate was dominated by shear and the time under the shear field (camp number) or the cumulative adsorbed energy.

The floc rearrangement and floc breakdown stage can also have mixing problems that are separate from the dispersion mixing problems. Calculating out the floc breakdown rate independently from the dispersion rate is another methodology to determine what type of mixing problem there may be. Figure 6 is a representation of a dispersion-type mixing problem that might be encountered. One method used to monitor the process is to place an FBRM device in the paddle mixer set-up. An alternative used in the Paste chapter example is to stop the mixing and perform a yield stress measurement and then restart the mixing. The FBRM will allow for monitoring of the peak of floc size, looking for a rapid onset of the peak yield stress. In MFT this typically happens before the 30 second mark. In a mixing problem scenario a delayed flocculation will be observed before the peak is reached. In a very poor scenario there will be no flocculation for an extended period and, once the peak is reached, an undulation around the peak strength will occur before a sudden drop off in yield stress. The peak floc size will typically be lower in a mixing problem scenario, so any optimisation of the mesomixing, micromixing or macromixing phenomenon should increase it.
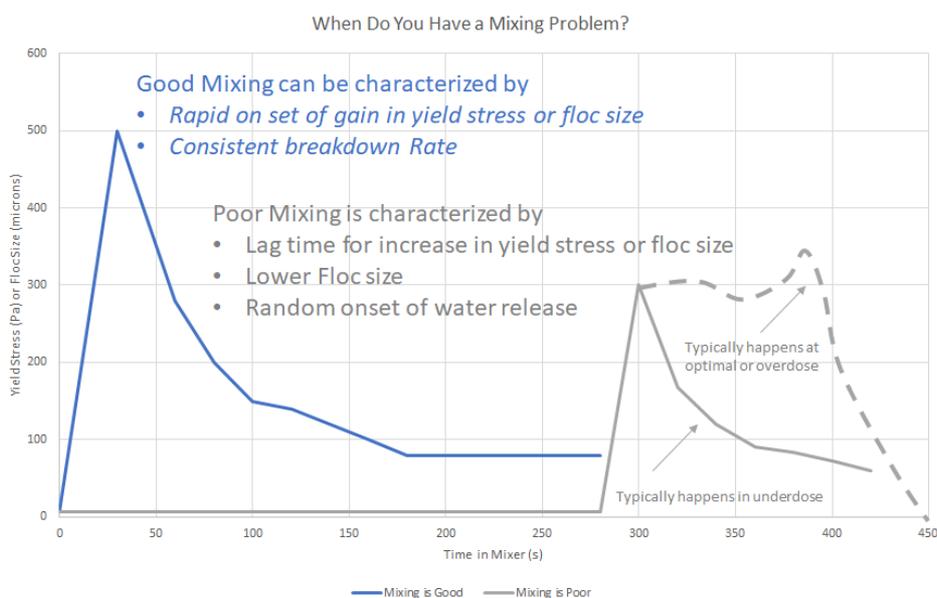

Figure 6   **Diagram showing the expected difference between a poor mixing system and a good mixing system. A good mixing system will display rapid and high floc size. A poor mixing system will show a delay in the increase of floc size or some undulation before reaching maximum floc size**

This mixing phenomenon can be illustrated by using some floc size to time data from Vajihinejad & Soares (2018), seen in the left-hand side of Figure 7. The raw experiment shows different flocculation outcomes in the FBRM at different shear rates. The raw data shows that the lowest shear rate gave the highest peak floc size, with the floc size decreasing as the shear rate increases and the time for reaching the higher floc size decreased. Examining the build-up, all the shear rates have a mixing problem. The two lower shear rates aren't building the floc size quickly enough and the higher shear rates aren't achieving a higher floc size. The lower shear rates are also showing an undulating pattern in building up to the peak floc size. In this case it looks like there is something wrong in the dispersion that means that the laboratory set-up is missing one or more of the mesomixing, micromixing or macromixing design parameters.

In the right-hand graph of Figure 7 the floc build-up data, or data prior to the peak floc sized measured by the FBRM, is removed. The floc breakdown data was then processed into a camp number (instead of mixing time) and a floc size ratio (floc size over peak floc size) instead of floc size. This allows for assessment of the breakdown rate. Examining the breakdown rate allows the addressing of another mixing problem which is critical for determining the appropriate distance from discharge to the injector. In the Paste chapter, Camp number scaling was outlined where the shear rate didn't matter as the camp number was the important factor (since the breakdown rate was a constant). Further experiments elucidated two important factors that weren't known when the Paste chapter was written. At a certain point, if the flow rate is dropped low enough, the breakdown rate decreases, meaning that at the end of the pipe the flocculated tailings will be undermixed or undersheared at discharge. At a high enough flow rate the breakdown rate increases, meaning that the flocculated tailings will be overmixed or oversheared at discharge. On the right side of Figure 7, the breakdown rate for the shear rates above 250 s^{-1} is about the same post-peak strength, but the 160 s^{-1} shear has a much lower breakdown rate.
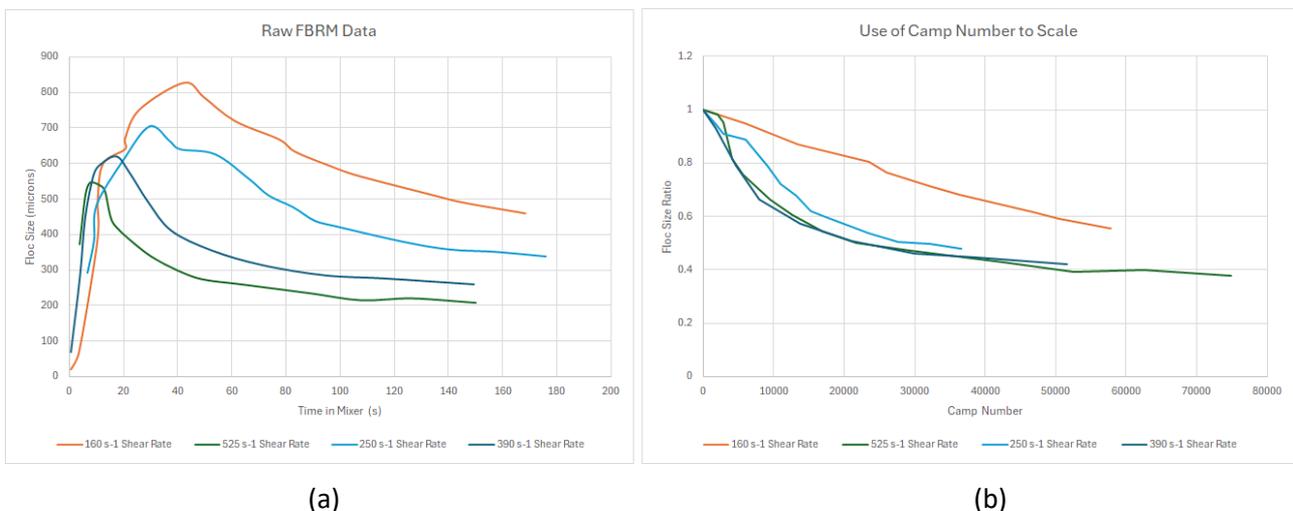

(a) (b)

Figure 7 **The effect of camp number scaling on Vajihinejad & Soares (2018) shear experiments showing two important factors. (a) Once the poor initial mixing has been removed the breakdown rate is similar for 250–390 s-^{1}. (b) At a low enough shear rate the breakdown rate can be reduced**

To set-up the position of the injector prior to deposition two factors must have been established: first, that dispersion is consistent, by understanding and optimising injector design; and secondly, that the constant breakdown rate of the tailings at operational flow rates and feed solids occurs. Once these two factors have been met the inline flocculation system will give consistent camp numbers for maximum dewatering, allowing a process to be designed.

As outlined in the Paste chapter, the paddle mixer can be used to estimate the distance to place the injector prior to the end of the pipe to produce maximum water release. Figure 8 shows an example of this from the development of the inline oil sands system. The Paste chapter only used a single feed example, so on the left side of Figure 8 the full range of solid content data from Sanchez et al. (2013) is brought in. On the right side of Figure 8 this is converted over to yield stress ratio and a camp number. The maximum water release occurs at a camp number of 2,000 and one third of the peak floc size or yield stress. Figure 9 shows calculations of the camp number for the 30.48 cm pipe and determines that 80 m of pipe should be required for maximum dewatering. This compares very well with the 86 m used in the commercial system for oil sands.
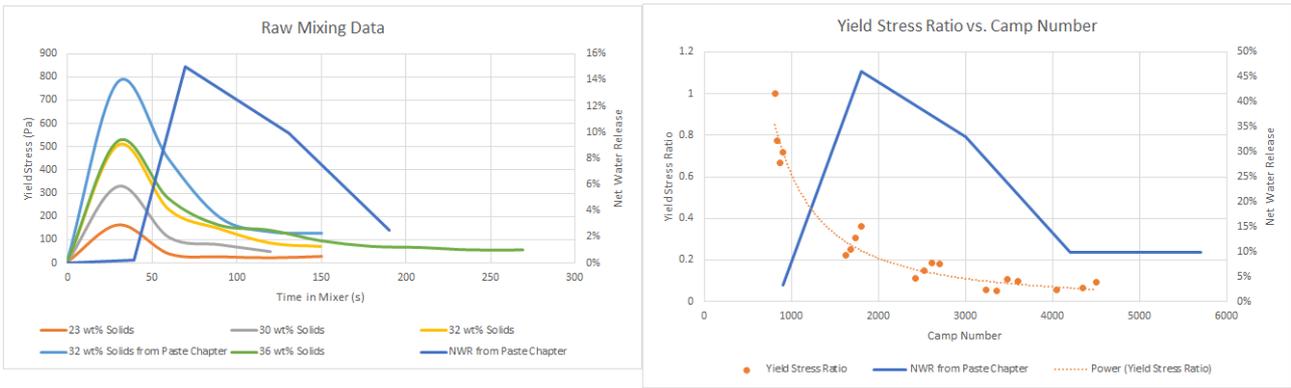
Figure 8 Combination of Paste chapter and Sanchez et al. (2013) data showing that all mature fine tailings feed solids have a similar breakdown rate and a water release onset at a camp number of 2,000
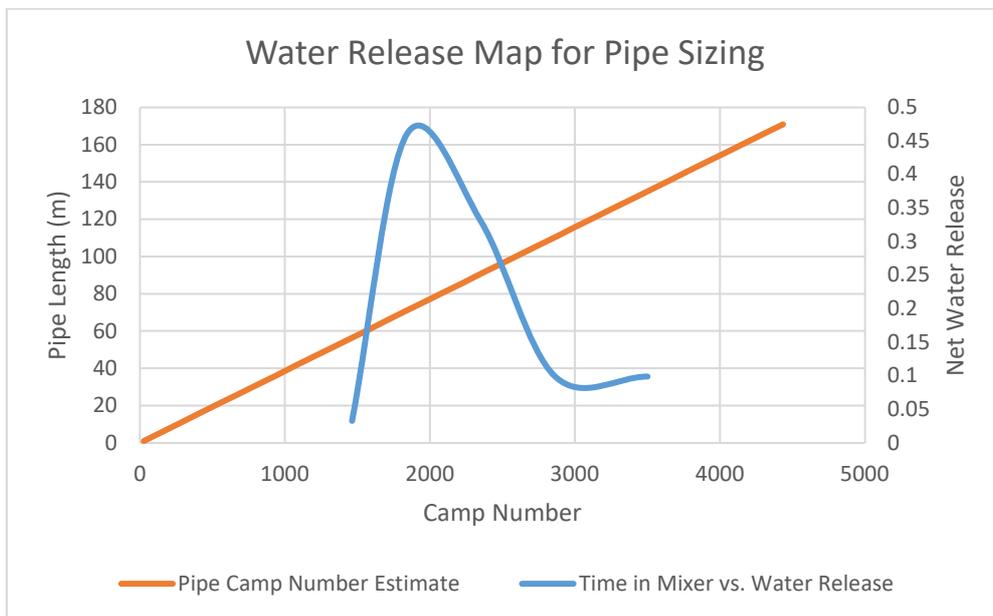

Figure 9 The 10.16 cm (4") cup data suggests that in a commercial 30.48 cm (12") pipe system around 80 m should be the peak of water release. The commercial system was designed with 86 m based on an iterative approach outlined in Wells et al. (2011)

6   Conclusion

Since the publication of the *Paste and Thickened Tailings Guide* (Jewell & Fourie 2015), ongoing testing and technical development within the oil sands industry has continued. Conducting this work with some of the most challenging tailings materials, and with the objective of achieving dewatering at unprecedented commercial scales, application of this technology required significant developments in the understanding of the fundamental science and engineering.

Since the 2015 Paste chapter, developments have resulted in the ability for laboratory testing of tailings materials to better identify design requirements for full-scale engineering of inline systems capable of dewatering tailings to levels not achieved by other technologies. Use of this inline technology offers the opportunity for significant reductions in capital costs to dewater tailings. Practitioners looking to achieve these dewatering rates at commercially viable flocculant dosages must understand these developments in the fundamental science as well as the translation of laboratory-scale to full-scale operation. It is hoped that through further and ongoing development and publication, the utilisation of inline flocculation will result in performance and cost improvements for operators, as well as reduce the risks associated with fluid tailings deposits.

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