Paste 2025 – AB Fourie, A Copeland, V Daigle & C MacRobert (eds)

doi:10.36487/ACG_repo/2555_11

Tailings particle size distribution methodology: the good, the bad, and the ugly

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Abstract

The determination of particle size distribution (PSD) is a critical aspect in the characterisation of mine tailings, influencing engineering assessments, particularly in the areas of thickening, rheology, transport and deposition. This paper critically evaluates various methodologies used to determine the PSD of tailings, with a focus on fractions smaller than two millimetres. The study highlights the variations in methodologies, particularly emphasising the inadequacies of traditional techniques originally developed for weathered soils, which are often inappropriately applied to freshly ground rock tailings. Through a comprehensive comparison, the paper identifies the strengths and limitations of each method, exposing outdated practices that may lead to inaccurate PSD results. The discussion culminates in a recommendation for the most suitable methodology for tailings PSD determination, considering the unique properties of tailings material. The findings aim to guide consultants and site-based personnel in selecting the most reliable and accurate techniques for tailings PSD analysis.

Keywords: *tailings, particle, distribution, PSD, laser, diffraction, sieve, hydrometer*

1 Introduction

1.1 Overview

Particle size distribution (PSD) provides a key input parameter in the analysis and management of mine tailings, impacting engineering decisions related to thickening, rheology, transport and deposition processes. In this paper, we provide a critical evaluation of the primary methodologies employed to determine the PSD of run-of-mine tailings that typically consist of particles smaller than two millimetres. The study provides variations in existing commonly used methods and highlights the limitations of traditional techniques, which are often adapted from weathered soil analysis and inadequately applied to freshly ground rock tailings. The strengths and weaknesses of each approach are examined, revealing outdated practices that could lead to erroneous results. The paper concludes with recommendations for the most suitable methods tailored to the wide variation in tailings characteristics, providing practical guidance for consultants and site-based personnel in achieving accurate and reliable tailings PSD analysis.

Detailed fundamentals into general particle size, shape and distribution are not discussed in this paper. A book by Han Merkus entitled *Particle Size Measurements: Fundamentals, Practice, Quality* provides a very good introduction to particle size measurements for a range of material types (Merkus 2009).

1.2 Multidisciplinary approaches to tailings particle size distribution determination

It is important to understand that in the mining industry, many engineers and scientists have different academic and training backgrounds whereby their knowledge of PSD can be specific to a particular discipline which may not be related to the mining industry. It is also common, particularly for civil and geotechnical

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engineers, to work with PSD that is much coarser than run-of-mine tailings, where sieving methodology is predominantly used to determine construction material grading, such as for tailings dam embankment construction. Applying methodologies that are typically used in the environmental, soil mechanics, geology and civil engineering fraternities to mine tailings can lead to errors in the accuracy of particle size determination, particularly for finer fractions.

Different disciplines use various terminologies to refer to the concept of PSD based on their specific needs and practices. For instance, terms like D80, X80, P_{80}, F_{80}, d80, cutoff size, cumulative size at 80% or 80% passing size are commonly used to represent the particle size at which 80% of the material, usually by weight, is finer. In geotechnical engineering, percentile notation, such as the 80th percentile, is often used to describe granular material characteristics. Similarly, other fields may refer to mesh size or sieve size numbers to indicate the size of particles that pass through a given screen. Additionally, when presenting PSD graphs, some disciplines plot the data from left to right and others from right to left, depending on convention and historical practices within each discipline.

The key disciplines involved with using tailings PSD data for design purposes are typically metallurgists, process engineers, civil engineers, geotechnical engineers and mining engineers. Run-of-mine tailings characterisation is key for process plant design and operation, including the tailings dewatering and handling system, the tailings transport system, the tailings storage facility (TSF) design and deposition arrangement. TSF personnel are also interested in the tailings PSD to understand variations observed in dewatering, rheology and deposition that can occur on a day-to-day basis.

When considering the key disciplines that interact with tailings PSD data, the range of interest often dictates the methodology used to determine the PSD. For example, a metallurgist focused on plant design, debottlenecking or operational optimisation is primarily concerned with the coarser fraction of the PSD curve, specifically the P_{100} to P_{50} range. This portion is critical for understanding grinding kinetics and optimising the recovery versus throughput model. Below P_{50}, the PSD becomes a ‘consequence’ of the grinding and flotation circuit design or upgrades, with the finer fraction impacting aspects such as reagent consumption and minor adjustments in transfer box performance due to changes in rheology. These finer particles, while relevant, pose relatively minor cost and design implications compared to the coarser fraction, which is of greater importance for processing design and operation. This is why metallurgists prefer sieving as a PSD methodology as it generally covers the size range of importance (3,000 to 37 micron), is quick and cheap, and has good repeatability. The sieving lower boundary can typically be Tyler Mesh 200 (75 micron) or Tyler Mesh 400 (37 microns). Finer sieving is achievable, but the mesh is much more fragile and not well suited to a metallurgical environment.

In contrast, for a tailings-focused engineer working on dewatering, the fraction passing 50 micron (P_{50}) is of primary concern and well beyond the finer mesh sizes used in sieving techniques. The fines, ultra-fines and clay fractions significantly affect the performance of thickeners, filters, pumping systems and the deposition behaviour of tailings, as well as water recovery and in situ density within the TSF. Finer tailings, particularly those with higher clay content and activity, increase rheology at the same solids concentration when compared to a coarser stream. Although the coarser fractions (P_{100} to P_{80}) influence faster settling through better colloidal stability and reduced hindered settling in thickeners, potential sanding in pumping systems and segregation along the tailings beach can be a concern. However, on balance, the finer fraction of the PSD curve is far more critical to design and performance in terms of dewatering, handling and storage for a specific project.

Figure 1 provides a general overview of the principal range of importance of a tailings PSD curve for a coarse grind base metal project having a target P_{80} of approximately 150 microns. Disciplines and their key range of interest in PSD in general is provided as a guide. The operating range of typical PSD measurement methodologies is also provided.

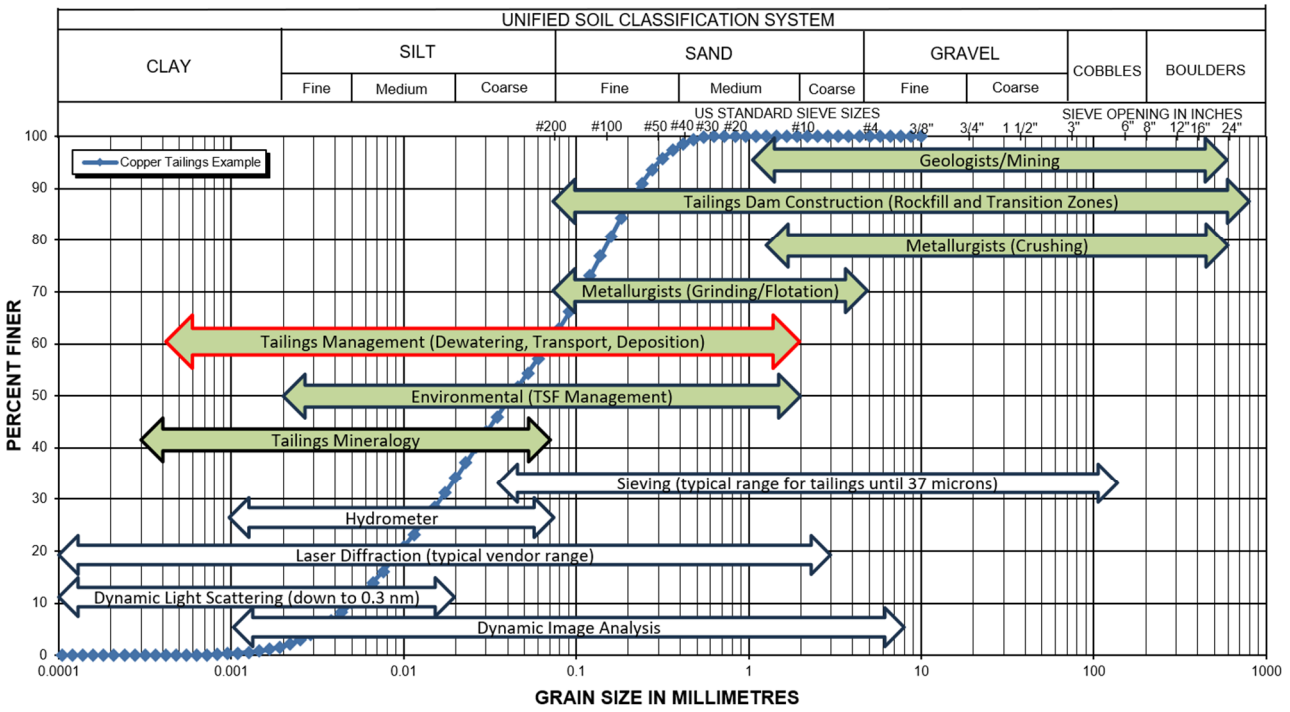

Figure 1 Comparison of typical base metal tailings particle size distribution with primary regions of interest of key disciplines and activities relating to tailings generation and handling

1.3 Understanding particle size measurement methodology

A spherical particle is easily characterised by a single value, its diameter, since all dimensions are equal. However, for non-spherical particles such as coarse fresh ground tailings (in most instances), multiple measurements such as length and width are needed to accurately describe their shape (Horiba Instruments Inc 2016). While these measurements offer more precision, they also introduce added complexity in how to determine a PSD, particularly when considering a particle is a 3D object and 2D measurements may not determine the correct geometry. To simplify the process, many analytical methods assume particles to be spherical, reporting a value known as the equivalent spherical diameter (Rawle 2000; Merkus 2009). This approximation provides a practical way to handle irregular particles in size analysis. Weathered soils tend to be more well-rounded and with a high sphericity compared to freshly ground hard rock minerals, which tend to have low sphericity and are very angular (Powers 1953).

Where the aspect ratio is large (such as in fibrous minerals, phyllosilicates and delaminated clays found in tailings), larger result variations occur between measurement methodologies. This is called the shape factor influence and can lead to discrepancies when different particle size analysers are used for the same sample as each technique measures size based on its own physical principles. For instance, a sieve tends to highlight the second smallest dimension of a particle due to the way particles orient themselves to pass through the mesh. The sedimentation process, such as a hydrometer method, measures how quickly a particle falls through a viscous medium to relate sedimentation rate to particle size, with interactions from other particles or container walls slowing its movement. Flaky or plate-like particles will orient to increase drag, resulting in a smaller reported size. Meanwhile, a light scattering device averages the particles' various dimensions as they move randomly and repeatedly through the light beam, producing a size distribution ranging from the smallest to the largest dimensions.

The particle size measurement methodologies typically applied to tailings are as follows (in order of most common):

- sieve analysis (typically > 38 microns)

- sieve analysis with hydrometer (typically > 75 microns for sieving and < 75 microns for hydrometer)
- laser diffraction (typically 3,000 microns to 0.01 microns).

As mentioned in the previous section, the primary reason that sieve and sieve/hydrometer analysis are used for tailings characterisation is mainly due to international standardisation and the wide use of these techniques in the environmental, geology, geotechnical and civil engineering fraternities. Metallurgists also rely on sieving for their standardisation during laboratory and piloting trials as well as process plant design purposes where PSD relating to feeds, recovery and tailings streams (e.g. rougher, scavenger, cleaner and final) is typically documented and used by consulting engineers for initial design purposes and carried through to the later stages of design as an initial benchmark.

Other particle size measurement methodologies that are much less common for tailings as they are more expensive, time consuming and/or limited in their measurement range are:

- microscopy (optical or electron)
- dynamic image analysis
- dynamic light scattering (typically < 10 microns).

2 Sieve analysis with/without hydrometer

2.1 Overview

Sieve analysis combined with hydrometer testing is a common method used to determine the PSD of tailings and is a methodology utilising mass fraction. The sieve analysis portion typically measures particles larger than 75 microns (200 Mesh) using a series of sieves with decreasing mesh sizes. The finer fraction, usually particles smaller than 75 microns, is analysed using a hydrometer test, which measures the rate at which particles settle in a suspension to infer their size distribution based on Stokes' Law. Standards such as ASTM D422-63 (*Standard Test Method for Particle-Size Analysis of Soils*) (ASTM International 2007) or ISO 11277:2020 (*Soil Quality – Determination of PSD in Mineral Soil Material*) (International Organization for Standardization 2020a) are typically referenced for these tests within the tailings industry. ASTM D422-63 was withdrawn in 2016 and replaced with D6913 (*Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*) (ASTM International 2017b) and D7928 (*Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*) (ASTM International 2021). These two new standards address issues with D422, which was seen as insufficient for some soil types, and the newer standards offer more precise methods tailored to specific particle size ranges. The original ASTM D422 standard was published in 1935 and although it has undergone various revisions, the use of a soil hydrometer for particle size analysis became widely adopted after its formal inclusion in the standard.

An important observation is that the previous ASTM and ISO standards mentioned, and their application, relate to soils and not tailings. Soil is created over long periods through the weathering of rocks and the decomposition of organic material which is very distinct to tailings, particularly freshly ground and milled ores. The ISO 11277 standard also quotes that the chemical pre-treatments and mechanical handling stages of the standard could cause disintegration of weakly cohesive particles. It is also noted that the standard was developed largely for use in the field of environmental science, and its use in geotechnical investigations is something for which professional advice might be required (ISO 2020). Interestingly, the new ASTM D7928 quotes that the standard is not applicable to soils containing extraneous matter, such as organic solvents, oil, asphalt, wood fragments, or similar items (ASTM International 2021). Tailings commonly contain trace processing reagents and solvents.

Stokes' Law assumes particles that are rigid, spherical and smooth are used as part of the hydrometer analysis. Tailings, particularly those derived from freshly ground and milled ore, do not generally match the requirements of Stokes' Law and generate inaccuracies, particularly for very fine particles (e.g. clay), where

particle shape, non-spherical particles and flocculation can affect sedimentation rates as part of the calculations of the standard (even when dispersing agents are used).

2.2 Applicability for tailings particle size distribution analysis

The following subsections provide some advantages and disadvantages of using either a sieve-only analysis or a sieve combined with hydrometer analysis for determining the PSD of tailings.

2.2.1 Sieve-only analysis (typically > 38 microns)

Advantages:

- Sieve analysis is a straightforward process that does not require complex equipment or specialised training.
- The equipment for sieve analysis (i.e. a set of standard sieves, shaker, oven and balance) is relatively inexpensive compared to more advanced methods like laser diffraction and other analytical process methods.
- Sieve analysis is governed by well-established standards like ASTM D6913 (*Particle-Size Distribution of Soils Using Sieve Analysis*; ASTM International 2017b) and ISO 13320 (International Organization for Standardization 2020b); albeit they are intended for soils.
- Sieve analysis can be performed on relatively large quantities of material and therefore may test a more representative sample of the bulk tailings.
- The equipment can be easily carried to site and tests performed where electricity and specialist equipment are not available.

Disadvantages:

- Sieve analysis is less effective for particles smaller than 75 microns (such as silts and clays), which are common in tailings. The use of a hydrometer is therefore recommended by international standards (for soils).
- Sieve analysis can be labour-intensive, especially for large sample sizes or when a wide range of particle sizes needs to be separated. Cleaning the sieves between tests and performing multiple trials can also add to the time required.
- The manual nature of sieving (i.e. not using a programmable sieve shaker) introduces the possibility of human error, such as an improper sieving technique, incorrect weighing or inconsistent shaking times. This can result in variability between tests.
- Sieve analysis only provides information on particle size and does not account for particle shape (unlike optical techniques such as laser diffraction).
- Fine particles may clog the sieve mesh (blinding) or the mesh may become perforated, causing inaccurate results.
- Tolerances of sieves during their construction are considered high. A 75 micron sieve can have tolerance of spacing of 70–80 microns, depending on the vendor. These tolerances also change as the sieve is used.
- Errors are cumulative on the sieves: more sieves in the stack means more errors are introduced.
- Different shaker methodology (using Ro-Tap® Series, Endecotts sieve shakers, tapping sieve shakers or electromagnetic vibratory sieve shakers) introduces variability in the final results.

2.2.2 Hydrometer (< 75 microns)

Advantages:

- Hydrometers are cheap and quick to implement.

Disadvantages:

- Hydrometers are not standardised for tailings, only soils.
- Hydrometers are not applicable for tailings with trace solvents, such as tailings generated from flotation, leaching and counter current decantation (CCD) circuits. Also, they are not applicable to oil sand tailings.
- Hydrometers require suitable preparation and the use of a dispersant reagent.
- Hydrometers require a specific stirring apparatus, dispersion cup and paddle dimensions (ASTM D7928-21; ASTM International 2021).
- Temperature control is necessary throughout the test period to prevent changes in the viscosity of the suspension fluid. In some cases, density correction needs to be applied and/or a liquid control cylinder used in parallel to the sample test.
- Reading a hydrometer suspended in a fluid can lead to errors in the misinterpretation of the meniscus. It is also very difficult to obtain a zero reading using a soil hydrometer in potable water.
- If the particles are slow settling, the time frame of running the test can exceed 24 hours.
- The different specific gravity of certain minerals in a sample can lead to variable settling.
- Trace process reagents (particularly surfactants), either in the suspension liquid and/or attached to the particle surface, will change the buoyancy properties of certain minerals. Some solids may float to the surface during the test.
- Elevated quantities of fines in tailings samples are generally reported in the results as the hydrometer becomes less efficient at measuring the finer fraction.

3 Laser diffraction

3.1 Overview

Laser diffraction is a widely used methodology for determining the PSD of various materials, including tailings, based on the principle of light scattering. In laser diffraction, particles are passed through a laser beam, and the angle and intensity of the light scattered by the particles are measured (most modern equipment uses the Mie theory of light scattering). Unlike the sieving and hydrometer methodology, which is mass based, laser diffraction uses a particle volume analysis to determine the distribution. This method allows for the rapid and precise measurement of a wide range of particle sizes, from sub-micron to several millimetres, without the need for extensive sample preparation or lengthy settling times, as in hydrometer analysis. Importantly this range of measurement is a single measurement mechanism (i.e. not a combination of two methodologies to generate a complete PSD curve) typically suited to understand the coarse to ultra fine fraction needed to recognise behavioural changes relating to tailings dewatering, transport and deposition. Additionally, laser diffraction does not rely on the assumption that particles are rigid, spherical or smooth, making it more suitable for materials like tailings, which may contain angular particles with irregular shapes. Common standards such as ISO 13320:2020 (*Particle Size Analysis – Laser Diffraction Methods*) (International Organization for Standardization 2020b) and ASTM B822-17 (*Standard Test Method for PSD of Metal Powders and Related Compounds Using Laser Diffraction*) (ASTM International 2017a) are often referenced for laser diffraction analysis.

Care must be taken to avoid potential pitfalls in laser diffraction such as improper dispersion of the sample, which can lead to particle agglomeration and skewed results. ISO 13320:2020 highlights the importance of ensuring adequate dispersion, especially for cohesive or material such as fine-grained tailings, to prevent inaccurate size distributions from being reported.

3.2 Applicability for tailings particle size distribution analysis

The following provides some advantages and disadvantages of using laser diffraction methodology for determining the PSD of tailings.

Advantages:

- The range of operation is mostly suitable for tailings grading to consider a single measurement mechanism (typically 3,000 microns to 0.01 microns, depending on the equipment vendor).
- Measurement time is typically a few minutes.
- Trace reagents don't typically impact the results.
- No settling properties are needed to understand particle size measurements; therefore variation in mineral specific gravity and surfactants changing the amphiphilic properties of tailings (used in flotation, for example) do not impact the results.
- It can be used for both liquid suspension and dry sample applications (liquid suspension is preferred).
- A laser diffraction unit does not require calibration. Methodology is grounded in fundamental scientific principles. Vendor audit standard samples are sometimes used if validation is needed.

Disadvantages:

- Equipment can be expensive and sensitive to dirty laboratory environments such as metallurgy and onsite mine assay laboratories.
- The refractive index of the primary minerals and dispersing medium properties needs to be preset based on the material type to be tested at the time (Mie theory).
- Air bubbles in the recirculating feed can be detected as particles. Mixer speed and dispersive medium volume need to be consistent.
- Samples size is small and might not represent the batch. Repetitions are necessary to confirm representability.
- Improper dispersion of the sample can lead to particle agglomeration and skewed results. Most wet dispersion instruments are equipped with ultrasonic ability to assist in preventing this.

4 Comparison of methodology results and typical errors

Sampling errors are the primary source of variation in particle sizing determination, particularly when measuring larger particles. This is inherent in any methodology used, particularly those that require small sub-samples such as laser diffraction. Section 5 of the paper provides a recommended workflow for measuring a tailings PSD (when the P_{100} is less than 3 mm) using laser diffraction methodology. However, if we consider that the sampling error is minimised it is interesting to compare mass versus volume PSD results.

4.1 Sieve with hydrometer and laser diffraction

As mentioned previously in this paper, sieving and hydrometer are two different particle size measurement methods that are presented on the same graph. It is common to observe a discrepancy or 'jump' at the intersection of these methods, which is typically either displayed as smoothed out or as is, with the latter approach aligning with ASTM standards. For tailings, particularly flotation tailings, fine particles below

30 microns often show higher percentage passing values in sieving/hydrometer tests compared to laser diffraction (as described in Section 2.2.2). Figure 2 illustrates this scenario by displaying PSD curves from various samples of a large mining project using laser diffraction, with sieving and hydrometer test results (in blue) overlaid. The sieving results generally align with laser diffraction data down to 75 microns, while the hydrometer results show elevated readings across the three samples. In this case, the client faced a discrepancy between tailings dam design consultants who conducted the sieving and hydrometer tests and the metallurgical laboratory that prepared the tailings samples and used laser diffraction. Ultimately, the hydrometer results were deemed inaccurate as they suggested nearly 13% of the tailings feed was under two microns, which would have negatively impacted the dewatering performance observed in prior testwork. Additionally, the unsheared and fully sheared rheology values would have been significantly higher if the material was indeed this fine. This example highlights the challenge of validating PSD methodologies, especially when multiple end users conduct independent analyses for their appropriate design purposes; each defending their results even when discrepancies arise.

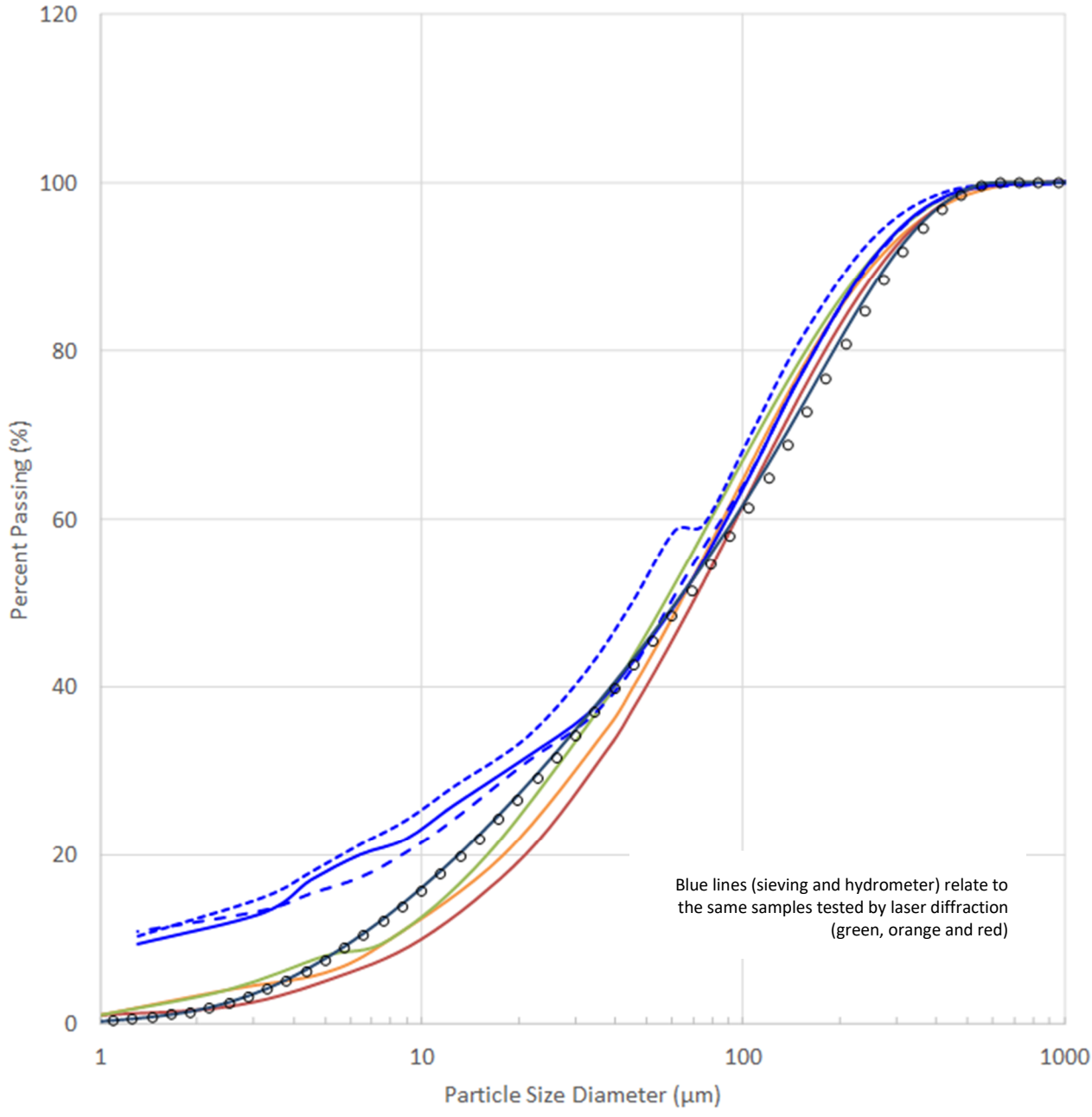

Figure 2 Sieving and hydrometer results (in blue) overlaid on laser diffraction data for the same samples

Figure 3 shows results from another project of six variability samples of flotation copper tailings (representing different phases of the orebody), where a university-accredited laboratory performed sieving and hydrometer analysis to ASTM D422 standards. The samples sent were previously measured by laser diffraction and are compared. It is clear there is some sampling error impacting the coarser fraction, but results highlight that the hydrometer consistently measured more fines compared to laser diffraction. It is also interesting to note the difference between the two methodologies in the central part of the curves around the P_{60} to P_{40} data range, where the hydrometer presented a much coarser distribution.

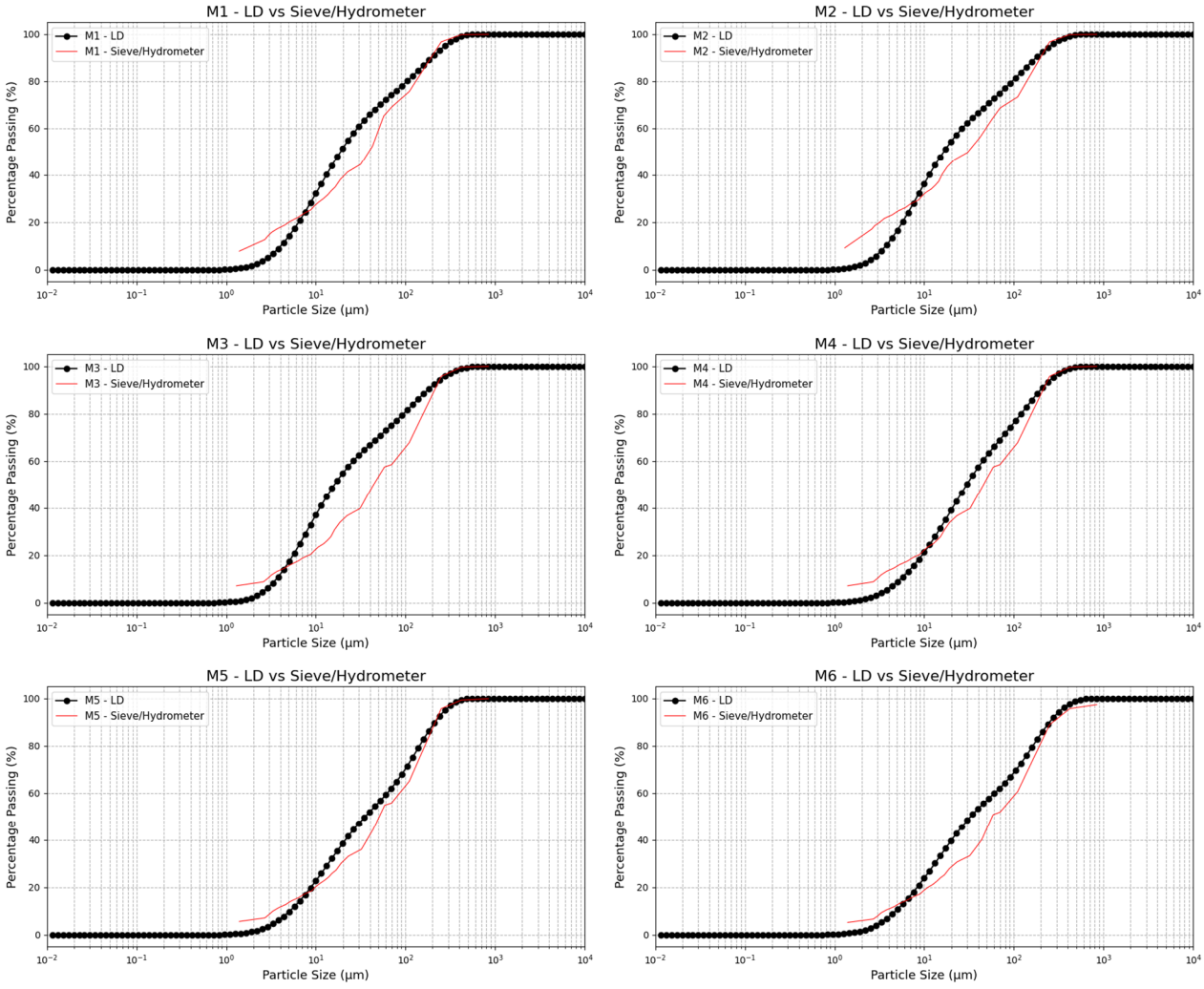

Figure 3 Sieving and hydrometer results compared to laser diffraction data for six tailings variability samples

4.2 Poor presentation of tailings particle size distribution

There are different methods of presenting tailings PSDs, such as presenting the data from left to right or right to left, and different terminology. Some vendors and consultants also combine methodologies on a single graph whereby sieving is used until 75 microns and, rather than using a hydrometer, the laser diffraction method is utilised, with all material passing 75 microns combined with the results of the sieve analysis. This is considered very poor practice as part of the PSD is measured through a mass analysis and another part of the curve is measured through an optical volume analysis. In almost all cases the two points of the curve will not match, and a break is observed in the intersection between the two methodologies (which is normally joined by a straight line). This has been seen by well-known international consultants and vendors within the tailings fraternity and Figure 4 provides an example.

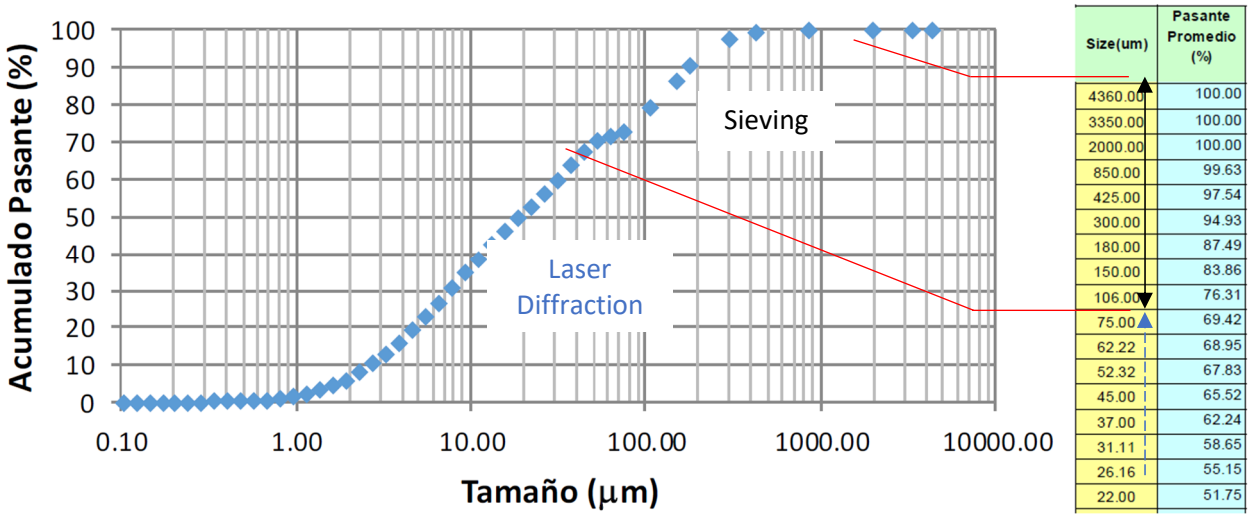

Figure 4 Combining sieving results with laser diffraction results on the same graph (note the jump in the dataset at the point of union)

Figure 5 is a graph from a dewatering vendor report that shows in grey the laser diffraction they conducted with their equipment, and in blue, a sub-sample that they sent to an accredited laboratory to conduct sieving and hydrometer analysis. It shows that the initial measurements made with the hydrometer generated a very flat part of the curve between 50 and 75 microns and, in general, the hydrometer part of the curve is very undulating and would not represent the true nature of a PSD. This sieving and hydrometer analysis should have been repeated or removed from the report. This is another example of the importance of presenting a single PSD methodology.

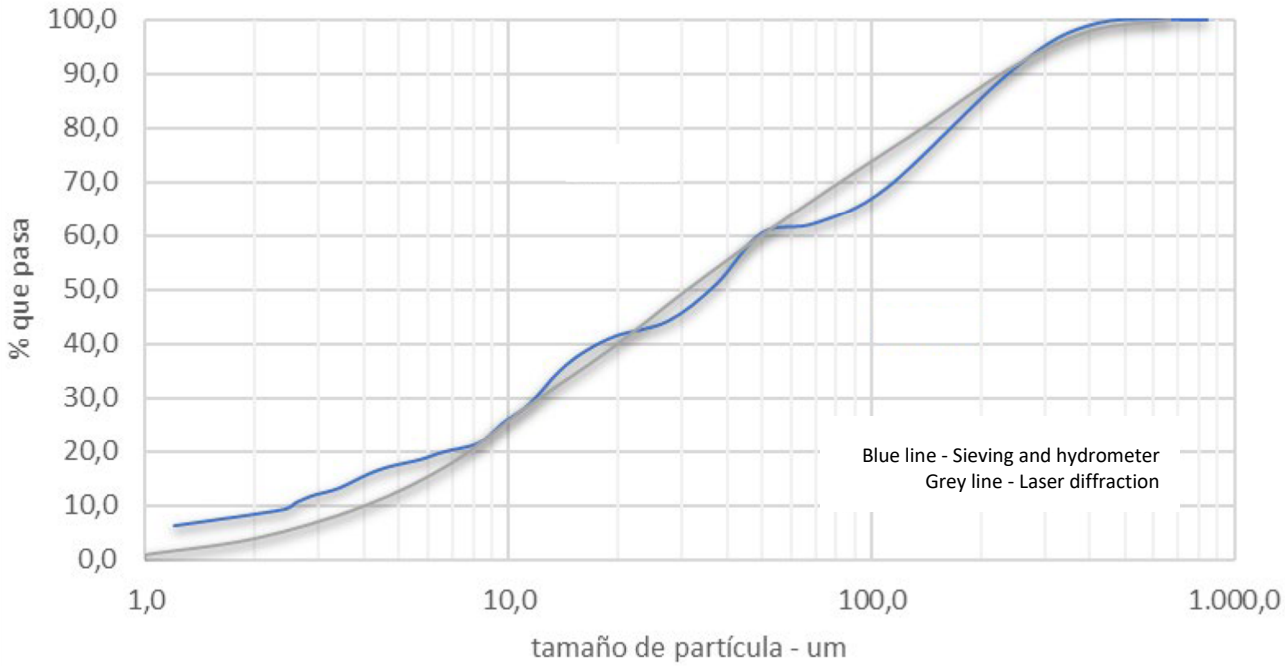

Figure 5 Presenting laser diffraction tailings particle size distribution and sieving/hydrometer analysis on the same graph

5 Recommended sample preparation and particle size distribution measurement of tailings for the laser diffraction method (when P_{100} is less than 3 mm)

The following provides recommendations for best practice attained by using laser diffraction equipment for tailings PSD determination, particularly tailings that have been generated from a flotation or leaching circuit. This is provided as a guide as some reagents and finer tailings samples (e.g. those for P_{80} < 20 microns) typically require more repetitions.

Primary sampling techniques to obtain a representative sample are not discussed due to the various methodologies that exist for wet and dry sampling. Hans Merkus's book should be referred to for understanding of the correct sampling methods and devices needed, based on the flow stream of tailings or storage vessel that requires sampling (Merkus 2009). Generally, tailings PSD data is required for a live flow stream or from storage vessels where tailings are generally stored in a slurry form. One big challenge is collecting a representative sample of tailings where a processing plant is operating a high throughput and various samples may need to be taken at different points of the stream to account for any segregation.

Secondary sampling techniques are required in the laboratory by taking a representative sample of the primary sample. Generally, not all of the primary sample is needed and therefore a sub-sample is required. If the primary sample is dry, well-known techniques such as cone and quartering, and rotary rifflers, can be used. For a tailings slurry the sampling technique is either done as a concentrated paste or dilute slurry. The following best practice steps start by considering a secondary sample of slurry tailings received in the laboratory, ready for laser diffraction analysis:

1. **Secondary sample subdivision** – allow the sample to settle for a minimum of 24 hours and remove any supernatant water (only if very clear and typically less than 10 NTU). A thick paste is ideal to prevent de-mixing prior to sample collection. For tailings that are colloidal or very slow settling, a centrifuge or additional settling time can be considered to naturally dewater the tailings and increase solids concentration. Filtering of samples should not be considered due to the loss of fines during this process. Low-temperature-assisted oven drying is a possibility in some circumstances, to increase solids concentration, but samples should not be dried out or they will agglomerate. The paste tailings can then be sampled with a spatula after thorough mixing of the paste. The use of a pipette or wide-mouth syringe is not recommended unless the tailings are high density but not of paste consistency (i.e. are more liquid).
2. **Dispersion** – it is highly recommended that a wet dispersion cell and stirrer with a capacity of 500 ml or more is used for the laser diffraction technique. These cells and stirrer units are typical add-ons for the laser diffraction equipment and circulate the sample on a continuous basis, allowing the laser to take repeat multiple measurements of the particles for a certain period of time set by the software of the instrument. It is also necessary that for a period of time the software correctly measures the background trace particles of the liquid medium being pumped around the cell prior to adding in the tailings material. This is a standard process on most laser diffraction wet dispersion units. Tailings should be added to the wet dispersion liquid gradually such that the software will identify a target range based on the obscuration (as the solids content increases). It is not uncommon to exceed the target range, especially when working with darker material such as concentrates. If this occurs the whole process needs to be restarted.
3. **Pre-screen** – a practice that we have is to pass the collected paste material through a 2 mm ASTM E11 No. 10 mesh sieve (Tyler 9 Mesh) when we know the top side of any tailings is likely less than 1 mm. This ensures there is not an oversized particle present or any plastic material that may have been collected from the sampling procedure (e.g. a scraping of plastic from the bucket). This also helps to protect the instrument and prevents the ingress of a large particle that can warp the results.

4. **Optical properties** – when working with a specific type of tailings the refractivity settings are generally fixed. However, in a laboratory that deals with different types of tailings from different mines, pilot plants, concentrates and other minerals that require PSD analysis, it is likely that the optical properties need to be changed prior to each sample test. Most instruments have preset values based on the primary mineral present in the tailings mixture (e.g. quartz). It is important that these reflectivity settings are correctly applied before any measurements. However, as described in the next section, this error in the material optical properties is not that great if incorrect properties are applied (for similar materials). It is also important to ensure the dispersant type is correctly applied.
5. **Measurement** – a background measurement of at least 30 seconds is recommended to allow a few full circulations of the cell unit prior to sample ingress. A measurement time of 30 to 45 seconds once the tailings have been placed in the dispersion unit has been found to be the optimal time frame for medium to coarse tailings fractions. Very coarse tailings (P_{80} of 300+ microns) required 45 seconds to allow the coarse particles to correctly lift out of the stirring vessel and circulate correctly at least a few times in the machine. The ultrasonic unit should be activated during this stage of measurement.
6. **Post rinse** – following a measurement, the instrument should be rinsed a minimum of two times to ensure the pump, stirrer, piping and cell arrangement are clean and free of trace particles.

The measurement process is repeated, importantly taking a new secondary sample subdivision rather than taking a sample from the first paste tailings collected. The entire process is repeated for a third time to generate three independent results for a single tailings sample. The best practice is to generate three subdivisions at the same time and allow each one to decant to generate paste conditions. The three sample results are needed to ensure that the sample subdivision is correct and that the measurements are reproducible. This is important because, as mentioned earlier, sampling errors are the primary source of variation in particle sizing determination.

Once all three results are obtained, the ISO 13320 standard suggests that the measurements can be validated when the coefficient of variation (COV) at the P_{10}, P_{50}, and P_{90} meet the following criteria:

- COV at the $P_{50} < 3\%$
- COV at the P_{10} and $P_{90} < 5\%$.

For particles below 10 µm these values double, highlighting the potential for added errors due to sample preparation and dispersion techniques. When these criteria are met, and this may require additional measurements, an average result, normally calculated by the laser diffraction device, is typically generated as the final report.

5.1 Laser diffraction optical properties variations (for coarse tailings)

The optical properties can generate error if not selected correctly. Significant errors can occur for material that is predominantly fine to ultra fine, which is habitual for some industries such as pharmaceuticals.

5.1.1 Optical material property variations

To demonstrate the error for a coarse grind tailings material when modifying the optical material properties, Figure 6 provides the same tailings sample presented in Figure 1 (a base metal project having a target P_{80} of approximately 150 microns) by applying a wide range of optical material properties, some of which are materials clearly different to minerals. Also presented is the Fraunhofer approximation, which assumes the particles are all opaque discs and does not require refractive index data. This should be avoided for tailings analysis as it generally produces a finer curve, as demonstrated in Figure 6.

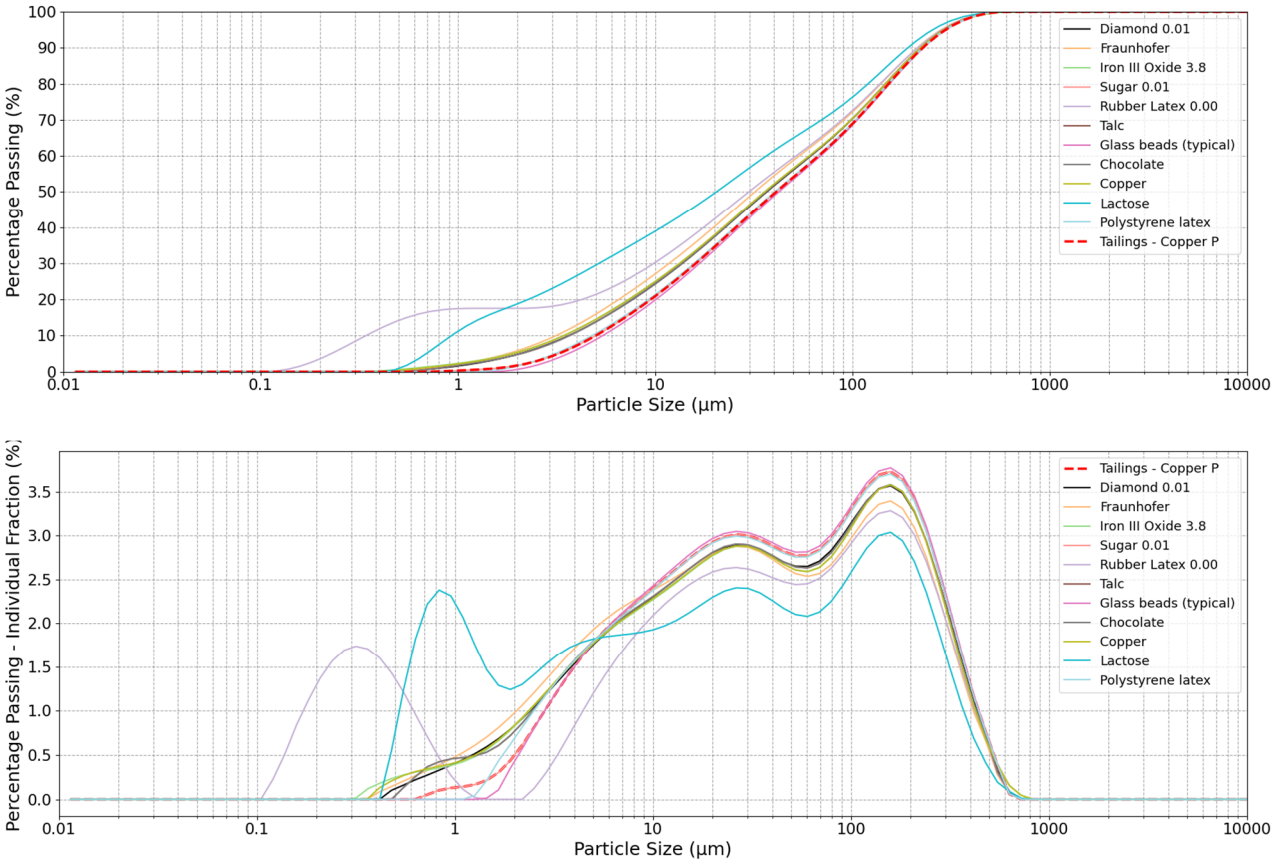

Figure 6 Comparison of optical material property variations for a base metal project having a target P_{80} of approximately 150 microns

Except for lactose, rubber latex and the Fraunhofer approximation, the error spread due to selecting incorrect optical material properties generates a maximum 3% error in the P_{90} data (1.5% average), a maximum 13% error in the P_{50} data (7% average) and a maximum 31% error in the P_{10} data (17% average). A 31% error may seem high, however, this is a P_{10} data variation which in this case was our base metal example (having a P_{10} of 4.988 microns) compared to a ferric oxide with a very high refractive index (having a P_{10} of 3.424 microns). Therefore, a 31% error is actually only 1.56 microns variation.

Figure 7 provides a screenshot of two laser diffraction results for two similar copper tailings samples from the same project, presented in the same report, where the operator used completely different equipment settings. It is also interesting to note that the obscurity of the laser was over 20% and should be around 10–15% for the particle range measured.

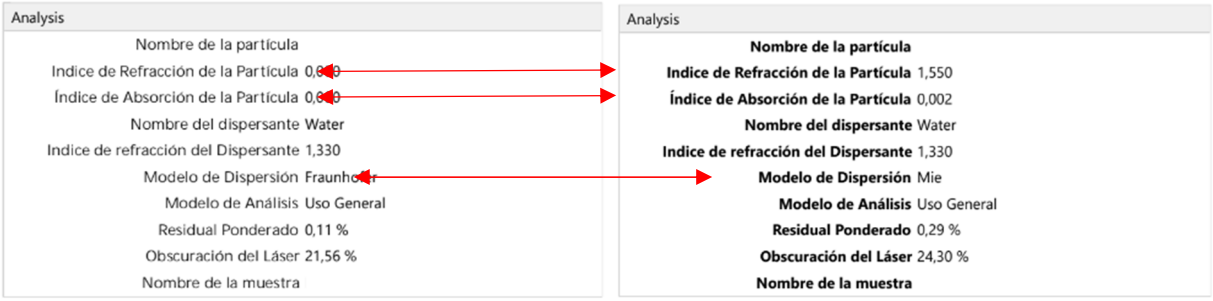

Figure 7 Example of the optical material property selection error for two similar copper tailings from the same project

5.1.2 Optical dispersant property variations

Figure 8 provides a comparison of variations in the PSD for the same base metal project having a target P_{80} of approximately 150 microns and applying the correct material refractive index properties but modifying the optical dispersant properties (i.e. the liquid refractive index).

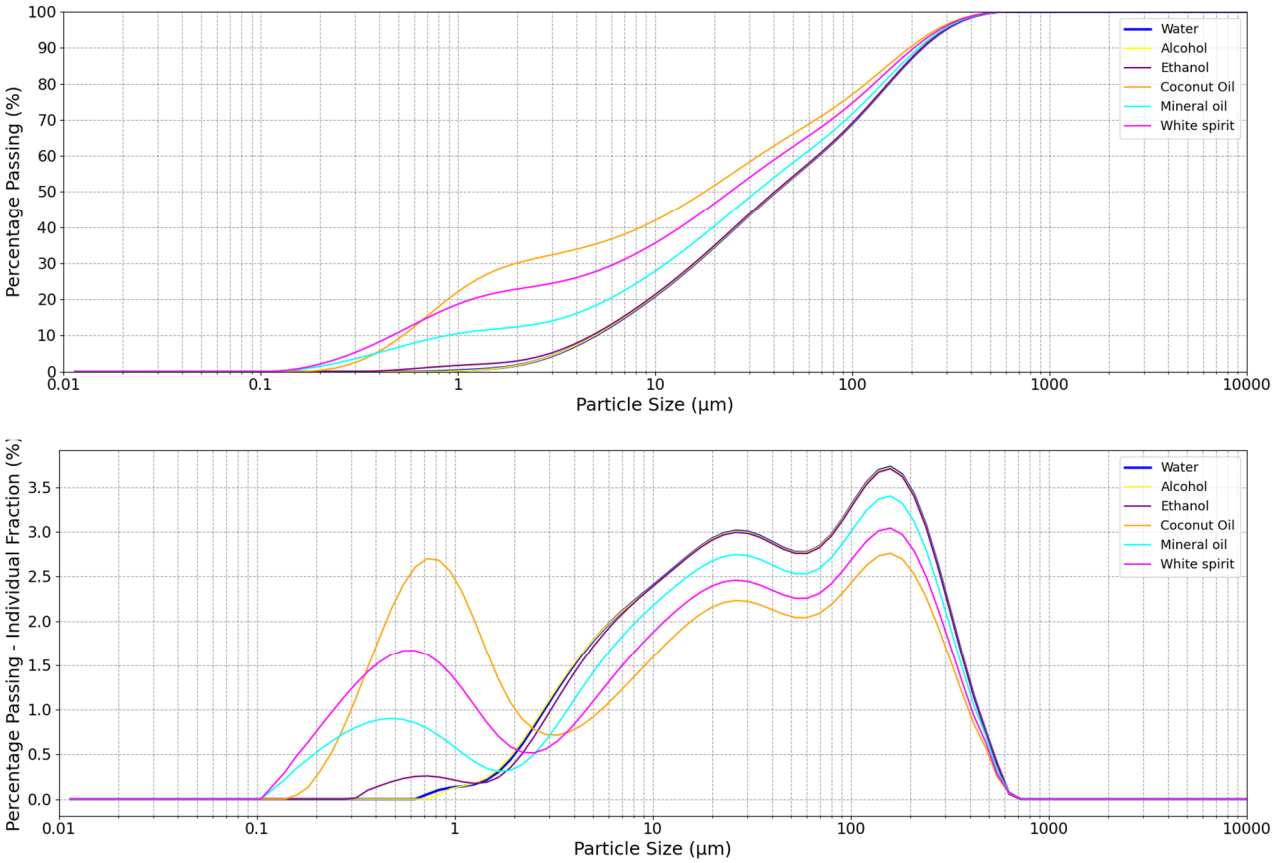

Figure 8 Comparison of optical dispersant liquid property variations for a base metal project having a target P_{80} of approximately 150 microns

A dispersant liquid changes the refractive properties and therefore has a bigger impact on the PSD curve compared to the optical material properties. Although some extreme dispersant liquid properties have been used for this example, and it is unlikely that a laboratory would measure a tailings PSD using coconut oil, it does demonstrate that operational error through selecting incorrect parameters can generate significant variation in results. Typically for tailings, water is predominantly the dispersant medium used for laser diffraction analysis utilising the wet cell method. Where the presence of oils is found, such as oil sands tailings, it can be more common to use a solvent-based dispersant.

6 Conclusion

Observations relating to different methodologies used to determine the PSD of tailings generated from a mineral processing plant have been provided. Advantages and disadvantages of the principally used methods of sieving, hydrometer and laser diffraction have been presented to provide the reader with guidance on which methodology to choose for a specific type of tailings. Although sieving and hydrometer methodologies remain common, it has been demonstrated that using a hydrometer is not relevant for tailings material due to the coarse angular nature of freshly ground tailings compared to the weathered soils for which the methodology and standardisation applies. Additional to this, trace reagents within tailings (where applicable) impact the buoyancy of specific minerals due to the process extraction techniques used to separate concentrate from gangue material. The key reagent class here is ‘surfactant’ consisting of frothers,

depressants, collectors, dispersants, activators and modifiers, where some reagents modify the surface properties of minerals to be amphiphilic (either be hydrophilic or hydrophobic) and are common in flotation, leaching and CCD circuits.

It is of the conclusion of the authors that sieving and hydrometer analysis should not be used for tailings characterisation for the reasons mentioned in this paper. The preferred approach to reduce operational error, implement standardisation for tailings of variable properties and provide quick turnaround times is that laser diffraction should be the applied methodology. The laser PSD should ideally be measured for a liquid suspension sample in a recirculating cell (i.e. not a dry sample). Although the authors are aware of other techniques such as image analysis, which not only provide a PSD but also information relating to the general shape and angularity of the particles, these are not only expensive but do not cover a sufficient operating window to measure from coarse to ultra fine material.

For tailings dams constructed with classified tailings (sand), the protocol for determining the fine fraction of sand (typically 10–25% < 75 µm, depending on jurisdiction) and validating the material for construction purposes requires careful consideration. The practicality of laser diffraction as a site-based method is limited as traditional practices rely on sieving. It is important to recognise that these two measurement methods yield different values, raising the question of whether sieving remains the most appropriate methodology for assessing the sand quality: a critical factor in the geotechnical evaluation of materials used in modern tailings dam construction.

In summary, for tailings PSD measurements used today there are many methods that are considered good (laser diffraction), bad (sieving) and ugly (hydrometer).

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