SECTION 1: INTRODUCTION

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1.1 OBJECTIVES OF THE GUIDE

The primary aims of this guide are to try to lay out in simple terms the advantages and disadvantages of thickening tailings prior to deposition, to a higher concentration or density than that achieved as underflow from conventional plant thickeners and to provide a technical resource about the relatively new application of thickening technology for surface disposal; thereby progressing the potential for its application. Extra effort is involved in producing and disposing of these higher density tailings and the processes involved in thickening and transporting the tailings and the techniques for depositing the tailings are covered in considerable detail. It has also been thought desirable to cover background issues such as rheology and material characteristics such that an appreciation may be obtained as to why the material behaves as it does and to outline the inherent differences between using the tailings in mine backfill as against surface deposition.

The ultimate objective has been to provide guidance and advice to those in the industry interested in finding out what is meant by thickened tailings and “high-density slurry” or “paste” tailings and in determining whether the effort of thickening tailings to a density higher than achieved in the underflow of normal plant thickeners can add value to their own operations. Because the terminology already in common use throughout the mining industry is at best inconsistent, an attempt has also been made to provide a logical basis for describing the different states to which suspensions of tailings and process water are thickened.

1.2 BACKGROUND

Under the guidance of Dr. E. Robinsky, the first attempt to produce thickened tailings for surface disposal was made in 1973 at the Kidd Creek Mine in Canada. Implementation of the first central thickened discharge (CTD) operation commenced using a conventional thickener, but it was not until 1995 after several iterations of thickener upgrade as the technology developed that the original vision was achieved. In parallel, the alumina industry set a goal in the mid 1980s of converting existing "wet" storages to "dry" storages. This was also accomplished with new generation thickeners and in a relatively short period, the *modus operandi* for the alumina industry globally became "dry" stacking. It is only now, however, that the concept of surface deposition of high-density slurries bordering on the consistency of a paste is being introduced to the general mining industry and it is this newly emerging technique that has been emphasised in this publication.

In parallel with developments for surface disposal, the technique for underground disposal of tailings as a cemented backfill was being developed utilising techniques adapted from the concrete industry in the 1970s at the Bad Grund Mine in Germany. In this application, backfill strengths in the MPa region were required, orders of magnitude higher than associated with surface disposal. There are considerable differences between surface and mine backfill disposal in terms of transport and disposal systems and yet the production of the thickened tailings itself is often identical. (A very comprehensive section on mine backfill is provided in Section 8 of the guide).

1.3 THE CURRENT SITUATION

The equipment now exists to make and to transport very high-density tailings and in general it will be the practicability and environmental and social advantages of any system that will determine whether it will be adopted by the industry. A practicable above ground disposal system will require that the tailings flow away from the point of discharge for a sufficient distance to avoid the need to locate the discharge points at very close intervals, or to install a discharge system that is excessively expensive to construct or to operate. The thickened tailings slurries used in most CTD projects will not segregate, but a limited amount of supernatant water will separate from the deposited tailings and flow down slope (as in the operation shown in Figure 1.1).

Figure 1.1 Uniform Beach Slope from CTD Discharge Ramp in Background

In general, the consistency (solids content or density) of these tailings will also be limited by the capability of a centrifugal pump to drive the material through a pipeline. Positive displacement (PD) pumps will pump much higher density materials at correspondingly higher discharge pressures. The cost of installing and operating positive displacement pumps has to be evaluated over the lifetime of the project to make a meaningful comparison with a system using multiple centrifugal pumps (or pump stations) required to generate a comparable pump discharge pressure.

The photos shown in Figure 1.2 typify the highest density materials that have been successfully deposited above ground to date. These are from the Nabalco alumina project at Gove in northern Australia (left) and the Bulyanhulu mine in Tanzania (right) and are probably best described as very high-density slurries (some say pastes). Clearly, they “stack” at a relatively high beach angle and do not segregate or release supernatant water down slope. By comparison, the thickened tailings shown in the photos on Figure 1.3 are very definitely “pastes” and would probably not flow far enough from the point of discharge to be practicable for above ground (surface) discharge.

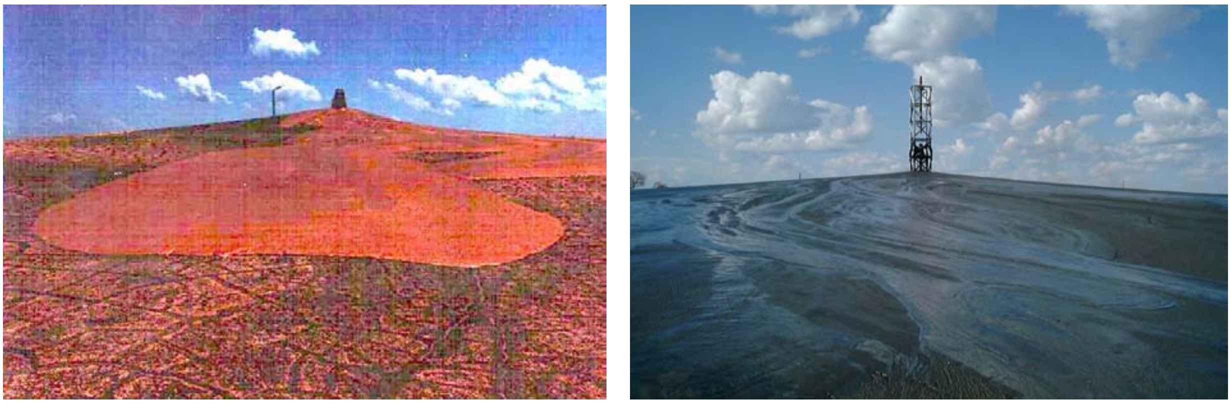

Figure 1.2 Examples of (Very) High-Density Thickened Tailings Deposition

Figure 1.3 Examples of Ultra High-Density (Paste) Thickened Tailings

1.4 THICKENED TAILINGS AS A CONTINUUM

In order to try to establish a logical system for labelling thickened tailings on the basis of consistency before addressing the more important properties and behaviour of the materials, the authors have proposed the system presented in Figure 1.4. This system was endorsed by an international group of people working in this field at a workshop held in Perth in April 2000.

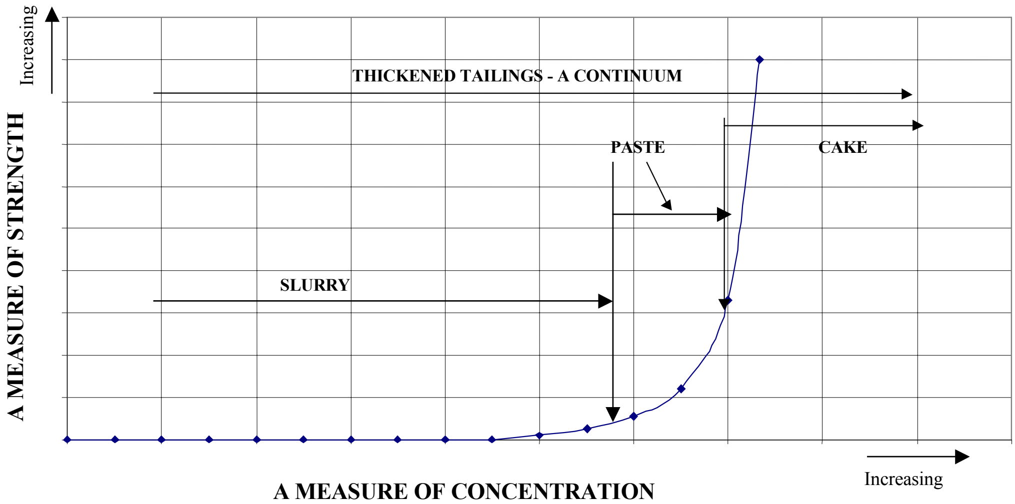

Figure 1.4: Basic Consistency Classifications for Thickened Tailings

The curve represents a plot of strength (say yield or shear stress) of a sample of tailings as the concentration of the sample (normally reported as solids content or density) is increased. The axes are not dimensioned because the location of the curve along the axis is a function (primarily) of particle size and mineralogy and a whole family of such curves can be plotted for different materials, (see for example Figure 3.4 in Section 3 of this guide).

The action of removing water from the slurry at any point in the process and hence increasing the concentration of the solids, essentially thickens and increases the strength of the material. From this, it can be seen that regardless of where one starts on the concentration axis, the removal of additional water further thickens the slurry. Hence, the process of thickening tailings may be viewed as a continuum. Within the continuum, however, it is possible to assign somewhat arbitrary labels such as slurry, paste and cake that describe the consistency of the product and this terminology has been adopted for use in this guide.

While these definitions may be somewhat arbitrary, they are indicators of how the material will perform when transported or deposited and of the types of equipment required to produce or to pump the product. More detailed relationships between consistency and a number of related characteristics such as the type of thickener needed and the type of pump needed to move it are further outlined in general terms in Figure 1.5. It must be stressed that these relationships are indicative only and can vary markedly in practice in specific situations where tailings with different grain size or mineralogy (for example) are handled, or different disposal management strategies are adopted.

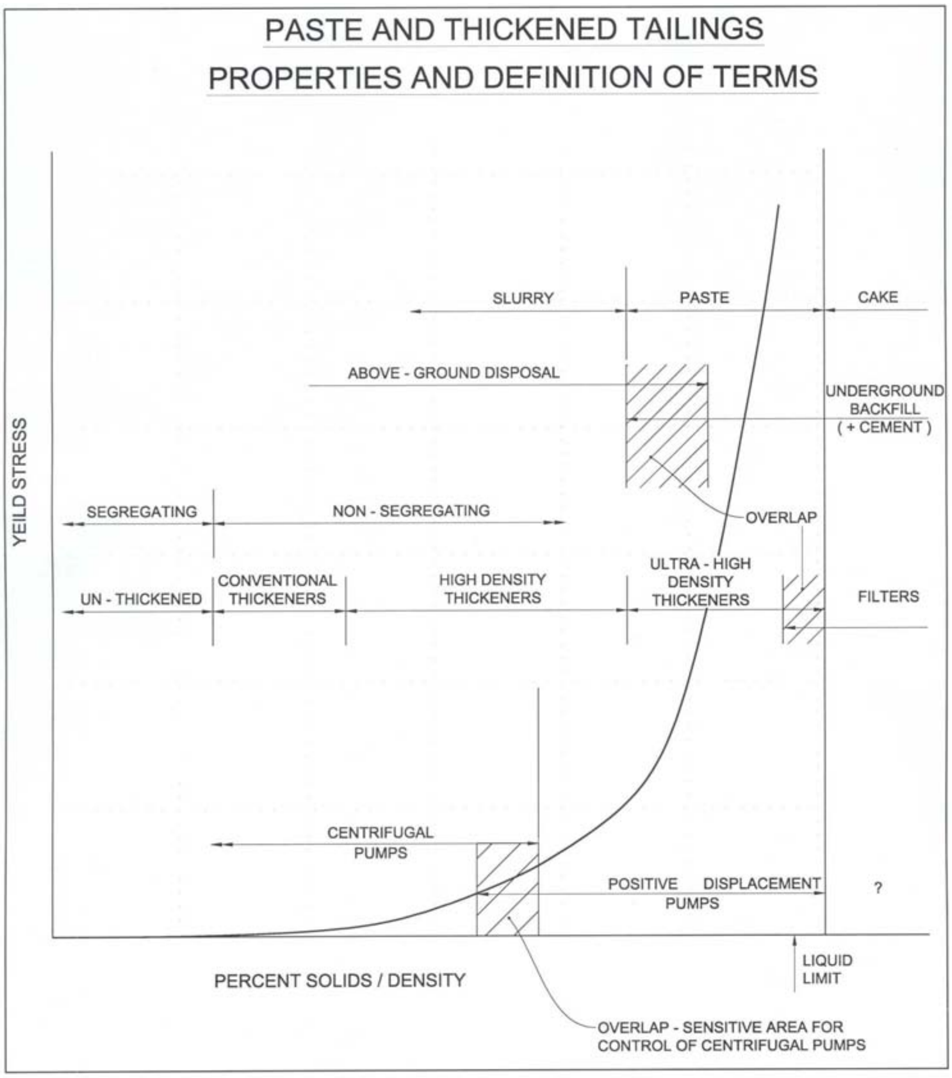

Figure 1.5: Indicative Ranges of Properties for Different Purposes (after P Williams)

1.5 CLASSIFICATION SYSTEM

The boundaries between slurry and paste will need to be defined by strength due to the variations in concentration possible for different materials as a result of different grain size, mineralogy and surface chemistry. Nevertheless, there is as yet no generally accepted shear stress value used to differentiate between slurry and a paste, nor indeed a reliable method of accurately measuring the low shear stresses involved; nor to differentiate between a paste and a cake. Even when stress measurements are quoted, it is necessary to define the type of stress and the test equipment and method of interpretation used to obtain it to ensure that the same things are being compared.

The thickener manufacturers (see Section 5) have adopted the term ultra high-density thickeners for their new range of thickeners capable of producing a tailings underflow with the consistency of a paste to differentiate them from their thickeners that produce high-density slurries. Other than that, there does not appear to be any terminology distinguishing between what constitutes a high-density slurry or a paste and the properties that may be attributable to each in common usage.

It is accepted that terminology in this field is already well established in some countries, industries and even specific organisations (and may never change). Currently it seems that for above ground (or surface) disposal, tailings are in general thickened at best to the consistency of a high-density slurry and ultra-high density (paste) materials are more usually produced for use in mine backfill. This situation appears to be related to real and or imagined limitations in transporting the thickened material and ensuring that the disposal system is practicable, as well as to the inherent resistance to change in the mining industry. This does not mean, however, that surface disposal schemes for tailings with the consistency of paste will not be adopted if practicable deposition systems can be designed to suit the flow characteristics of the specific material.

In spite of all of these qualifications, it still seems to be desirable to try to provide a logical basis for distinguishing between the various consistency states.

1.5.1 Proposed System

It is the properties of the thickened tailings at the point of discharge that will determine how they can be used practicably and will also provide the basis for distinguishing between them. Hence:

- A yield stress range of the order of say 200 +/-25 Pa (at the point of discharge) is proposed as marking the transition between slurry and paste. The yield stress proposed is as depicted on Figure 3.3 and obtained using the vane-shear instrument and technique outlined in Section 3.6.
- The term "slurry" will in general apply to thickened tailings that will flow a sufficient distance from the discharge point for practicable, large scale above ground (surface) deposition. In a practicable system, even where PD pumps are required to transport the slurry, the yield stress at the point of discharge will most likely be less than 200 Pa even if the material densifies further as it moves away from the discharge point.
- Slurries can be further subdivided according to the extent of thickening into low, medium, high and (possibly) very high-density slurry.
- The term "paste" will in general be applied to ultra high-density thickened tailings with low flow characteristics and appropriate viscosity. At present pastes are mainly prepared for underground mine backfill uses, but providing a practicable deposition system can be designed to suit the flow characteristics of the paste, surface disposal operations may increasingly utilise this consistency of material in the future.
- The transition between a paste and cake can be defined subjectively as the material changes from a plastic "paste" to a semi-solid "cake". This transition also probably delineates the maximum consistency that can be pumped by PD pumps, although there may be exceptions to this rule of thumb.

1.5.1.1 Above ground deposition

A practicable above ground disposal system will require that the tailings flow away from the point of discharge for a sufficient distance to avoid the need to install a discharge system that is excessively expensive to construct or to operate.

With tailings derived from hard rock ores, the clay sized (passing 2 μm) fraction is primarily comprised of granular (rock flour) shaped particles. The density of such a slurry discharged at a very high-density may well increase as it flows down a slope and releases excess “bleed” water. In that situation, the characteristics of the flowing slurry may approach a paste or even a partially saturated cake. These tailings would cease flowing once the self-weight forces on the solidifying tailings stop the forward momentum. The resulting beach would be relatively steep and short and these tailings would require relatively closely spaced discharge points.

On the other hand, the very high-density slurry deposited by Alcoa at its plants in Western Australia (see case study in Section 10.3) comprises the fine fraction of the total tailings stream and contains a high proportion of clay minerals. On deposition, this slurry flows for a considerable distance at a slope in the order of 1 in 80 and ceases flowing when the discharge line is turned off. The consistency of the tailings along the entire length of beach is uniform throughout the deposition process and only stiffens up with time as further consolidation takes place as a result of the removal of pore water from the surface through evaporation. This however needs to be compared with the “red mud” being deposited at Gove (see Figure 1.2) where the slurry builds a steep beach.

Tailings may also be classified through the needs for the various disposal strategies adopted. In Australia, the authors of Section 3 distinguish between CTD (see case studies in Sections 10.2 and 10.4), and “dry” stacked tailings (see case study in Section 10.3) on the basis of the rheological characteristics of the material. It is their experience that for most CTD operations, the tailings are thickened to about the gel point (the consistency at which a yield stress is first developed). Here there may be a maximum yield stress of the order of 20 Pa, the tailings can be pumped by centrifugal pumps, there will be some supernatant water running down the beach slope on discharge, but segregation is unlikely.

With "dry stacking", the dry surface disposal technology primarily used by the alumina industry and now being picked up by a few others, the tailings are thickened (by Alcoa) to a yield stress of the order of 30-100 Pa and then delivered and stacked.

1.5.1.2 Below ground deposition

With mine backfill, the “thickened tailings” are largely produced from filters to as high a density as can be delivered from disk, drum or press filters (see Section 8). The consistency of the product delivered to the mine may be as high as can be dumped or pushed down a pipe back into the mine, or more usually may be reconditioned by mixing with water to achieve the consistency necessary to achieve the required slump when mixed with aggregates and a binder. Here, materials with yield stresses in excess of 200 Pa are generally employed and there are instances where materials with yield stresses of the order of 800 Pa are produced. It is believed that tailings having yield stresses in excess of 200 Pa can be produced with the newer ultra high-density (paste) thickeners (see Section 5) and from a rheological perspective there are some very interesting flow problems associated with a material at that consistency.

1.5.1.3 Justifying proposed limits

The proposal to recommend a yield shear stress range around 200 Pa as the transition between slurry and paste is primarily based upon knowledge of the Alcoa experience, input from rheologists as outlined in the two preceding subsections and observation of the properties and beaching characteristics of tailings “slurries”. The yield stress indicated is as depicted on Figure 3.3 and obtained using the vane-shear instrument and technique outlined in Section 3.6 and is to be measured on slurry at the consistency at the point of discharge.

1.5.1.4 Subdivision within slurry consistency

It is suggested that slurries could be further subdivided according to the extent of thickening into low, medium, high and very high-density slurry. There would not appear to be any basis for (or need for) an objective distinction between these categories.

On a subjective basis, tailings discharged from plants where thickeners are not utilised would conform to low-density slurry and the underflow from most well operated plant thickeners and other earlier generation thickeners could be classified as medium-density slurries. High to very high-density slurries can be produced by the modern generation of high density, high rate or deep bed thickeners (see Section 5).

Because of the rapid build up of yield stress with consistency once the gel point has been achieved, the consistency range between the gel point and the paste boundary is likely to be relatively small for most materials. If the top of the medium-density range was to be taken as being at or marginally above the gel point, it may be sufficient to use high-density to cover the whole range without the necessity of introducing the additional very high-density category. “Very high-density” is however a term that fills the “gap” left by the thickener manufacturers when they adopted the term “ultra high-density” for their paste thickeners and might be useful in some situations.

In terms of the performance of tailings thickened for surface discharge, consider the following;

- Low-density slurries
    - Unthickened tailings directed to surface deposition operations. Tailings segregate and produce copious amounts of supernatant water.
- Medium-density slurries
    - Tailings thickened to the “gel” point, or to a negligible yield stress for CTD operations (see Figure 1.1). Little segregation and some supernatant water flow possible.
- High to very high-density slurries
    - Tailings thickened to a consistency involving a yield shear stress up to the paste boundary. No segregation or supernatant water flow, but will still flow down a slope. Used for “dry” stacking and multiple discharge point operations (see Figure 1.2).

Table 1.1 further presents the relationships between pumping and segregation characteristics and consistency that are outlined in Figure 1.5 and may assist the reader by setting out these relationships in another format.

<table>
<tr><td colspan="6">SLURRY & PASTE (Pumpable)</td><td>CAKE (Non-pumpable)</td></tr>
<tr><td>Low density slurry</td><td colspan="2">Medium density slurry</td><td colspan="2">High to very high density slurry</td><td>Paste</td><td rowspan="3"></td></tr>
<tr><td colspan="4">Centrifugal pump generally satisfactory</td><td colspan="2">PD pump required</td></tr>
<tr><td colspan="2">Segregating</td><td colspan="4">Non-segregating</td></tr>
</table>

Table 1.1 Indicative Pumping and Segregation Characteristics for Slurry, Paste and Cake

1.6 ABOUT THE GUIDE

This guide is presented as a series of self-contained sections that follow a sequence established by the authors at the workshop held in Perth in 2000 referred to in the preface. Each section has been prepared by a number of authors selected as having expertise in the specific area and representing the mining industry around the world. These included a mix of operators, consultants and regulators, with a lead author given the task of coordinating and being responsible for the section. These sections were then edited by an editorial peer group to provide a coordinated coverage of the topic. All of those contributing significantly to the preparation of this publication have been acknowledged in the section with which they were associated.

Following this introduction, the sections cover the very important ***Key Business Issues*** and then ***Rheological Concepts*** and ***Material Characterisation*** that are fundamental and relevant to all sections. Key Business Issues covers the decisions that fundamentally influence the choice of deposition method including environmental and community perception issues, as well as the usual economic factors. Rheology in particular was recognised by those developing the outline of the guide as the single most important issue influencing our ability to thicken, transport and deposit paste and thickened tailings.

The following sections then cover ***Thickening Process, Transport*** (pumps and pipelines), and ***Above Ground Deposition***. ***Below Ground Disposal*** *(Mine Backfill)* is included because of the overlap with thickener technology. A section on ***Closure Considerations*** and another covering three ***Case Studies*** follow. The final two sections then provide a ***Glossary of Terms*** and a list of ***References*** that are intended to provide definitions for terms used in the guide relevant to paste and thickened tailings and a comprehensive listing of the references used by the various authors.

In a number of sections, the authors refer as an example to specific mining operations at which the equipment or process to which they are referring, are in operation. Clearly, these are operations with which they are familiar and there is no inference that these are the only operations around the world using that equipment or process. They do, however, show that the concepts discussed really do work in practice.

It must be stressed that this is a guidance and advice document and in no way is intended to be a design manual. As indicated in the preface, the intention has been to provide sufficient information such that the principles and terminology are understood to the extent that a competent briefing can be prepared for a consultant commissioned to provide a feasibility study for an operation.

1.7 AUTHOR DETAILS

Author and Lead Editor

Richard Jewell
Richard has recently retired as an Associate Professor from the University of Western Australia and as Director of the Australian Centre for Geomechanics (ACG). He has worked on mine tailings issues for over 25 years. Richard now works part time with the ACG and as a consultant concentrating on tailings management and mine closure issues.