Paste 2011 — R.J. Jewell and A.B. Fourie (eds)

doi:10.36487/ACG_rep/1104_01_Boger

A personal perspective on paste and thickened tailings — a decade on

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Abstract

The technology to manufacture "designer waste" (Jones, 2000) is now available. This paper examines the very important and positive impact the International Paste and Thickened Tailings Seminars have had on developing this technology, examines the current technology and challenges, looks at the broader environmental perspective and finally, lists some recommendations. The major conclusion and recommendation is that traditional tailings dams can and should be eliminated for flocculated fine particle suspensions by producing and stacking a designer paste. Reclamation can and should then occur concurrently with the paste stacking.

1 Introduction (our involvement)

Newspaper headlines like "Hungary battles to clear up killer sludge", "Mini Tsunami of toxic sludge hits villages", and "Toxic sludge floods several villages in Hungary" do not enhance the image of the mining industry. Could the Hungarian bauxite residue tailings dam failure on October 4, 2010 have been avoided by depositing a dewatered waste? The most probable answer is yes, as this is the practice in much of the alumina industry worldwide.

The authors' own research for 46 years has been in rheology and non-Newtonian fluid mechanics. The early and continuing work was in polymer rheology, i.e. viscoelastic fluid mechanics. Particle suspensions became a parallel interest in 1974 after an approach from Peter Colombera (now deceased) and Mark Want from Alcoa in Western Australia. We were introduced to the waste product of the alumina industry, bauxite residue, more commonly known as red mud. At the time we thought that 15,000 t of a fine particle (dry) waste pumped to disposal at a pH of 13 as a low concentration suspension (Newtonian fluid) was a huge amount of waste. We were not aware that other miners at that time were producing as much as 100,000 t (now 240,000 t on a dry basis) of fine particle waste of a Newtonian fluid suspension on a dry basis, and also pumping the low concentration suspension to the tailings dam.

We now know that the minerals, oil sands and coal industries produce on the order of ten billion tpa of fine particle waste as a Newtonian fluid suspension worldwide. It was through our work with Alcoa that they were able to exploit rheology in moving from wet to dry disposal, a more sustainable practice. We in turn learned about the alumina industry and its waste and the techniques needed to measure the rheological properties of mining wastes.

The majority of the alumina industry has moved to a more sustainable practice (Cooling, 2007). Our work continued with Alcoa until the submission of the Cooling PhD thesis in 2005 (Cooling, 2005). During this time both Alcoa and the industry in general went from pumping a material at a concentration of about 15–20% solids to a situation where the material is handled at about 50% by weight solids which has allowed them to go from a wet disposal dam like those in Hungary to dry stacking. The industry has not stopped at this level of improvement. Cooling's thesis describes in some detail, supported with pilot plant data, how sequestering of CO_2 in the caustic red mud can be used to considerable advantage. The alumina industry represents (as the author believes) the world's best practice in management of tailings. The key has been compression dewatering in super-thickeners, pumping non-Newtonian materials, and understanding the rheology such that the paste material can be spread into drying pans, dried in the environment and then layered.

The next defining moment in our involvement with the mining industry and its waste was in 1994 when the author was a plenary speaker at the XVIIIth International Mineral Processing Conference held in Sydney. It became obvious at this meeting that while the industry was very interested in mine stope fill materials they had little interest in, or were not aware of the alumina industry and its movement towards dry stacking on the surface. The communication across industrial boundaries, i.e. copper – coal – alumina, etc., was not good. With the advent of the Paste and Thickened Tailings seminars starting in 1999 these boundaries have been breached although it is still sometimes difficult to move from one sector to another; they have different "cultures".

The author's first involvement with the Paste and Thickened Tailings seminars was at the Perth meeting in the year 2000. The first in this series, a learning seminar, organised by Bruce Regensburg from Syncrude, was held in Edmonton, Canada in November 1999. Interestingly, it was the oil sands industry that hosted the first meeting. Richard Jewell and the Australian Centre for Geomechanics organised the Perth meeting in 2000 which was originally conceived by Richard and Ted Lord in 1998. Richard, Ted, and somewhat later Andy Fourie, formed the team that has been the major driving force in these meetings. The 120-plus number who attended the 2000 seminar was about the same number that attended in 1999. In Toronto in 2010 the number exceeded 400! The meetings rotate around the world and have been held in Canada, Australia, Africa, Chile and Europe. What an impact they have had, particularly on the development of technology for paste and thickened tailings. But we still have not been able to get into the minds of the people who write the cheques.

In his opening remarks at the 2000 meeting Richard Jewell said, and I quote, *"It is the practical issues of producing (thickening) and transporting the high density product that are addressed in greater detail in this seminar."* The object has been achieved. The very significant progress in these areas will be reviewed in the plenary papers in this meeting but the result has not seen a significant increase in the application of the technology to operations.

A two day workshop was held immediately prior to the 2000 meeting and was attended by about 30 persons from around the world already working in the field. The meeting established the authors and editors for the first Paste and Thickened Tailings Guide which was published in 2002 (Jewell et al., 2002). It was here that the importance of rheology in thickening, pumping and waste distribution became very apparent. An updated second edition of the Guide was published in 2006 (Jewell and Fourie, 2006). The guide represents the definitive reference on the subject.

Richard Jewell started the working part of the discussion in 2000 by presenting the diagram shown in Figure 1, asking the question "What is a paste?" It has now been established that the measure of strength shown on the ordinate in Figure 1 is the rheological yield stress and the concentration is generally reported in weight percent. The question as to what is a paste is almost redundant; a paste has a yield stress! So-called thickened tailings have yield stresses that perhaps do not exceed 10 Pa, while paste can have a yield stress variation from perhaps 10 to almost 1,000 for mine stope fill material. The alumina industry handles a material with a yield stress of about 40 Pa. There can be a great deal of variation in the yield stress concentration curve for a particular industry; Figure 2 illustrates that variation within Alcoa World Alumina.

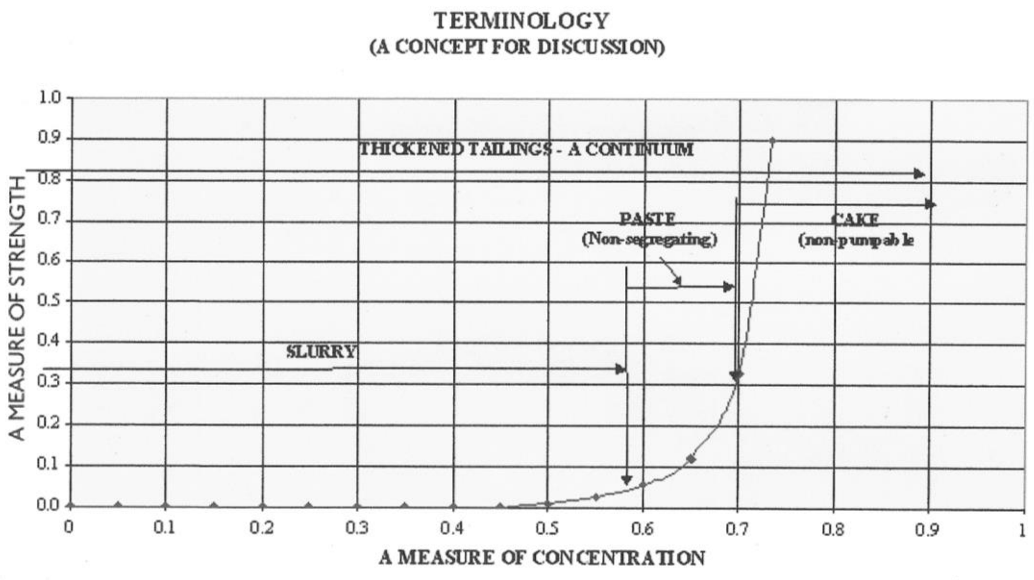

Figure 1 Original Jewell strength-concentration curve

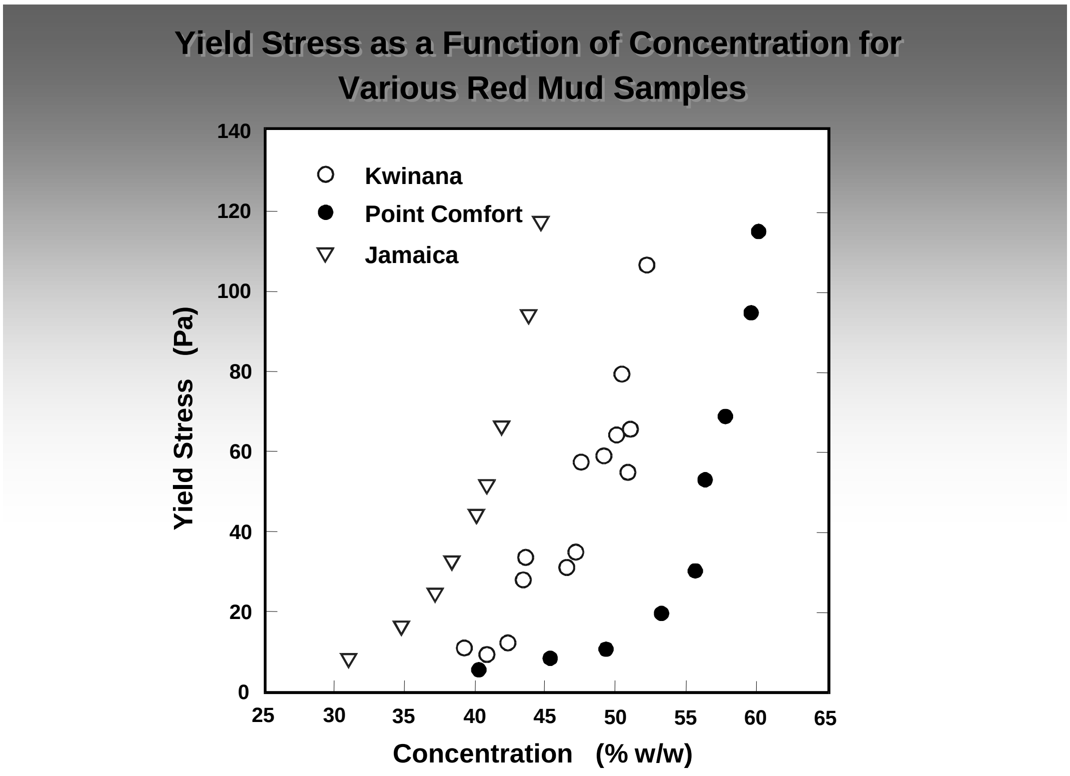

Figure 2 Yield stress as a function of concentration for red mud from different alumina samples (Pashias, 1996)

There can also be a great deal of variation from industry to industry, as is illustrated in Figure 3. Paste-like behaviour (rheology) can be observed over a concentration range from approximately 0.1–0.75 mass fraction (10–75%wt). Concentration does not define a paste.

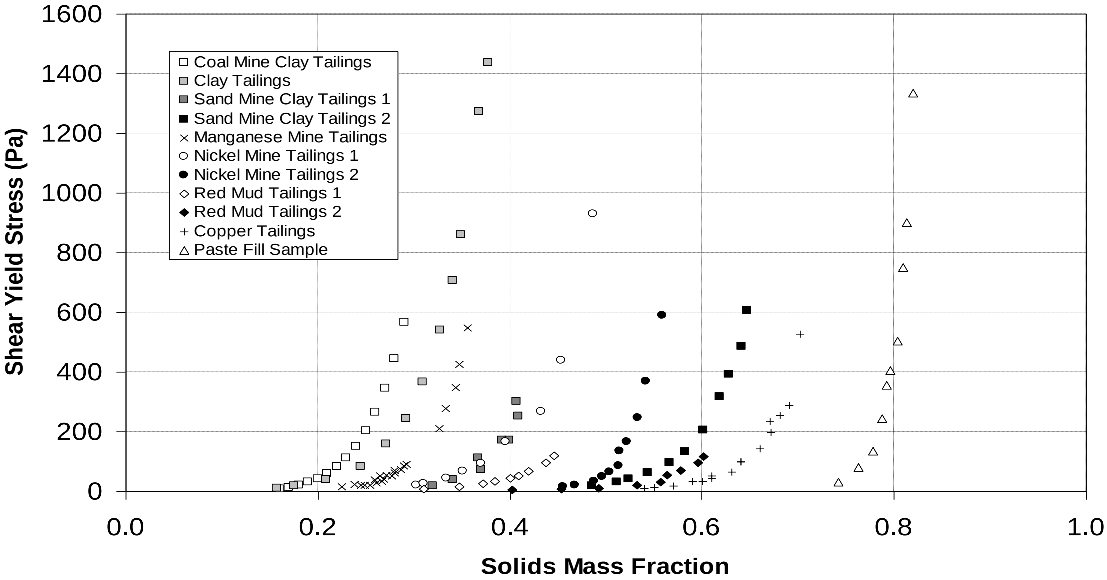

Figure 3 Comparison of the yield stress concentration behaviour for the fine particle waste from a variety of minerals

Sustainability and the triple bottom line are being promoted throughout the mining industry, largely through promoting social sustainability and initiatives such as stakeholder involvement and community development programs. Environmental issues associated with tailings waste seem to be avoided in the sustainability argument. The view was reinforced in 2004 when the author attended an Inaugural Sustainable Development Conference sponsored by the Minerals Council of Australia, BHP Billiton and Rio Tinto, the two largest resource companies in the world. The theme of the conference was "sustainability and innovation". The outcome of the conference was to conclude that more sustainable development in the minerals industry can in fact lead to innovation and affect the bottom line in a positive way. What was noticeably absent in the conference was any discussion of the major amount of waste produced by this industry and any attempt to deal more effectively with the fine particle waste which is produced as a suspension and pumped to storage sites, where it remains for the life of the mine; even though at the Johannesburg summit of heads of government the Mining, Minerals Sustainable Development Project (MMSD) Report specifically nominated waste as one of the three issues for the industry. Later conferences on sustainability and minerals have also avoided a serious discussion on the waste produced. Are both the industry and the regulators in denial in regard to the liability to the taxpayer represented by tailings stored in dams? Almost certainly, but how do we get them to lift their game? This is a question which needs to be addressed.

2 Current technology and challenges

Fiona Sofra coined the phrase *"Environmental considerations dictate that we must manipulate tailings to fit a particular environment rather than manipulating the environment to contain the tailings"* (Sofra, 2000). Hugh Jones, at the 2000 meeting, was saying the same thing using the term "designer paste". Figure 4 illustrates a suggested approach for design of a tailings disposal system. Jones has suggested that this diagram should start with the intended post-mining land use. An understanding of the basic shear rheology now plays an important role in tailings management. Sofra will be presenting a paper on: "The history, state-of-the-art and future directions in rheology".

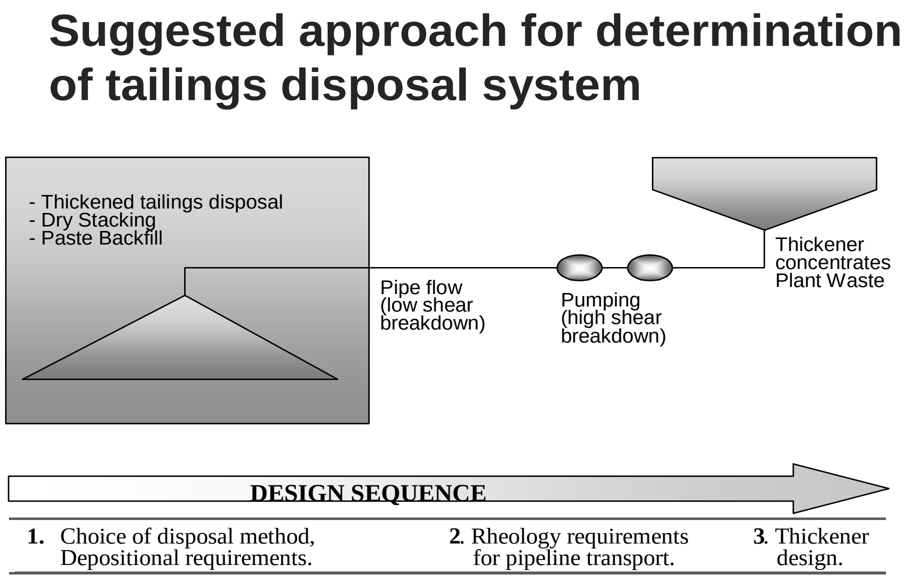

Figure 4 Suggested approach for determination of tailings disposal system

Compression rheology (in addition to shear rheology) is important in thickener design but is much less well understood. A future challenge is in understanding the interaction of shear and compression in thickener design and operation. The research required here is very fundamental in so far as a three dimensional constitutive equation is required for flocculated suspensions. The rheology community has been so preoccupied with polymers and polymer solutions that the fundamentals of suspension rheology have largely been neglected. The gap has been identified largely as a result of a need in thickener design.

Even with this gap in fundamental understanding the progress in practical compression and compression thickener design and construction has been absolutely amazing. The topic will be addressed in the keynote presentation by Fred Schoenbrunn: "Dewatering to higher densities – an industry review".

Similarly, there has been very significant progress in paste and thickened tailings pumping which will be reviewed by Angus Paterson in the keynote: "An historical review of past mistakes, lessons learned, and current technologies". In addition Lionel Pullum will present an overview on: "What is going on in slurry pumping".

While thickening and paste materials are being distributed and/or stacked in many operations the issue of predicting beach slopes remains. Paul Sims has the difficult task of reviewing beach slope prediction techniques.

The industry is served by thickening experts, pumping experts, geotech designers of tailings impoundments and a myriad of equipment manufacturers, most represented at this meeting. The Paste and Thickened Tailings Seminars have gone a long way towards improving communications across these discipline boundaries which may have been wanting in the past.

A major environmental liability as a result of the mining industry is acid mine drainage and the heavy metals carried with the drainage. Acid mine drainage is usually associated with rock and mine overburden and has not been a subject for discussion at these seminars. Do traditional tailings dams present a significant potential for acid mine drainage now and in the future, and if so, can the movement to paste tailings significantly reduce this liability? Gavin Mudd from Monash University, Civil Engineering will deal with this question in his keynote: "Paste and thickened tailings - friend against acid and metalliferous drainage?" This is a topic which should be of great interest. If acid mine drainage can be significantly reduced and/or eliminated with paste tailings then there will be even more incentive to move in this direction.

The technology is now in place and the risk has been minimised for implementation of thickened and/or paste waste disposal. While there are now significant movements in this direction what is holding up the change? COST!

Figure 5 illustrates the costing fallacy. Basically closure, rehabilitation and long-term maintenance of a tailings dam (facility) are not properly costed. In fact these costs have often been an unfunded liability, a liability sometimes escaped by companies through bankruptcy and other means. There are many examples; two that come to mind in the personal experience of the author are in the Florida phosphate industry and in the Pennsylvania coal industry. In each case the individual States have been left with a significant financial liability for clean up. Yes, performance bonds and/or environmental sureties have become a requirement in many countries as a means of reducing potential exposure of governments and the taxpayers from rehabilitation and long-term maintenance costs. Governments will always carry the can in the end! But these sureties are often never enough. The Achilles Heel of the mining industry is its environmental record. According to the United States Environmental Protection Agency, mining has contaminated portions of the headwaters of 40% of the watershed in the western continental USA and reclamation of 500,000 (!!) abandoned mines in 32 States would cost tens of billions of dollars. This is the situation in a country which today exhibits the most intense regulations, which was not the case in the past. What of the rest of the world and particularly the Third World?

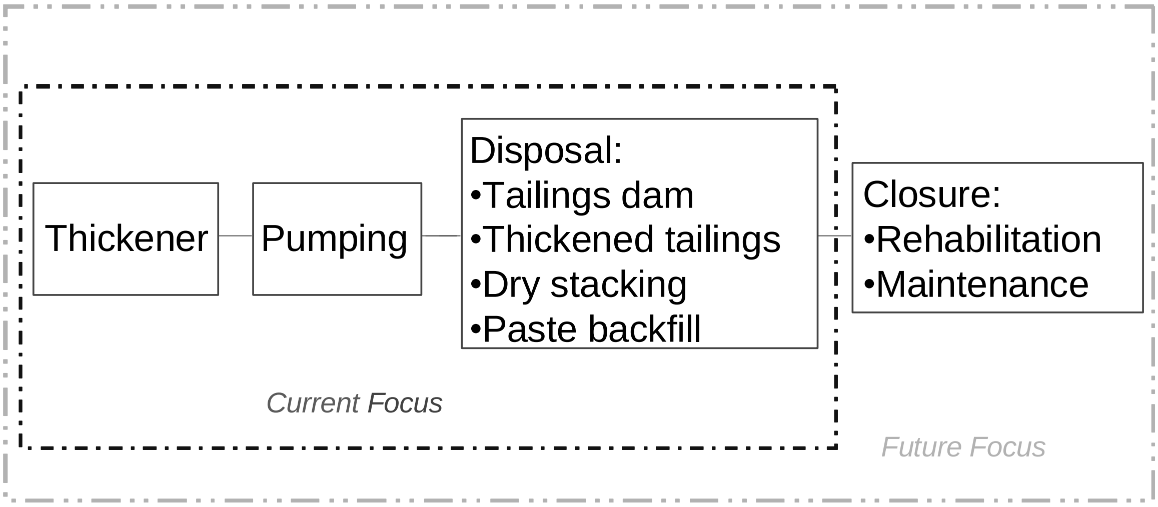

Figure 5 When costing, examine the lifetime picture

A large waste stream produces no profit so expenditure of up-front capital to improve waste management is not encouraged and is generally avoided. Net present value (NPV) accounting is not a good system to evaluate long-term environmental costs. Another capital cost which is avoided and often not recognised is that with the removal of significant water for recycle in the production of a paste, chemical engineering principles would dictate that a water cleanup step needs to be added to the flow sheet, as is illustrated in Figure 6. There also may need to be a bleed stream in the water recycle from the waste storage which is not illustrated in Figure 6. The water cleanup is necessary to remove the components which will accumulate and contaminate the process. In the Paste and Thickened Tailings Seminar there is a need to hear more about paste production and processes for cleaning up recycle water. Each application will be unique in that only certain impurities will have to be removed in each case.

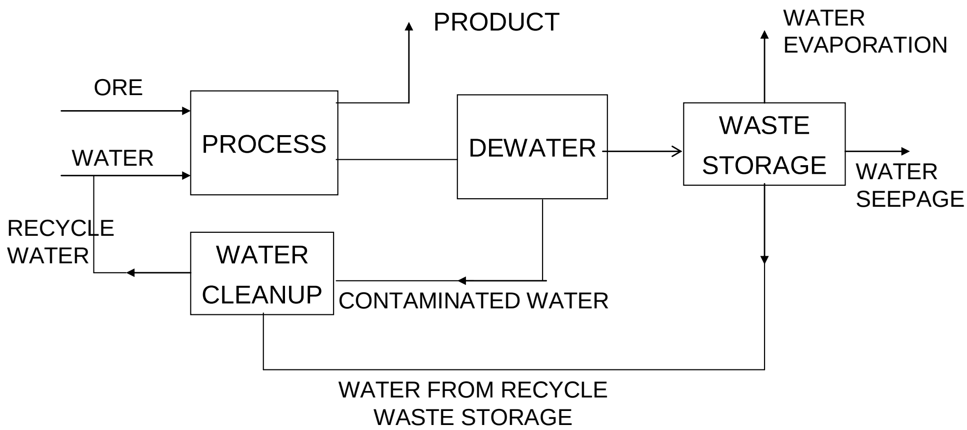

Figure 6 A not-so-typical process flow sheet

3 Challenges and the broader perspective

The opening presentation at the Paste Technology 2000 Seminar in Perth was presented by Hugh Jones, Senior Consultant for Golder Associates in Perth. The presentation is as relevant today, a decade on, as it was then. As there was no proceedings published for the 2000 Seminar and because of its importance, I have appended the Jones (2000) presentation to this paper which should be read by all delegates at Paste 2011.

Jones (2000) concludes with the statement: *"Most of the presentations that follow in this seminar discuss the technical aspects of paste and thickened tailings… Our challenge is to see that the knowledge being made available is applied. It is my view [and that of this author] that this means considering thickened tailings and paste as risk reducing options for tailings disposal."*

In this seminar once again most of the presentations will discuss or review technical aspects of paste and thickened tailings; the major difference being that the technology has advanced considerably to the extent that very high yield stress and low water content pastes can be handled and produced. The knowledge is available but not applied to the extent that it might be.

To be consistent with the principles and code of practice for company membership in both the Minerals Council of Australia and the International Council on Mining and Metals (London), both which espouse lofty and environmental goals such as "seek continual improvement in our environmental performance", I would have expected more proactive behaviour in tailings production and management from the major miners. Instead they seem to be avoiding the subject. In the Annual Sustainability Conference of the Minerals Council of Australia 2010 no mention was made of waste tailings or its management in the conference highlights posted on the MCA website. Nor was there apparently a paper on the subject in the programme.

The technology and its potential within a proper cost framework (commonsense accounting) is not reaching the right people. Perhaps it is and they don't want to know! Basically we preach to ourselves at these meetings. We need to inform senior management in the major mining houses, senior regulators in government, and those who represent the industry, for example, the Minerals Council of Australia and the International Council of Mining and Metallurgists. Better yet, these people should be invited to the Paste Seminars and asked to make a presentation on their approach and plans for managing the tailings waste, i.e. how they are implementing the basic tenets of sustainability: Reduce, Recycle and Reuse. Such a presentation would be of great interest in regard to the justification, for example, of the proposed Pebble Mine in Alaska where one of the two tailings dams is proposed to be 225 m high and 7 km long, filling up an entire valley in a seismic active region at the headwaters of major salmon spawning rivers feeding the Bristol Bay. Paste does not seem to be a consideration for the Pebble Mine where the partners are Anglo-American, Mitsubishi and Rio Tinto. We in turn (this conference) should prepare a summary paper on the status of paste and thickened tailings to be presented at mineral sustainability conferences worldwide. Let's make a concerted effort to be heard.

Since the Jones (2000) paper, there have been 21 documented tailings dams failures (WISE Uranium Project on the web). Ten people were killed in the October 4, 2010 Hungarian disaster and 240 in the Chinese failure on September 8, 2008. When will we learn? Einstein said: *"A problem cannot be solved with the same kind of thinking that created it and expect a different outcome."*

Companies should be getting the not-so-subtle message that the public is responding to their poor environmental record. For example, the Norwegian government's wealth fund, the world's second largest sovereign fund (465 billion) has divested itself of one billion dollars worth of Rio Tinto shares because of complicity in severe environmental damage at the Grasberg Mine (The Grasberg copper/gold mine in West Papua discharges about 230,000 t per day of fine particle tailings on a dry basis into the Ajikwa River). Rio Tinto is a joint venture partner (40%) with Freeport. Furthermore, the fund has excluded Barrick Gold Corporation (177 million) and Vedanta Resources (13.2 million) from the portfolio. One would think that the licence to operate for the mining industry will be more difficult to obtain as a result of the environmental record. To use the Jones (2000) analogy: *"…the "rubbish" end of our business still [ten years on] has far too many bins being spilt over our neighbour's front gardens!"*

Jones (2000) in his introduction to the 2000 Paste Seminar made a very strong case for paste and thickened tailings as a risk reduction alternative and highlighted other advantages in Table 2. The case for is much stronger now as most of the technological uncertainty has been removed.

In paste and thickened tailings we are not talking about rocket science; we are talking about accounting practices which encourage degradation of the environment and regulators (governments) who do not have the courage to implement the latest technology. There are two groups of people here – the public servants and the elected representative. Elected representatives are the ones who lack the political fortitude while the public servants lack resources in quality and quantity. Realising that each case can be different, the author believes that most tailings dams could be eliminated for flocculated fine particle wastes by implementation of paste thickening. Producing and stacking a designer paste would allow the concurrent reclamation. Wouldn't that be a major step forward? Maybe the industry will take the initiative!

4 Conclusions and recommendations

Specific conclusions and recommendations have been made in the text. General ones follow.

- Read Appendix 1, Jones' (2000) introduction to the 2000 Paste Seminar, which made the case for paste and thickened tailings a decade ago.
- As a group (ACG?) let's prepare a summary paper on the status of paste technology for presentation at minerals sustainability conferences worldwide.
- Current accounting practices encourage environment degradation. Lifetime analysis (common sense accounting) is essential for ethical management of mining waste. How can it be changed?
- Future paste conferences should be extended and broadened to include senior management from the major mining houses, senior regulators and representatives of groups like the Minerals Council of Australia (and other countries) and the International Council of Mining and Metals. Paste and thickened tailings conferences have brought us to the point where issues now are much broader than the technology itself and need exposure to a broader audience. An alternative may be to "gatecrash" a few conferences such as the proposed Second International Future Mining Conference 2011, 22–23 November 2011, New South Wales, which is now calling for abstracts.

Acknowledgements

Thank you to the great group of research students who worked on mineral waste related issues: G. Sarmiento, PhD 1978; Q.D. Nguyen, PhD 1983; N.J. De Guingand, M.Eng.Sc 1986; N. Pashias, PhD 1996; F. Sofra, PhD 2000; D. Cooling, PhD 2005; B. Ruse-Hart, PhD 2007. Also to Alcoa WA for their ongoing support; in particular I thank David Cooling and Don Glenister for their friendship and support. Finally this paper could not have been put together without the support of my colleagues and friends, Hugh Jones and Christine Collis.

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Appendix 1

Reprinted from Paste Technology Seminar, Perth, August 13-14, 2000

Designer Waste

Hugh Jones *Senior Consultant, Golder Associates, Australia*

The management of waste in the mining industry has historically been very low on the priorities of mining companies and governments. This attitude was very well expressed by the Tribunal appointed to inquire into the disaster at Aberfan in their report issued in July 1967, some 8 months after that disaster. The three man Tribunal, chaired by Sir Herbert Edmund Davies, stated:

> *"At the start of this Inquiry we were aware of the fact that the great bulk of mining operations take place below ground and that most of the best men in the industry are employed there. It is there that the coal is won and in that direction that the attention of those employed in the industry is naturally turned. Rubbish tips are a necessary and inevitable adjunct to a coal mine, even as a dustbin is to a house, but it is plain that miners devote certainly no more attention to rubbish tips than householders do to dust bins."*

Later in the same report the Tribunal issued a very strong statement about the way we, as a mining industry go about our tasks and gives us at this Seminar our challenge. The Report states:

> *"As we shall hereafter seek to make clear, our strong and unanimous view is that the Aberfan disaster could and should have been prevented… But the Report which follows tells not of wickedness but of ignorance, ineptitude and a failure in communication. Ignorance on the part of those charged at all levels with the siting, control and daily management of tips; bungling ineptitude on the part of those who had the duty of supervising and directing them; and failure on the part of those having knowledge of the factors which affect tip safety to communicate that knowledge and see that it was applied."*

The management of waste in most of the mining industry has not, and is not being conducted with the overall design objective of ending up with a safe, stable and aesthetically acceptable post-operational tailings structure. As attendees at this seminar we all carry some responsibility for the way our industry operates, as we all have some role in the siting, control, supervision, direction and/or communication of safety knowledge about tailings. Our challenge here is to advance our knowledge, assist others advance theirs and lead a thrust towards more stable and safer tailings structures that are considerably more acceptable to the community. A second challenge will be to drive this change using cost effective solutions.

Since the Tribunal reported in 1967 many good things have happened in our industry, but as tailings incidents over the past few years show our industry's record in looking after its "dust bins" has not improved as well as would have been expected. Table 1 below shows the "rubbish" end of our business still has far too many bins being spilt over our neighbour's front gardens! Our challenge is to get our industry into the mindset that sorts its wastes, some for re-cycling the balance for disposal in a safe, stable and aesthetically acceptable structure.

Table 1 Recent tailings related incidents compiled by WISE Uranium Project, 10 March 2000

Date	Location	Parent Company	Type of Incident	Release
10 Mar 2000	Borsa, Romania	Remin S.A.	Tailings dam failure after heavy rain	22 000t of heavy–metal contaminated tailings
30 Jan 2000	Baia Mare, Romania	Esmeralda Exploration 50%,Remin S.A. 44.8%	Tailings dam crest failure caused by heavy rain & snow melt	100 000cu.m. of cyanide contaminated liquid
26 Apr 1999	Placer,Surigao del Norte, Phillippines	Manila Mining Corp	Tailings spill from damaged concrete pipe	700 000t of cyanide tailings
31 Dec 1998	Huelva, Spain	Fertiberia	Dam failure during storm	50 000cu. m. of acidic and toxic water
25 Apr 1998	Los Frailes, Spain	Boliden Ltd.	Dam failure	4-5 million cubic metres of water and slurry
22 Oct 1997	Pinto Valley,Arizona, USA	BHP Copper	Tailings dam slope failure	230 000 cu.m.of tailings and mine rock
29 Aug 1996	El Porco, Bolivia	Comsur (62%),Rio Tinto(33%)	Dam failure	400 000t

The general practice in the industry has been to receive reject slurry from the processing plant and place it in an impoundment, usually as close as possible to the processing plant. A range of different impoundment structures have been developed to meet the combined challenges of the site and available resources (cash). All have a common design feature, they all have to accept and handle the tailings stream produced by the process plant. The tailings stream, in turn, has its properties driven by the requirements of the metallurgical processing plant and the need to dispose of the tailings at the minimum operating cost. Very little real consideration is normally given to designing the tailings stream so that it will be placed in a location and in a condition that will optimise its short and long term safety, ultimate stability and aesthetic acceptability.

This means that post-mining decommissioning cannot be undertaken in the most efficient manner for the mining industry as a whole (i.e. produce a structure that is stable, safe and acceptable to the community). For example, many structures today are built using the upstream method although it is well recognised within the industry that this construction method produces a structure that is highly susceptible to erosion. In a recent paper Blight and Amponash-Da Costa reported erosion losses of over 500 t/ha/year as being quite common on unprotected tailings slopes, with up to 200 t/ha/year being lost from vegetated tailings slopes. Structures with these erosion characteristics are unlikely to be defined as stable or meet the acceptance of the community, but, as the TV ad says “we’re cheeeep”!

I believe that it is necessary for the industry to reorientate its thinking with regard to waste management, particularly tailings, and begin to make real efforts to design waste streams and structures that are specifically directed towards nominated post mining land uses and effectiveness of post mining closure. In other words what we should be attempting to do is to design the structure from the outset with its final land use as a major objective of the design. This means the tailings stream itself should be an integral and potentially variable part of the design considerations. In effect the final structure must become a customer of the metallurgical plant rather than a receiver of the rejects from that metallurgical plant. The waste should be designed and not just happen, otherwise our industry will not attain the level of community acceptance we require.

Why do we need to change? What are the problems associated with current tailings systems that we would like to eliminate through designing our waste? Table 1 listed a number of overseas examples of why change is needed, but what about Australia? The current practice of managing tailings in Australia has identified four chronic difficulties:

- many structures suffer problems with seepage
- many structures carry supernatant ponds with potentially toxic levels of chemicals
- post mining rehabilitation often cannot be undertaken for many years after tailings deposition has ceased
- some structures are sources of considerable dust.

Australia has not recently had the sort of acute tailings mishap that would be registered on the international "bad boys" list, but I'm certain that if we do then the media and public focus on tailings management in the industry will increase considerably. This will increase the urgency with which we need to address these chronic difficulties listed above as well as the acute case which brought us to the public attention.

The elimination of these four chronic difficulties would go a considerable way towards making our industry's waste management acceptable to the community. The challenge is to design our tailings management so that:

- seepage is (practically) eliminated
- toxic chemicals are not retained in solution on the structure
- rehabilitation can be undertaken immediately after cessation of deposition
- the structure is stable against erosion.

The first three of the above design goals can be effectively met by managing the tailings as a paste or, slightly less effectively, as a thickened tailings. None of these three design goals can be met using the slurry without thickening. The fourth design requirement can be addressed through either the current armouring of the structure wall using run-of-mine waste, or adding reagents (cement) to the paste in strategic locations.

Every mine is unique and not every operation would expect to arrive at the same tailings management solution. The decisions are rarely clear cut and the weighting placed by individual operators on various "properties" offered by different tailings management solutions will depend on their individual circumstances. Listed below is an attempt to subjectively compare the various "properties" of the three main tailings management options.

In Table 2 the term paste means a non-segregating material that has no supernatant water, thickened means tailings that has been thickened to reduce the amount of process water being discharged to the tailings structure and slurry means tailings ex treatment process.

Will the image of our industry change if we are able to change our way of managing tailings and design for minimum chronic and acute risk?

Table 2 Comparison of properties

	Slurry	Thickened (CTD)	Paste
Final density	Low	Medium/high	High
Segregation	High	Slight	None
Supernatant water	High	Some	None
Post placement shrinkage	High	Some	Insignificant
Seepage	High	Some	Insignificant
Rehabilitation	Delayed	Immediate	Immediate
Permeability	Medium/low	Low	Very low
Application	Above ground	Above ground	Above and under ground
Footprint	Medium	High	Low
Water consumption	High	Medium	Low
Reagent recovery	Low	Medium	High

One way of addressing this very important question is to consider some of the consequences of the seven recent tailings mishaps listed in Table 1. Esmeralda is currently in administration, possibly on the road to bankruptcy; Romania and its neighbouring countries are in dispute; Boliden has a multimillion dollar cleanup bill; BHP Copper has been subject to legal action in the USA; all companies have suffered the loss of production during clean up and the intangible impact on employees and company image. If the operators of the projects listed in Table 1 had been able to predict the acute problems they have had I'm certain they would have changed some of the design factors that contributed to their mishaps.

Let us now consider how many of the mishaps would have occurred and what the overall impact of the mishaps may have been if the tailings had been placed either as paste or thickened tailings rather than as a slurry as it appears to have been in the cases in those operations. In most of the mishaps the major problem was reported as the supernatant water and its contained chemicals rather than the tailings in the structures. Operating a tailings management system with minimal or no supernatant water would in most of the cases prevented the mishap from occurring, while in other cases the overall impact would have been considerably less if there had been no supernatant water on the structure.

Overtopping and wall failure are dramatic events that catch the attention of the world media. They can be avoided to a very large degree through careful design of the total waste system.

The industry also need to address some of the less acute problems associated with tailings such as seepage, rehabilitation and utilisation of the mine site post mining. Table 2 compared the properties of the three general types of tailings with regard to seepage and rehabilitation. Utilisation of the mine site post mining will depend on the stability of the structure.

At an extreme end of minimising the impact of tailings disposal at a mine site paste can be placed underground where it will have the added benefit of minimising the chance of collapse of underground voids. A less radical option for tailings management is placing tailings in an abandoned pit, a solution that has been tried with various degrees of success at a number of operations in this State. Using thickened tailings or paste rather than slurry [creates] a major difficulty with in-pit disposal, namely the very long lead time between placement and the completion of settlement, and hence post mining rehabilitation.

Increasingly in the mining industry decisions are being made on the basis of assessing risk. Looking at the seven recent examples of tailings mishaps in Table 1 and their consequences suggests there is need for the industry to update its risk assessment models and give due consideration to the real risks posed by failure to correctly manage its tailings. The current industry practice of usually placing tailings as ex-plant slurry in a structure located close to the operating plant often results in excessive water and reagent consumption and an unnecessary exposure to chronic and acute risks. These risks can be offset to a large degree by designing the waste stream.

Most of the presentations that follow in this seminar discuss the technical aspects of paste and thickened tailings and include many case studies. It is a considerable body of knowledge which will be communicated and shared. This communication of knowledge was one of the elements missing at Aberfan. Our challenge is to see that the knowledge being made available is applied. It is my view that this means considering thickened tailings and paste as risk reducing options for tailings disposal.

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