Proceedings Tailings and Mine Waste 2011
Vancouver, BC, November 6 to 9, 2011

Cycloning of Tailing for the Production of Sand as TSF Construction Material

Christian Kujawa

Paterson & Cooke Ltd., Golden, USA

Abstract

Hydro-cycloning of plant tailings is an often used tool to produce relatively coarse free draining sand (cyclone underflow) for Tailing Storage Facility (TSF) embankment construction. This paper outlines the available choices and design considerations involved for the minimization of sand production costs by cyclone, looking among others at parameters such as sand yield, water recovery, and consistency of sand quality.

A number of changes in drivers to the disposal of tailings make this a relevant subject. Previously not as specifically managed and regulated, the sand quality specification has become considerably more stringent. This and the generally finer grind required for more difficult and lower grade ores often requires double stage cycloning to produce the necessary sand quality. At the same time there have been new advances in cyclone technology. In many parts of the world a shortage of water impacts mining projects. As water is an inherent part of the hydro-cyclone operation, the sand production by cyclone is an integral part of the water management of a tailing management facility.

Introduction

The disposal of tailings is mostly categorized according to method such as conventional disposal, thickened tailing, paste or even dry stacked tailing. The selection of tailing disposal method and containment structure is generally driven by topography, climatic, operational, geotechnical or geochemical considerations. In turn the choice of tailing disposal method determines the tailing transportation requirements as well the resulting water balance.

Often some of the tailing can be converted into a cost defraying by-product stream. Examples of these are the wall board product, cement fill or soil conditioner from fly-ash, or the chromite for stainless steel production from platinum operations in South Africa. One such component often inherent to the tailing stream is the coarser particle size fraction, if separated out can serve as valuable TSF construction material, rather than often more expensive mine waste rock which has to be quarried and still transported. The hydraulic transport of the coarse particle size fraction is generally more cost effective than truck transport of the waste rock. More importantly every ton of tailing converted to by-product serves simultaneously as a reduction in tailing to be stored. Figure 1 shows how a 35% by mass yield of coarse sand from the tailing reduces the overall tailing storage requirement of 103,000 mtpd to 66,950 mtpd, reducing containment structure construction while at the same time producing the containment construction material.

This paper focuses on the use of conventional cyclones for the extraction of the coarser sand component from the tailing. Hydro-cyclones are low in capital cost, with short retention times easy to control and especially if available hydrostatic head can be used to feed the cyclones eliminating the need for pumping, inexpensive to operate.

The relatively free draining material for construction from the final cyclone underflow is generally referred to as sand.

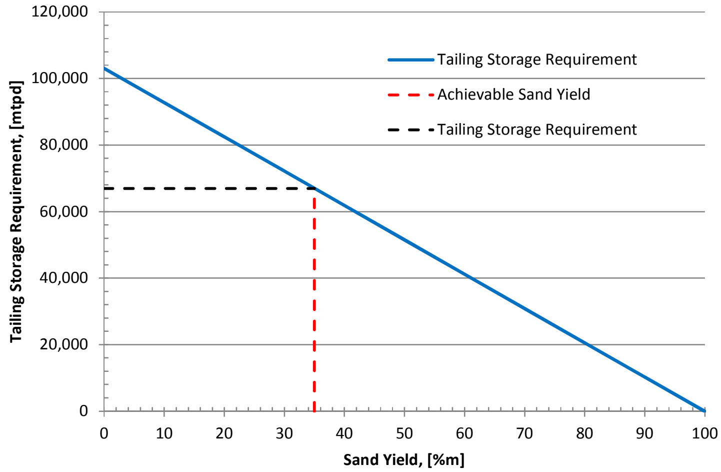

Figure 1: Example of Reduction in Tailing Storage Requirement with the Production of a Coarse Sand

Tailing Particle Size Distribution

Not all tailings might qualify for sand production considerations and generally it could be argued that the large scale operations such porphyry copper applications will more likely benefit from sand production because of a coarser grind common in these. Figure 2 shows some gold and some porphyry copper tailing particle size distributions. The figure shows that gold tailing are not necessary any finer.

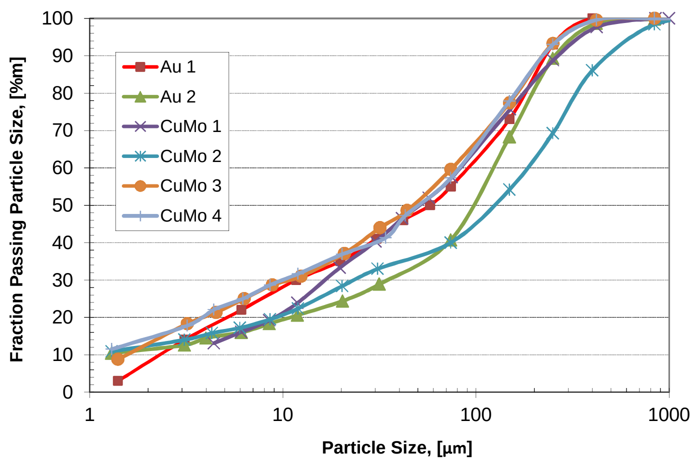

Figure 2: Gold and Porphyry Copper Tailing Particle Size Distributions

Figure 3 shows the adjustment required to shift the tailing particle size distribution to the required sand particle sand distribution that is characteristic of a relatively free-draining material.

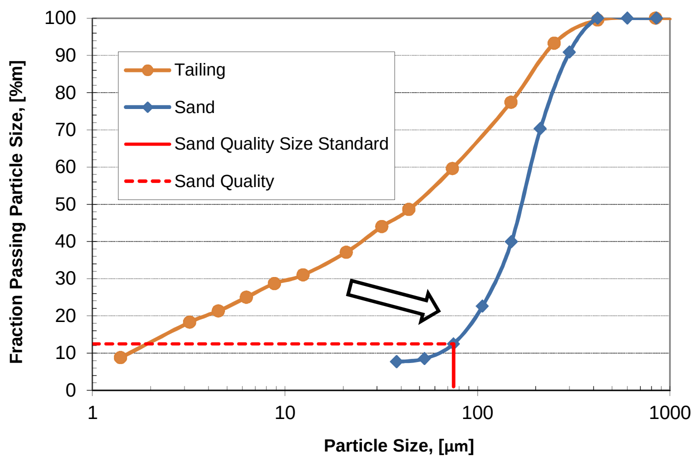

Figure 3: Feed to Product Particle Size Distribution Change

Cyclone Performance

Cyclone Operation

Hydro-cyclones work on the same principle as many gravity based separation devices, with the exception that the centrifugal acceleration forces at work are many times that of gravity.

Hydro-cyclones are generally classified by make and diameter, although a number of other parameters which define the cyclone and influence its performance exist. The tube making up the upper outlet protrudes into the cyclone is referred to as vortex finder. The lower discharge is called the apex or spigot. The size of opening of each aperture, whether feed inlet, vortex finder or apex, has an influence on the separation characteristics achieved by the cyclone.

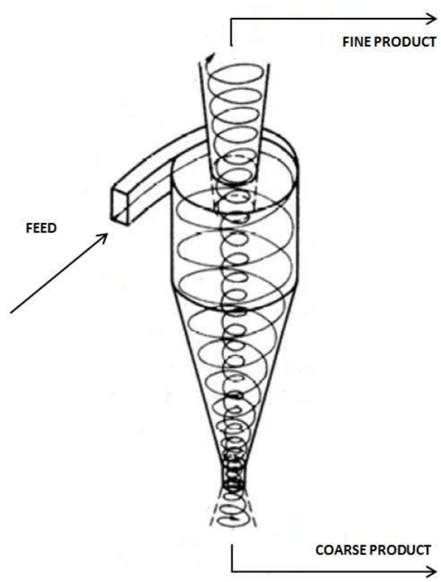

Figure 4: Principle of Centrifugal Acceleration as used in the Cyclone

In a hydro-cyclone the water fluid medium is also distributed between the cyclone overflow and underflow. The fluid medium serves as a carrier fluid for the finer particle sizes and therefore in practice it is found that the separation in a cyclone is also characterized by a by-pass fraction of fine particles that are carried by the water to the underflow which otherwise would have been deported to the cyclone overflow. By convention, it is assumed that all particle sizes are carried in the by-pass stream in proportion to their concentration in the feed to the cyclone. Figure 5 gives a diagrammatical outline of the by-pass in a hydro-cyclone.

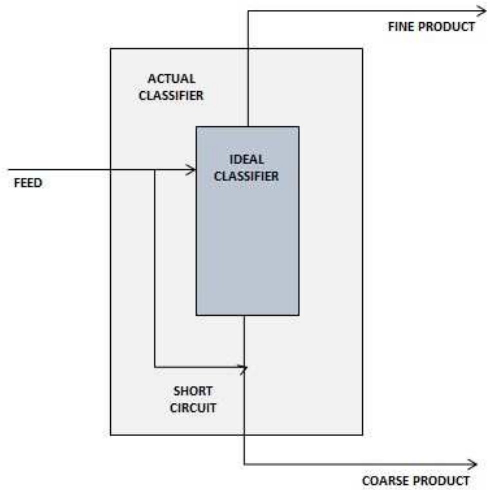

Figure 5: Cyclone Performance Flowsheet Skematic

Efficiency Curve

Also called the Tromp or the partition curve, the efficiency curve shows what fraction of a certain particle size is being recovered from the feed to the cyclone underflow.

Figure 6 shows that efficiencies actually achieved compared to the step change curve of an ideal and perfect separation. Also shown is the corrected form of the curve in which the by-pass is eliminated to yield the true classification action of the cyclone.

The corrected efficiency curve is characterized by two parameters. The first of which is the 50% cut-size which is the particle size at which half of the material at that cut-size reports to the underflow and half reports to the overflow, generally denoted by d50c. The other parameter is the sharpness of separation, generally denoted by m, which can be likened to the slope of the efficiency curve at the d50c point.

Mathematically the corrected efficiency curve is often represented by the Plitt equation (1) (Heiskanen 1987).

$$E = (1 - Rf)\left(1 - e^{\left(-0.693\left(\frac{d}{d50c}\right)^{m}\right)}\right) + Rf \qquad (1)$$

The performance of a cyclone can therefore be completely described by three parameters: the by-pass fraction (Rf), the cut-size (d50c) and the sharpness of separation (m).

A Rf of less than 20%m is considered low, while a by-pass below 30%m is seen as moderate, above 30%m as high.

A sharpness of separation of below 2 is seen as poor, above 2 as moderate with 3 and higher being excellent.

The d50c cut-size is mostly a function of cyclone diameter, but can be changed to a certain extent through feed rate and vortex and apex opening size changes.

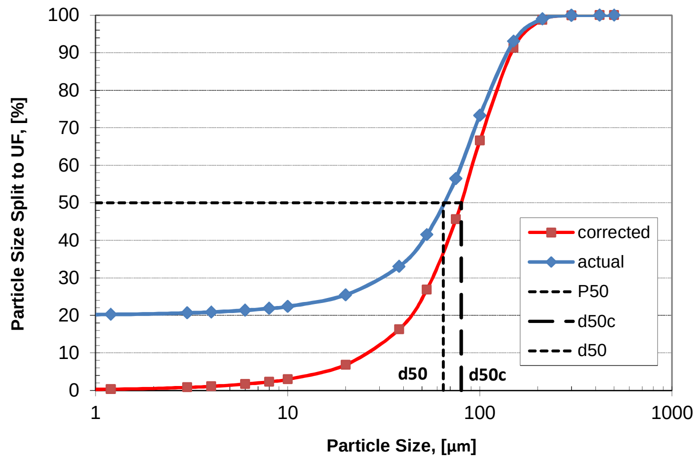

Figure 6: Efficiency Curve summarizing the Cyclone Performance

Cyclones of the same diameter but of different make do not necessarily perform the same for a similar application in order to fullfill a common design criterium Figure 7 shows how two different cyclone makes perform for the same application with the same feed. Table 1 lists the salient performance parameters of the two cyclone makes. If needed, feed solids concentration, feed pressure, vortex finder and apex could be changed for the two differing cyclones types so that more similar responses over the whole PSD range can be achieved, but not all cyclones should be regarded as equal in performance.

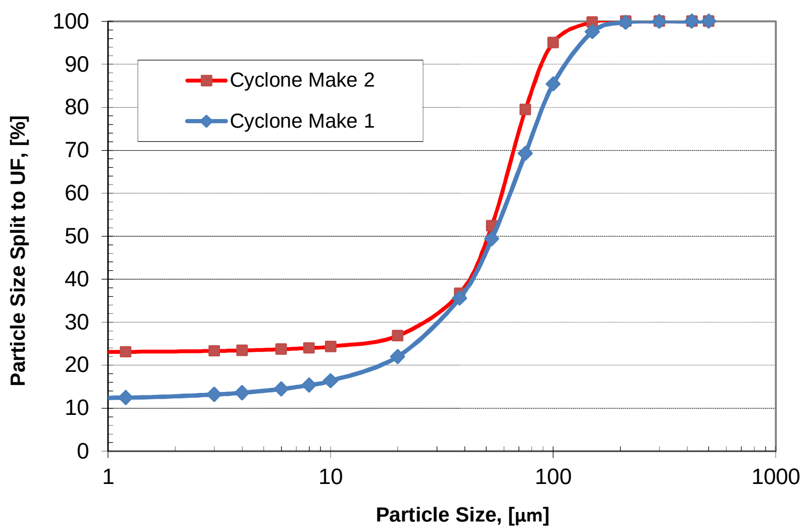

Figure 7: Efficiency Curve showing difference in Cyclone Performance possible for the Same Application

Table 1: Cyclone Make Performance Parameters

Parameter	m	Rf	d50c
Cyclone Make 1	1.8	12%m	60µm
Cyclone Make 2	2.9	23%m	60µm

Solids Balance

Sand Yield and Quality

On the cyclone product output side two defining parameters are required, the solids split and a size specification on one of the two products. In this application the two parameters are the sand yield and sand quality.

The relatively free-draining characteristic of the sand is defined by the mass fraction of particles of less than 75µm. This is a concept borrowed from the soil sciences where by definition free drainage occurs at a particle mass fraction of 5% passing 75µm. The definition has been amended for tailing dam construction to slightly higher percentages by mass passing 75µm, with 15%m being common, 18%m considered on the high end.

The sand yield of course defines the efficiency and therefore the cost expended and viability of the sand production at the right quality. While the largest contributor to the sand yield is the coarseness of the original tailing stream, much of the sand yield is also determined in how the cyclones are set up and operated.

Figure 8 shows how a coarse grained tailings stream in a single efficient cyclone stage can indeed meet both design constraints, and in this case, a sand quality of 12.5%m and a sand yield of 40%m. The feasible design envelope is shown as the shaded area. A cut-size of 120µm to 230µm will result in an acceptable performance.

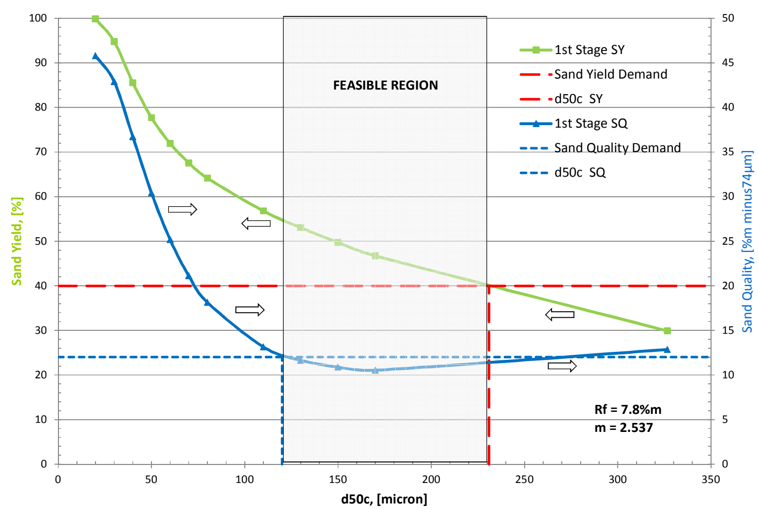

Figure 8: Feasible Solution with a Single Stage Cyclone Operating Envelope (Rf = 7.8%m and m = 2.537)

Should the achievable efficiency of the cyclone in this application fall short, it could be that no feasible solution exists. Figure 9 shows that if the cyclone by-pass is as high as 15%m for the previous scenario, then no feasible solution for a single stage cyclone operation exists. In such a case a second cyclone stage in series is required.

As can be seen the optimum cut-size range has not shifted much.

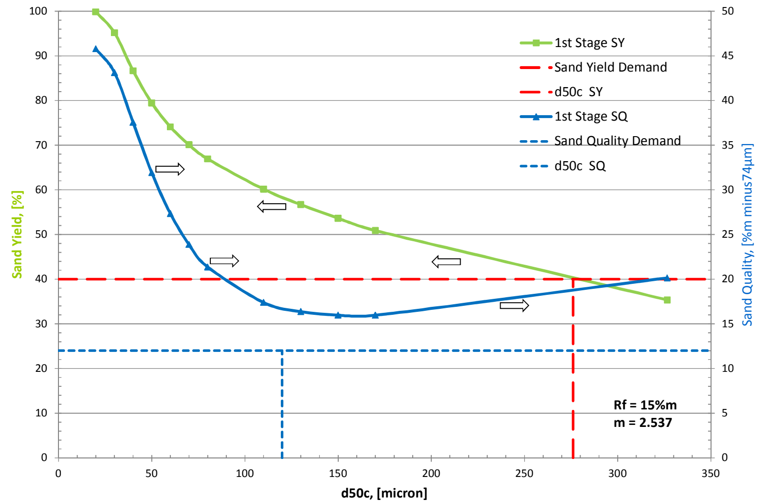

Figure 9: No Feasible Solution for Single Stage Cyclone (Rf = 15%m and m = 2.537)

The staging of cyclones in series improves the sand yield or sand quality. The objective of the first cyclone stage is to ensure coarse particle recovery, while the aim of the second stage is to polish the product, ensuring that product quality is achieved. Figure 10 shows the effect of the second stage on the overall performance. In the case used in this study the feasible solution envelope is opened up considerably with a second stage of cyclones. It should be noted that this is true even though the first stage operation was not even set for the optimum cut-size range of around 120µm to 230µm, but only at 60µm.

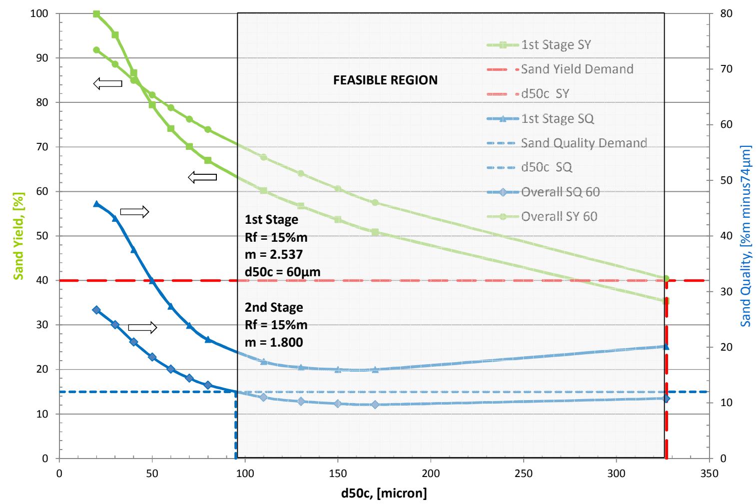

Figure 10: Feasible Solution with a Two Stage in Series Cyclone Arrangement (1st Stage d50c of 60µm)

From a theoretical perspective the maximum sand yield is achieved when both cyclone stage effect the separation at the correct and identical cut-point. In practice this is not always achievable.

Water Balance

Intrinsic to any tailing disposal is the objective of water recovery. There exists an interaction between water recovery and the cost of water recovery involving equipment for any tailing handling.

This is no different for hydro-cyclones. The efficiency of a cyclone in terms of cut-size, sharpness of separation and by-pass fraction is very much a function of the liquid content of the feed. The quantity of liquid impacts the viscosity and thereby separation efficiency. The more dilute the feed generally the better the separation efficiency (Heiskanen 1987).

These benefits of dilution have to be balanced against the dilution water requirements, which involve transportation consideration as well as potential loss through handling.

Figure 11 and Figure 12 show results from such a case study.

Figure 11 shows how the increasing the solids concentration to the 1st Stage (at constant 42%m solids concentration in feed to the 2nd Stage) reduces the sand yield. An improvement in sand quality is seen. The dilution water requirement is reduced.

The same effect is seen in Figure 12 where the feed solids concentration to the 2nd Stage is increased (holding the feed solids concentration to the 1st Stage at a constant 42%m). The impact on the sand yield reduction is less and the final sand quality improves more than in the 1st Stage. The reason for the difference is that the quantities involved in the 2nd Stage are less and the feed is generally lower in finer particle sizes.

In both cases the improvement in final sand quality can be ascribed to the fact that while an increase in solids concentration reduces the separation efficiency, the reduced liquid translates to a reduction in by-pass and therefore short-circuiting of fine particles to the underflow.

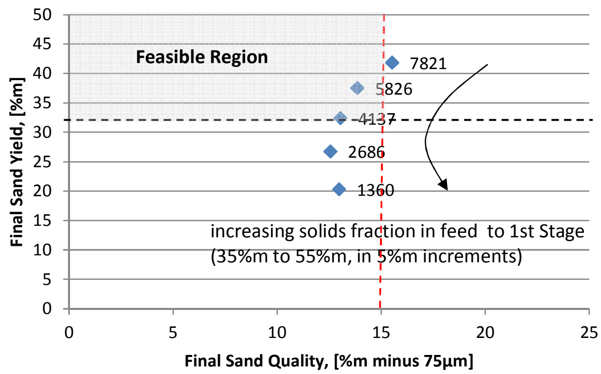

Figure 11: Effect of Increasing Solids Concentration to 1st Stage (Data labels represent dilution water flow in m3/h) (Feed to 2nd Stage of 42%m solids)

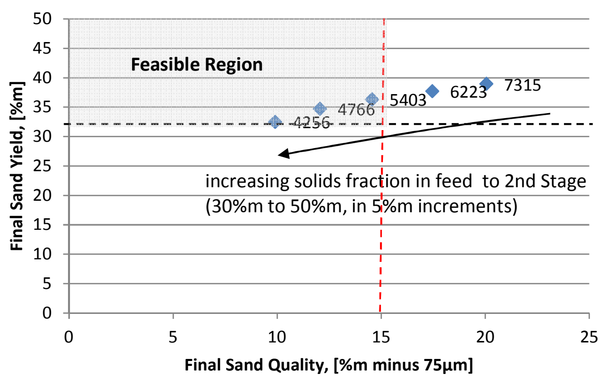

Figure 12: Effect of Increasing Solids Concentration to 2nd Stage (1st Stage Feed constant at 42%m)

Water Balance (Overall)

The distribution of the water between the overflow and underflow of the cyclones needs to be tied in with the overall water balance requirements. Here other considerations impact on the water recovery such location of the TSF with respect to the concentrator (remote or close by) or for example the topography (at same elevation or much lower in elevation than the concentrator). Both of these have implications on the transportation costs and the water recovery. Both of them will as a result have differing flow sheets for optimized water recovery and handling cost.

Figure 13 and Figure 14 below show how with a TSF at an elevation well below that of the concentrator and cyclone station, the economic optimum calls for the thickener capacity to be located at the cyclone station rather than at the concentrator. The water pumping cost from reclaim water pond is higher than the pumping cost from a thickener located close in elevation to the cyclone station. Location of the thickener at the TSF rather than at the concentrator is not common. It requires a change in mindset, dictated by the economic facts.

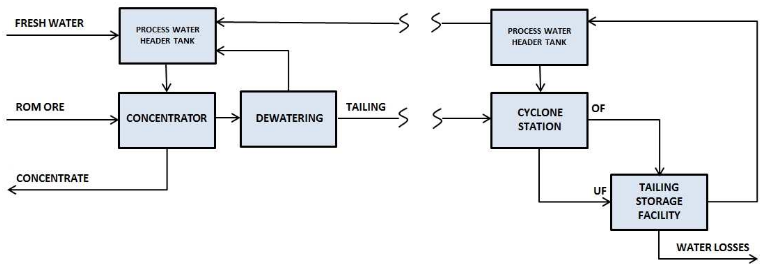

Figure 13: Tailing Management Flowsheet without Elevation Differences

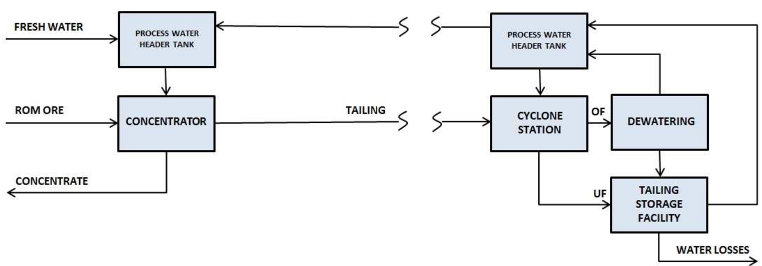

Figure 14: Tailing Management Flowsheet with Elevation Differences

Other Consideration

Environmental

Not mentioned explicitly, the sand tailing might require further treatment so that environmental impact is eliminated. This incurs of course an additional treatment cost. Examples of this are the cyanide destruction required in case of gold ores and the sulphide removal so that AMD is eliminated with sulphide ores. In the case of acid generating tailing, the cyclones tend to concentrate the heavier sulphide minerals in the underflow thereby reducing the treatment to the smaller sand fraction of the tailing only (Rasmussen et al. 2004) This is all the more important if the sand will be used for construction where it is exposed to air and intermittent water seepage, conditions ideal for acid generation.

Real World

Reality will have it that the tailing will characterized by variation in PSD, mineralogy, mass flow rate and solids concentration. The same theoretical tools can be utilized to analyse the effect of the variances.

New Developments

This paper is based on the traditional or conventional cyclone type, which are the main stay. There are however new developments in cyclone technology worth looking at, especially for use with special applications. Some of these are:

The Recyclone® technology is based on Twin Vortex concept already in use in the early eighties (Heiskanen 1987.). The technology has however now been expanded to large diameter cyclones. Instead of two different stage, the Recyclone® technology consists of two cyclones joined in series as a combined unit, the upper cyclone however is fitted with a straight instead of conical section leading into a transition piece between the combined cyclones. Dilution water added to this transition zone in conjunction with the straight upper section assists with the disruption of the viscous layer normally contributing to entrainment of fines into the underflow of the upper cyclone. The design of the transition zone and the dilution water reduce the wear in that region, reduces the by-pass of fines to the lower cyclone and regulates the inlet pressure to the lower cyclone (Castro et al. 2009, Weir Group PLC 2011, Cavex® Recyclone® Brochure).

CycloWash™ is a related concept in which water is introduced tangentially to the underflow spigot under a shroud. The fresh water in the spigot turning with the underflow vortex permits the transition of larger particles, but keeps the by-pass liquid fraction and smaller particles from leaving the cyclone in the underflow (FLSmidth CycloWash™ 2011)

The CycloStack™ technology employs a syphon with controlled suction on the cyclone overflow and a polyurethane flapper valve on the underflow to de-water the underflow at the same timer creating a stack of sand. This technology might especially be suitable when the discharge from the underflow requires no further mechanical displacement action, such as for example if placement can be down a steep slope (FLSmith CycloStack™ 2011).

Conclusions

By extracting a coarse relatively free draining sand fraction from the tailing a valuable by-product can be generated, at the same time reducing the tailing storage requirement. Cyclones are cost effective for the application especially if gravity flow is available for feeding the cyclones.

The design envelop is complex due to the huge number of possible combinations and the interactive nature of the application. The tools however exist to allow determination of the optimal solids and water balances.

Nomenclature

Y Mass Fraction passing a certain Particle Size, [-] or [%m]

d50c Cut-Size Particle Size reporting at equal proportions to cyclone outputs, [µm]

m Sharpness of Separation, [-]

Rf By-Pass Fraction, [-] or [%m]

Abbreviations

UF Cyclone Underflow

OF Cyclone Overflow

AMD Acid Mine Drainage

%m mass concentration

Definitions

Sand

The free-draining coarse particle size fraction from the tailing stream.

Free-Draining (Relatively)

Gravel or crushed rock containing less than 15% by mass minus 74µm.

Sand Yield

The fraction of sand recovered from the tailing stream as acceptable sand quality.

Sand Quality

The free-draining nature of the sand as determined by the minus 74µm fraction.

Separation Efficiency

Measure of sharpness of classification.

By-Pass

Fraction of liquid in feed reporting to the cyclone underflow.

References

Castro E., Lopez J., Switzer D., 2009. Maximum Classification Efficiency through Double Classification using the Recyclone. *Recent Advances in Mineral Processing Plant Design*, SME.

Cavex® ReCylone® Brochure 1109 Final.

FLSmidth Krebs. Krebs Sand Stacking Cyclones. *Bulletin*: #1-201.

FLSmidth. Available from: http://www.flsmidth.com/en-US/Products/Product+Index/All+Products/Hydrocyclones/Hydrocyclone+Accessories/CycloWash [Accessed 4 August 2011].

Heiskanen K., 1987. *Larox Classification handbook.* ISBN 951-99881-3-0.

Rasmussen G., Hoffert J., Tucker G., Kinch J., Colwell D., 2004. The Kemess Mines Ltd. Tailings Dam Construction Using Tailings Construction Sand. *Proceedings of the 36th Annual Meeting of the Canadian Mineral Processors*: Paper 4.

The Weir Group PLC. Available from: http://www.weirminerals.com/products__services/hydrocyclones/hydrocyclones/cavex_recyclone.aspx [Accessed 4 August 2011].