GREEN PAPER
SLURRY PUMPING 101

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Slurry definition

A slurry is a liquid containing SOLID particles whilst a liquor contains DISSOLVED particles. Pumping solids raises different requirements for a pump compared to pumping just a liquid.

Liquid properties

Except for density the characteristics of a liquid are decided by its viscosity.
Liquids deform continuously as long as a force is applied to them. They are said to flow. When a flow takes place in a liquid, it is opposed by internal friction arising from the cohesion of the molecules. This internal friction is the property of a liquid called viscosity.

In most liquids, the viscosity decreases rapidly with increasing temperature.

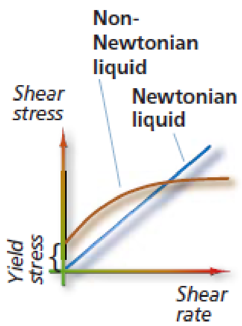
Newtonian liquids

Newtonian liquids give a shearing stress that is linear and proportional to the velocity gradient, or the shearing rate. Water and most liquids are Newtonian.

Non-newtonian liquids

Some liquids, such as water based slurries with VERY fine particles, do not obey the simple relationship between shearing stress and shearing rate (compare non-settling slurry). They are referred to as non-Newtonian liquids.

Some non-Newtonian liquids have a unique property of not flowing until a certain minimum shear stress is applied. This minimum shear stress is known as the yield stress. Consider fine wet beach sand at the shore break (or in the extreme quicksand). When you stand on it, it remains hard. Stamp your feet on it, and it turns to liquid and you start sinking. The slurry needed an initial energy input to enable it to begin to act as a flowable product.



The KETO Pipe calc will calculate pipeline losses for viscous fluids but NOT non-settling fluids.

Slurry properties

A number of characteristics of the slurry and of the system must be known to be able to select a slurry pump correctly.

When selecting a slurry pump it is necessary to know certain parameters.

The “KETO Slurry Questionnaire”, shows the parameters that should be included when making calculations for a slurry pump. The accuracy of the results will be better if the slurry parameters are well defined, and as many of values are requested are provided. If some values aren’t available, the accuracy of the selection will likely be compromised.

It is always possible to send samples for full rheology tests to KETO Australia for analysis.

Slurry parameters

The following parameters must be determined when calculating slurry pump systems and selecting pumps.

Particle size and distribution

Particle size d_{50} (d_{85}) is a measure of the percentage of particles in the slurry with a certain size or smaller.

The value is determined by sifting the solids through screens with varying mesh and then weighing each fraction. A sieve curve can then be drawn and the percentage of particles of different sizes read.

Example:
d_{50}= 3 mm means that 50% of the particles have a diameter of 3 mm or less.
d_{85}= 3 mm means that 85% of the particles have a diameter of 3 mm or less.

Mass fraction of small particles

The fraction of particles smaller than 50 mm.

It is important to determine the percentage of small particles in the slurry. If the slurry is a typically widely graded mixture, then particles smaller than 50 mm can to some extent facilitate the transport of larger particles. However, if the percentage of particles smaller than 50 mm exceeds 50%, and the weight of the slurry by concentration exceeds 10%, the character of the slurry changes towards non-settling and the calculations cannot be done using conventional programs as they are Non-Newtonian**.** Contact your KETO support for advice.

Mesh sizes

The d_{50} particle size is the most useful description of solids to the slurry pump manufacturer. Sometimes clients are only able to provide a Mesh size which can be used to roughly approximate the slurry properties. Whenever possible obtain the d_{50} particle size.

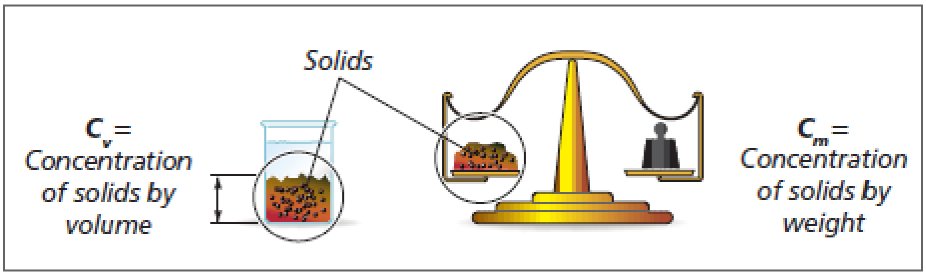
There are several different methods to determine the 'Mesh Size' of solids. All use a mesh to help analyse the size of solids by seeing if the solids will fall through a sieve or not. One of the most frequently used is the Tyler Mesh size which states the amount of holes per square inch the mesh has. For example a Mesh size of 16 means 16 holes per square inch. Powders and granular materials are sometimes described as having a certain mesh size (e.g. 30 mesh sand). By itself, this type of description is ambiguous to slurry pump companies. More precise specifications will indicate that a material will pass through some specific mesh (that is, have a maximum size; larger pieces won't fit through this mesh) but will be retained by some specific tighter mesh (that is, a minimum size; pieces smaller than this will have passed through the mesh). This type of description establishes a range of particle sizes.

One notation for indicating particle size distribution using mesh size is to use + and - designations. A "+" before the sieve mesh indicates the particles are retained by the sieve, while a "-" before the sieve mesh indicates the particles pass through the sieve. This means that typically 90% or more of the particles will have mesh sizes between the two values.

For instance, if the particle size of a material is described as -80/+170 (or could also be written -80 +170), then 90% or more of the material will pass through an 80 mesh sieve and be retained by a 170 mesh sieve. A mesh size conversion chart is included in Appendix A.

Concentration of solids

The concentration of particles in the slurry can be measured as a volume percentage, Cv, and a weight percentage, Cw.



Density/specific gravity

The density of the solids is stated as the Specific Gravity. This value, SG_s, is determined by dividing the density of the solid by the density of water.

The vast majority of slurries use water as the fluid medium. The density of water is 1000 kg/m^3 (SG =1.0) at 20^{o}C. The KETO Pipe Calc program does however allow for calculations using fluids with different SG's (SG_l).

In most applications people want to pump a certain amount of solids in a given time frame. The known variables required for the calculations are the SG_s, SG_l and C_w. The program incorporates a nomograph to enable calculate C_w of these variables if the C_v is known.

Slurry characteristics

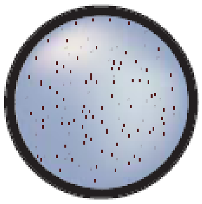
Slurries can be divided up into **non-settling** and **settling** types, depending on the parameters mentioned on previous pages.

Non-settling slurries (particle size <50mm)

A slurry in which the solids do not settle to the bottom, but remain in suspension for a long time. A non-settling slurry acts in a homogeneous, viscous manner, but the characteristics are non-Newtonian.

A non-settling slurry can be defined as a homogeneous mixture (solids and liquid in which the solids are uniformly distributed).

At low concentrations by volume the slurry will have pipe friction losses similar to that of water. At high concentrations by volume the slurry will start behaving in a viscous style manner where the yield stress needs to be overcome in order to 'begin pumping'. Special pipe friction loss calculations are often required. Open impellers, which create more shear, are often useful for this type of duty.



Homogeneous mixture

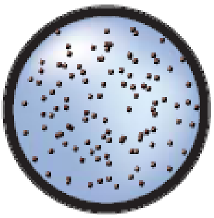
Settling slurries (particle size >50 mm)

These are by far the most common types of slurries. This type of slurry settles fast during the time relevant to the process, but can be kept in suspension by turbulence.

A settling slurry can be defined as a pseudo-homogeneous or heterogeneous mixture and can be completely or partly stratified.

Pseudo-homogeneous mixture

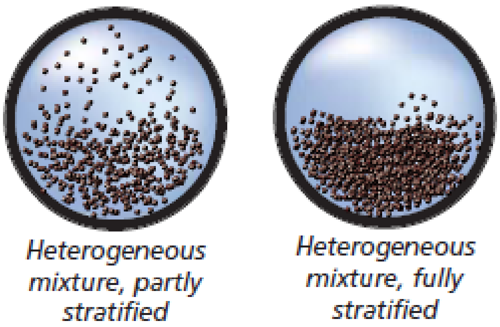
A mixture in which all the particles are in suspension but where the concentration is greater towards the bottom.



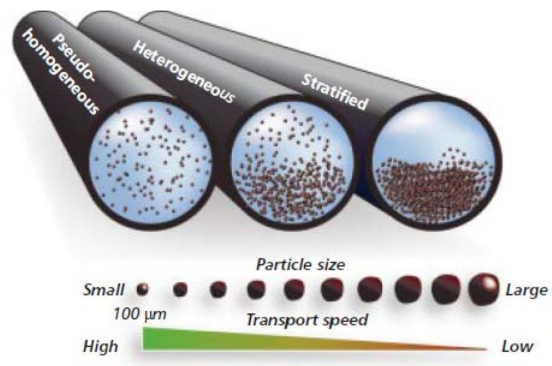
Pseudo-homogeneous mixture

Heterogeneous mixture

A mixture of solids and liquid in which the solids are not uniformly distributed and tend to be more concentrated in the bottom of the pipe or containment vessel (compare to settling slurry).



The diagram shows how different types of slurry behave, depending on particle size, and transport speed.

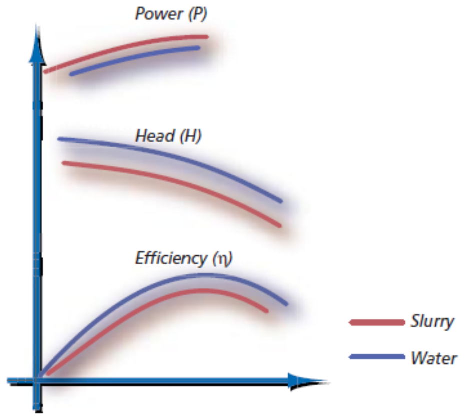


A high transport speed and/or small particles means that all the particles are in suspension. The slurry behaves pseudo-homogeneosly.	When the particle size is larger and the transport speed is lower, the particles tend to become more concentrated towards the bottom of the tube or are in mechanical contact with it. The slurry behaves heterogeneously.	At low transport speeds and/or large particles, the slurry tends to collect/glide. A slurry consisting of large particles can also move like a sliding bed.

Pump performance

The head developed by a centrifugal pump pumping slurry differs from the performance with clean fluids depending on the amount of solid particles in the slurry as the solids do not behave in the same manner as liquid. The difference is estimated by the Head Ratio and Efficiency Ratio.

The factors that are affected are the Power (P), Head (H), and Efficiency (E). The differences between slurry and water are shown schematically in the curves below.



The diagram illustrates the increased power requirement and the reduction in head and efficiency of a centrifugal pump operating at constant speed and handling slurry.

Head ratio (HR)

The HR is equal to unity for water (as this is what centrifugal pump curves are based on) but decreases as the concentration of solids increases in the slurry mixture. The HR for any given slurry is affected by the particle size and specific gravity and shape of the solids as well as the volumetric concentration of solids in the mixture. The reason being the centrifugal force applied to the solids does not have the same effect as the force applied to the liquid.

An increase in the solids by volume can have a marked effect on the HR. For this reason KETO and other experts in the field of pumping slurry, are particularly interested in the solids by volume being pumped.

Efficiency ratio (ER)

The ER is similar to the HR, but infers the effect the slurry directly has on the efficiency of the pump. For slurries with concentrations by volume of up to 20%, the ER is the same as the HR. Slurries whose concentration by volume exceeds 20% have a greater drop in ER than the HR.

Determining the HR and ER

The only way to accurately determine the exact HR and ER for a slurry is to conduct extensive site tests on the exact slurry being pumped with the exact pump being used. This is not usually practical: hence estimations based on laboratory testing of similar slurries are provided. These estimations are conservatively within +/-15%. The drive systems for slurry pumps are usually supplied to enable simple adjustment of the speed on site if 'fine tuning' of the flow is desired.

KETO impellers, which have modern 'twisted vane' impeller designs, are known to be less effected by the slurry than older 'plain vane' impeller designs used by others. The results being that not only are KETO impellers more efficient when pumping water, they are significantly more efficient when pumping slurries.

System design

Static head

Suction Static head is the vertical height difference from the surface of the slurry at the source to centerline of the pump impeller. Discharge static head is the vertical height difference from centerline of the pump impeller the discharge point.

Friction losses

When the liquid starts to flow through the pipe line(s) and valves, friction will arise. When pumping slurry, friction losses caused by pipe roughness, bends and valves, are different compared to the corresponding losses when pumping water. The friction losses can be rapidly estimated by using the 'KETO System Calculator'.

Pressure fed equipment

Many slurry services contain cyclone separators' or filter feed presses which require a particular discharge pressure at the end of the pipe in order for pressure fed equipment to work effectively.

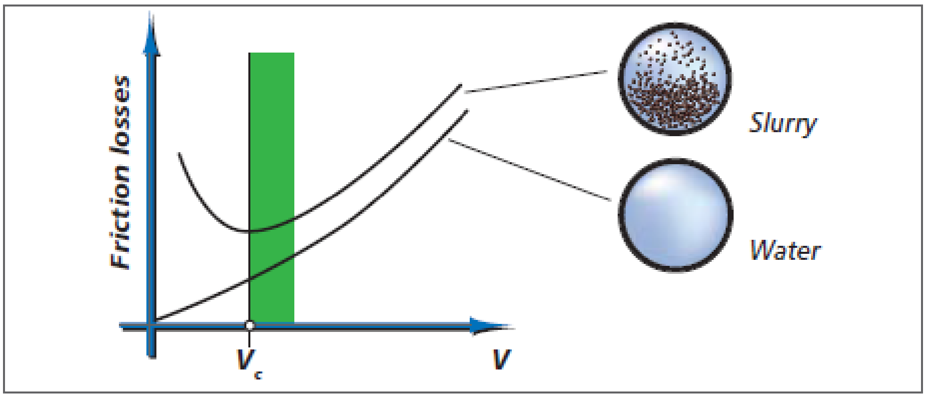
Total discharge head

This value is used for pump calculations and comprises the static head plus friction losses plus pressure feed equipment needs caused by pipes and valves, converted to metres of water.

Critical velocity

In general, the flow velocity in the pipes must be kept above a certain minimum value.
If the flow velocity is too high, friction losses will increase. This may also increase the wear in the pipe system. Flow velocities that are too low will result in sedimentation in the pipes and, thus, increased losses.

This is illustrated in the diagram below, in which the critical velocity (Vc) indicates the optimum velocity where losses are kept to a minimum (between the critical velocity and 130% of the critical velocity).



When making calculations for a slurry pump for a certain flow, the desired flow velocity (V) must be compared to the critical velocity (Vc) for the slurry and the pipe system in question. As the figure above shows, the ideal velocity (marked green) is immediately above the critical velocity (but with a margin for the extreme cases that can arise or changes in the slurry characteristics that may occur). The area marked green provides the most efficient transfer of solids through the system, as this is the region where the Total Dynamic Head (TDH) is near its lowest for a given flow, without the slurry settling out.

The KETO System Calculator uses the modified Durands formula (for the widely graded slurries found in most applications). The program allows the engineer to enter other values of limiting setting velocity (FL).

Slurry pump types

Both 'positive displacement (PD)' and 'centrifugal' pumps are used to pump slurries. By far the most common and economical to run style of slurry pump is the centrifugal slurry pump which is the style that KETO specialise in and that this paper details.

PD Pumps

PD Pumps 'force' the slurry from suction to discharge by mechanical means, all containing a method of back flow prevention. Many can develop very high pressures in comparison to the flowrate. The most common types of PD pumps used to pump slurries are:

1. Helical Rotor Pumps. Also called 'Mono Pumps', 'Progressive Cavity Pumps'. The leading brands in this field are 'Mono', 'Southern Cross', 'Moyno', 'Seepex' and 'Bornemann'.
2. Air Operated Diaphragm (AOD) Pumps. The leading brands in this field are 'Wilden', 'Sandpiper', 'Versamatic' and 'Husky'.
3. Double Diaphragm Piston or Hose Diaphragm Piston. The leading brands in this field are 'Wirth' and 'Feluwa' Pumpen, both of Germany.

PD pumps are generally used to pump slurry in two situations: when the flow is extremely low; when the pressures are extremely high.

Centrifugal pumps

Centrifugal pumps utilise the centrifugal force generated by a rotating impeller to impart energy to the liquid and transfer it from suction to discharge.

Centrifugal slurry pumps are designed specifically to transfer solids. This entails care taken in the hydraulic design, material options, casting thicknesses, and ease of maintenance.

Horizontal centrifugal slurry pumps

These types of pumps have the shaft located in the horizontal plane and are usually 'end suction' design with 'tangential discharge'. Our KETO HS range falls into this category. They are sometimes called dry mounted too, as the hydraulic end and the drive unit is located outside the sump, having a positive feed from a hopper. It is the main type of slurry pumps and they are available for a wide range of head and flow conditions and material options.

These types of pumps normally use standardized electrical motors and seals.

Vertical centrifugal slurry pumps

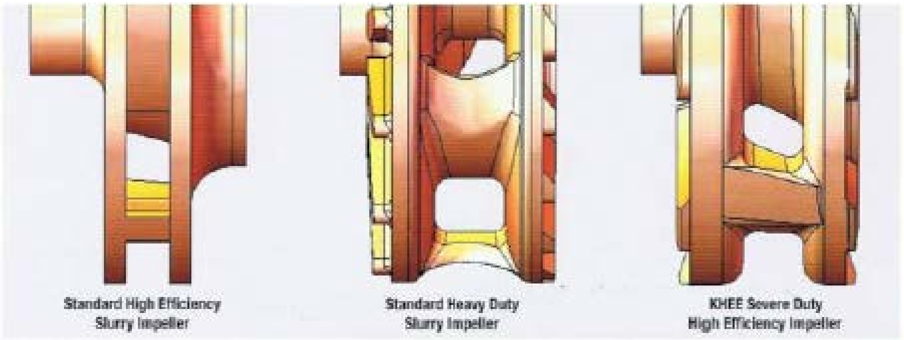
These types of pumps are called vertical slurry pumps as the shaft is located in the vertical plane. Our KETO VS range falls into this category. This type of pump can be subdivided into two main groups:

- Tank pumps
- Cantilever/sump pumps

Tank pumps are considered as *dry installed* pumps. The sump is incorporated in the pump. Open sump and vertical inlet prevent air blocking and give smooth operation. For reduced maintenance needs it is important with this type of slurry pump that there are no submerged (plain) bearings as these are prone to damage by the slurry. If the sump is deep and the product is not overly corrosive or hot, and the pumpage is a heavy slurry, we recommend a heavy duty submersible slurry pump such as an ITT Flygt 5100/5150. For abrasive, but not heavy slurry duties (such as those found in mine dewatering) we recommend the Raptor series from PumpEng.

Hydraulic design

Pumping slurry can cause a severe reduction in the hydraulic efficiency of a pump. The KETO impellers and volutes are designed to optimize the efficiency AND wear life. Higher pumping efficiencies due to advanced twisted vane designs result in three major benefits: less turbulence than occurs in older plain vane impellers; less recirculation damage when the pumps operate at reduced flow; better suction performance. These benefits are due to less turbulence losses as the liquid enters the vanes and due to there being less turbulence, less erosion occurs in the pumps.



To achieve a long wear life, the vanes and shrouds must remain a heavier section than water pumps so they maintain their high efficiency during the slurry wear cycle. For optimum performance on slurries impellers should also maintain the pump out vanes which reduces wear on the liners. For these reasons even modern slurry pumps still remain less efficient than water pump designs in the ‘as new’ test lab condition, but as lighter duty impellers found in water pumps soon lose their efficiency in slurry applications, the initial efficiency benefit is lost whilst the KETO KHEE impellers maintain their efficiency over the long term in even the most severe applications.

The KETO KHEE impellers dramatically often outlast plain vane impeller designs by a factor ranging from two to seven times.

Selecting slurry pumps

Slurry pumping can usually be separated into four categories which ANSI/HI Standard 12.1-12.6-2005 categorises as light slurries (Class 1), medium slurries (Class 2), heavy slurries (Class 3) and very heavy slurries (Class 4).

The HI Standard defines the Classes in Figure 1 shown below.

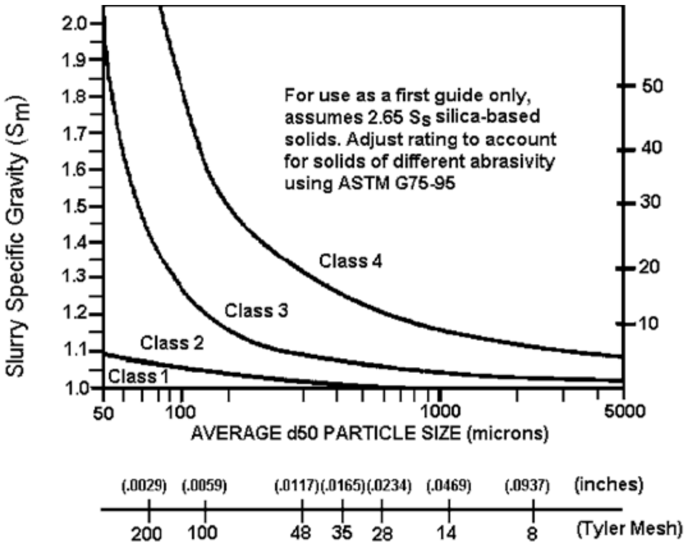


Figure 1: Service Class Chart for Slurry Pump Erosive Wear

Most usually the light (Class 1) slurries are those not deliberately intended to carry solids. The presence of the solids occurs more by accident than design. On the other hand, very heavy slurries (Class 4) are those normally designed specifically to transport solids from one location to another. Very often the carrying fluid in very heavy slurry is just a necessary evil in helping to transport the desired material. The medium (Class 2) and heavy slurry (Class 3) fall somewhere in between.

Material selection guide

The optimum slurry pump material will often vary even across a single processing plant that is transferring the same solids (but having different sizes). For example a single processing plant may use all white iron 'Mill Discharge' pumps, through to a rubber lined pumps with urethane impeller to dispose of the tailings. The same solids are being transferred, often with the same or a very similar carrying fluid, but different slurry pump wear materials will be required.

The above explains why the best severe duty slurry pump ranges provide a selection of liners an impeller materials that can be fitted in the same pump 'wet end'. This enables sites to maximise interchangeabity throughout their plant, whilst ensuring that the most economical means of transferring the solids is achieved.

The HI Standard provides an approximate guide to attain the maximum operating values for acceptable wear for the pumps that should be installed. If for example, a very heavy slurry is being pumped at a head of 70m pumps in series should be considered as a single pump is expected to wear too quickly.

	Service class			
	1	2	3	4
Maximum head per stage: meter / feet	123 / 400	66 / 225	52 / 168	40 / 130
Maximum impeller peripheral speed: All-metal pump (m/s) / (ft/min)	43 / 8500	38 / 7500	33 / 6500	28 / 5500
Rubber-lined pump (m/s) / (ft/min)	31 / 6000	28 / 5500	26 / 5000	23 / 4500

Table 1: Suggested Maximum Operating Values for Acceptable Wear

Considerations that need to be addressed when selecting a pump model and its materials include:

- Abrasive hardness
- Particle shape
- Particle size
- Particle velocity and direction
- Particle density
- Particle sharpness
- Concentration of Solids by Weight or Volume
- Temperature of slurry
- Corrosive nature of carrier fluid/slurry

The KETO Slurry Questionnaire provides clients with an easy way to gather and send the information required to correctly select and supply a suitable pump.

Class 1 slurries

Class 1 are often non-settling, comprising a d_{50} particle size of less than 50mm. Slurries found in the other Classes nearly always being settling.
If the carrier fluid is below 70°C and not corrosive then the following material guide applies:
Class 1 Slurries: Standard slow speed water pumps fitted with 420SS wear rings and a suitable shaft seal arrangement can be considered.

Class 2 slurries

If solids have relatively round edges and heads less than approx 50m use KETO slurry pumps fitted with natural rubber liners. When the d_{50} particle size is less than 100mm use a urethane impeller and when larger use a white iron impeller. If particles are sharp or head exceeds approx 50m use an all white iron pump or consider pumps in series.

Class 3 slurries

If solids are relatively round edged, their maximum size is less than 5mm, and the head is less than 40m use KETO pumps with rubber liners. When the d_{50} particle size is less than 100mm use a urethane impeller. When larger than 5mm use a white iron impeller. If the d_{50} particle size exceeds particles 1mm OR are sharp OR the head exceeds 40m use a pump with all white iron liners and impeller or consider pumps in series.

Class 4 slurries

If solids are relatively round edged, their maximum size is less than 10mm, and the head is less than 30m use KETO pumps with rubber liners. When the d_{50} particle size is less than 100µm use a urethane impeller and when larger use a white iron impeller. If the d_{50} particle size exceeds particles 1000µm OR are sharp OR the head exceeds 30m use a pump with all white iron liners and impeller or consider pumps in series.

Duty point considerations

Although not used by other pump companies, Andrew Collins, Engineering Director of KETO Pumps recommends the kinetic energy in the slurry will have a large impact on the amount of erosion caused. The hypothesis is based on the collision impact theory where:

$$\text{Kinetic Energy} = \frac{(\text{Mass x Velocity}^2)}{2}$$

Doubling the velocity gives the slurry particle 4 times the energy to cause erosion!

Small particles, particularly if they are also light, get entrained in the fluid carrier and follow the same fluid path. They enter and leave the suction and discharge of the pump closely following the flow path of the carrier fluid. Under such conditions the pump should be selected close to the pumps best efficiency point as at the best efficiency point of the pump there is the least amount of turbulence and the lowest possibility of the solids colliding with the slurry pump surface.

At the other extreme large heavy particles do NOT want to change direction. They travel into the suction of the pump with their momentum wanting to carry them directly towards the impeller eye where they collide with the impeller before changing direction and being carried through to the discharge of the pump. Considering the kinetic energy involved in the collision, the impeller will have a far superior life if the pump is operated at reduced capacity (ie reduced suction and discharge velocities). As the larger solids are not following the fluid path through the pump, operating the pump close to BEP is less important to the anticipated wear life. Consider the enclosed Case Example from an Australian Manganese miner.

If the solids have sharp edges, the collision impact has an increased wear effect as due to the localised stress points encountered when the sharp solids impact the impeller or liners.

Due to the above parameters KETO Pumps recommend the following selection guidelines:

Operating Limits	**Service Class**			
	1	2	3	4
Recommended % of BEP Flowrate	45 - 120%	40-110%	35-100%	30-85%

Summary

This brief guide to pumping slurry provides the reader with the basics of selecting the correct pumps and materials for the majority of services. KETO stock rubber lined pumps with 27% Chrome White Iron (WI05) impellers as it will be found these meet the majority of general service slurry pumps. The design enables quick retrofits to other liners and impellers either in the KETO facility, or indeed on site where the material selections can be refined.

More detailed analysis of slurry pumps, slurry pump materials, slurry pump materials for corrosive duties, the use of adjustable speed controllers, and so on is available on request from KETO Pumps.

Appendix A: Common solids SGs and Mohs hardness

Material	Specific Gravity	Mohs Hardness
Aluminium	2.55-2.75	1-2
Amber	1.06- 1.11	
Ambylgonite	3-3.1	5.5- 6
Andesine	2.66- 2.94	6- 6.5
Aragonite, CaCO3	2.94- 2.95	3.5- 4
Argenite	7.2- 7.4	2- 2.5
Asbestos	2.1- 2.4	2
Asphaltum	1.1- 1.5	
Asphalt Rock	2.41	
Barite	4.5	3- 3.5
Basalt	2.4- 3.1	8- 9
Bauxite	2.55- 2.73	
Bentonite	1.6	
Bertrandite	2.6	6
Beryl	2.66- 2.83	7.5- 8
Biotite	2.7- 3.1	2.5- 3
Bone	1.7- 2	
Borax	1.71- 1.73	2- 2.5
Bornite	5.06- 5.08	3
Braggite	10	
Braunite	4.72- 4.83	6- 6.5
Brick	1.4- 2.2	
Clacite	2.72- 2.94	3
Camotite	2.47	1- 2
Cassiterite	6.99- 7.12	6 - 7
Carbon, Amorphous Graphitic	1.88- 2.25	
Celluloid	1.4	
Cerussite	6.5- 6.57	3- 3.5
Chalcocite	5.5- 5.8	2.5- 3
Chalcopyrite	4.1- 4.3	3.5- 4
Chalk	1.9 - 2.8	
Charcoal, Pine	0.28- 0.44	
Charcoal, Oak	0.47- 0.57	
Chromite	4.5	5.5
Chrysoberyl	3.65- 3.85	8.5
Cinnabar	8.09	2- 2.5
Clay	1.8- 2.6	2
Coal, Anthracite	1.4- 1.8	2
Coal, Bituminous	1.2- 1.5	
Coal, Lignite	1.1- 1.4	
Cobalite	6.2	5.5
Coke	1- 1.7	
Colemanite	1.73	4.5
Columbite	5.15- 5.25	6
Copper	8.95	2.5- 3
Cork	0.22- 0.26	
Covelite	4.6- 4.76	1.5- 2
Cuprite	6	3.5- 4
Diabase	2.94	
Diatomaceous Earth	0.4- 0.72	
Diorite	2.86	
Dolomite	2.8- 2.86	3.5- 4
Enargite	4.4- 4.5	3
Epidote	3.25- 3.5	6
Feldspar	2.55- 2.75	
Fluorite	3.18	4
Fly Ash	2.07	
Galena	7.3- 7.6	2.5- 2.75
Glass	2.4- 2.8	7
Goethite	3.3- 4.3	5- 5.5
Gold	19.3	2.5- 3
Granite	2.6- 2.9	
Graphite	2.2- 2.72	1- 2
Gravel, Dry	1.55	4- 5
Gravel, Wet	2	
Gypsum	2.3- 2.37	2
Halite	2.2	2.5
Hausmannite	4.83- 4.85	5.5
Helvite	3.2- 3.44	6
Hematite	4.9- 5.3	5- 6

Material	Specific Gravity	Mohs Hardness
Hessite	8.24- 8.46	2- 3
Ice	0.917	
Ilmenite	4.68- 4.76	5- 6
Iron, Slag	2.5- 3	
Lepodolite	2.8- 2.9	2.5- 4
Lime, slaked	1.3- 1.4	
Limestone	2.4- 2.7	2- 5
Limonite	3.6- 4	
Linnaeite	4.89	
Magnetite	4.9- 5.2	5.5- 6.5
Manganite	4.3- 4.4	4
Marble	2.5- 2.78	4
Marl	2.23	
Millerite	5.3- 5.7	3- 3.5
Monazite	5.1	5
Molybdenite	4.62- 4.73	1- 1.5
Muscovite	2.77- 2.88	2.5- 3
Noiccolite	7.784	5- 5.5
Orpiment	3.5	1.5- 2
Pentlandite	4.8	2.5- 3
Petalite	2.412- 2.422	6.5
Phosophite	3.21	
Phophorus, white	1.83	
Polybasite	6- 6.2	2.3
Porphyry	2.6- 2.9	
Potash	2.2	
Powelite	4.21- 4.25	3.5- 4
Proustlite	5.57	2- 2.5
Psilomelane	4.71	5- 6
Pumice	0.37- 0.9	
Pyragyrite	5.85	2.5
Pyrites	4.95- 5.1	3.5- 4.5
Pyrolusite	4.8	6- 6.5
Quartz	2.5- 2.8	7- 8
Quartzite	2.68	7
Realgar	3.65	1.5- 2
Rhodochrosite	3.7	3.5- 4
Rhodonite	3.57- 3.76	5.5- 6.5
Rutile	4.2- 5.5	6- 6.5
Sand (see Quartz)	1.7- 3.2	7
Sandstone	2- 3.2	7
Scheelite	6.08- 6.12	4.5- 5
Schist	2.6- 3	
Serpentine	2.5	2.5- 3.5
Shale	1.6- 2.9	
Siderite	3.9- 4	2- 4.5
Silica, fused, tras	2.21	
Slag, Furance	2- 3.9	
Slate	2.8- 2.9	
Samltite	6.48	
Soapstone, talc	2.6- 2.8	2
Sodium Nitrate	2.2	
Sperrylite	10.58	6- 7
Spodumene	3.03- 3.22	6.5- 7
Sphalerite	3.9- 4.1	3.5- 4
Stannite	4.3- 4.5	4
Starch	1.53	
Stibnite	4.61- 4.65	2
Sugar	1.59	
Sulfur	1.93- 2.07	1.5- 2.5
Sylvanite	8.161	1.5- 2
Taconite	3.18	
Tallow, beef	0.94	
Tantalite	7.9- 8	6.5
Tetrahedrite	4.6- 5.1	3- 4.5
Titanite	3.5	
Trap Rock	2.79	
Uraninite	8.11	5- 6
Witherite	4.29- 4.3	3.5
Wolframite	7.12- 7.51	4- 4.5
Zinc Blende	4.02	4
Zincinite	5.64- 5.68	4

Appendix B: Mesh size conversion chart

ISO	GBR	USA	USA	Description
Microns (μm)	Mesh	Tyler Mesh	USS Mesh	
75000			3 in.	Screen Shingle Gravel
50000			2 in.	
26500		1.05 in.	1.06 in.	
22400		0.883 in.	7/8 in.	
19000		0.742 in.	3/4 in.	
16000		0.624 in.	5/8 in.	
12500			1/2 in.	
11200		0.441 in.	7/16 in.	
9500		0.371 in.	3/8 in.	
8000		2.5	5/16 in.	
6700		3	0.265 in.	
5600		3.5	3.5	
4000		5	5	
2360		8	8	Very Course Sand
1700		10	12	
1400	12	12	14	
1180		14	16	Course Sand
1000		16	18	
850	18	20	20	
710	22	24	25	
600	25	28	30	
500	30	32	35	Medium Sand
425	36	35	40	
355	44	42	45	
300	52	48	50	
250	60	60	60	Fine Sand
212	72	65	70	
180	85	80	80	
150	100	100	100	
125	120	115	120	
106		150	140	
90	170	170	170	Silt
75	200	200	200	
63	240	250	230	
53	300	270	270	
45	350	325	325	Pulverised Silt
38	400	400	400	
32	440	450	450	

Appendix C: Slurries – definitions of common terms

Apparent viscosity:
The viscosity of a non-Newtonian slurry at a particular rate of shear, expressed in terms applicable to Newtonian fluids.

Critical carrying velocity:
The mean velocity of the specific slurry in a particular conduit, above which the solids phase remains in suspension, and below which solid-liquid separation occurs.

d_{50} particle size:
The single or average particle size used to represent the behaviour of a mixture of various sizes of particles in a slurry. This designation is used to calculate system requirements and pump performance.

Friction characteristic:
A term used to describe the resistance to flow which is exhibited by solid-liquid mixtures at various rates of flow.

Heterogeneous mixture:
A mixture of solids and a liquid in which the solids are net uniformly distributed.

Homogeneous flow (fully suspended solids):
A type of slurry flow in which the solids are thoroughly mixed in the flowing stream and a negligible amount of the solids are sliding along the conduit wall.

Homogeneous mixture:
A mixture of solids and a liquid in which the solids are uniformly distributed.

Non-homogeneous flow (partially suspended solids):
A type of slurry flow in which the solids are stratified, with a portion of the solids sliding along the conduit wall. Sometimes called heterogeneous flow" or "flow with partially suspended solids."

Non-settling slurry:
A slurry in which the solids will not settle to the bottom of the containing vessel or conduit, but will remain in suspension, without agitation, for long periods of time.

Percent solids by volume:
The actual volume of the solid material in a given volume of slurry, divided by the given volume of slurry, multiplied by 100.

Percent solids by weight:
The weight of dry solids in a given volume of slurry, divided by the total weight of that volume of slurry, multiplied by 100.

Saltation:
A condition which exists in a moving stream of slurry when solids settle in the bottom of the stream in random agglomerations which build up and wash away with irregular frequency.

Settling slurry:
A slurry in which the solids will move to the bottom of the containing vessel or conduit at a discernible rate, but which will remain in suspension if the slurry is agitated constantly.

Settling velocity:
The rate at which the solids in a slurry will move to the bottom of a container of liquid that is not in motion. (Not to be confused with the velocity of a slurry that is less than the critical carrying velocity as defined above.)

Viscosity types:
(For definitions of the various types of viscosities applicable to slurries. see Rheological Definitions.)

Yield value (stress):
The stress at which many non-Newtonian slurries will start to deform and below which there will be no relative motion between adjacent particles in the slurry.

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