



# AN INTRODUCTION TO SLURRY PUMPING



ICS Wear Group Inc.  
Slurry Pumping  
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## 1.0 Slurry Definition

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

## 2.0 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.

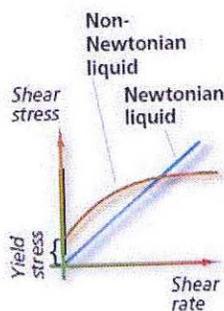
### **a) Newtonian liquids**

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.

### **b) 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 in it, and it turns to liquid and you start sinking. This slurry needed an initial energy input to enable it to begin to act as a flowable product.



The ICS Pipe calc will calculate pipeline losses for viscous fluids but not non-settling fluids.

## 3.0 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 “ICS 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 the values as are requested are provided. If some values are not available, the accuracy of the selection will likely be compromised.

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

## 4.0 Slurry Parameters

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

### **a) 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:

$d_{50} = 3\text{mm}$  means that 50% of the particles have a diameter of 3 mm or less.

$d_{85} = 3\text{mm}$  means that 85% of the particles have a diameter of 3 mm or less.

### **b) Mass fraction of small particles**

The fraction of particles smaller than 50  $\mu\text{m}$ .

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  $\mu\text{m}$  can to some extent facilitate the transport of lesser particles. However, if the percentage of particles smaller than 50  $\mu\text{m}$  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 ICS support for advice.

**c) 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.

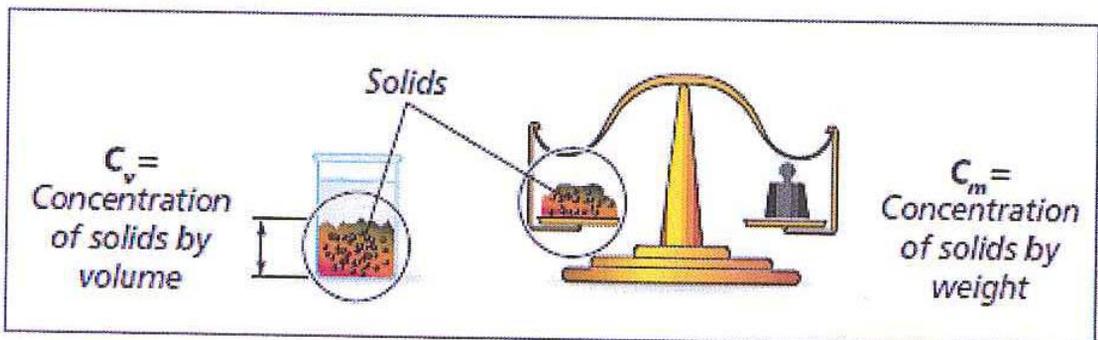
There are several different methods to determine the ‘Mesh Size’ of solids. All use a mesh to help analyze the size of solids by seeing if the solids will fall through a sieve or not. One of the most frequently used is the Tyler Mesh size which states the amount of holes per square inch the mesh has. 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 (eg. 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 established 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.

**d) Concentration of Solids**

The concentration of particles in the slurry can be measured as a volume percentage,  $C_v$ , and a weight percentage,  $C_w$ .



### **e) 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 the water.

The vast majority of slurries use water as the fluid medium. The density of water is  $1000 \text{ kg/m}^3$  ( $SG=1.0$ ) at  $20^\circ\text{C}$ . The ICS Pipe Calc program does however allow for calculations using fluids with different SG's ( $SG_1$ ).

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  $SG_s$ ,  $SG_1$  and  $C_w$ . The program incorporates a nomograph to enable calculating  $C_w$  of these variables if the  $C_v$  is known.

## **5.0 Slurry Characteristics**

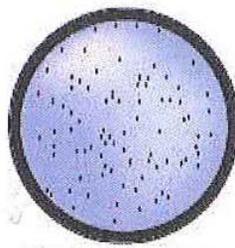
Slurries can be divided up into non-settling and settling types, depending on the parameters mentioned on previous pages.

### **a) Non-Settling Slurries (particle size $<50\mu\text{m}$ )**

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

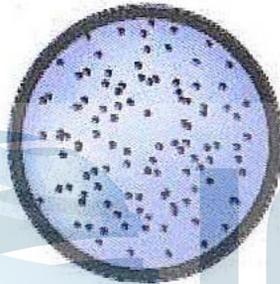
**b) Settling Slurries (particle size >50  $\mu\text{m}$ )**

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 pseudohomogeneous or heterogeneous mixture and can be completely or partly stratified.

*i. Pseudo-homogeneous mixture*

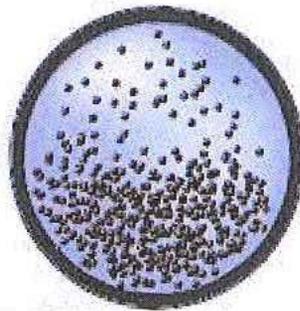
A mixture in which all the particles are in suspension but where the concentration is greater towards the bottom.



Pseudo-homogeneous mixture

*ii. Heterogeneous mixture*

A mixture of solids and liquids 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)

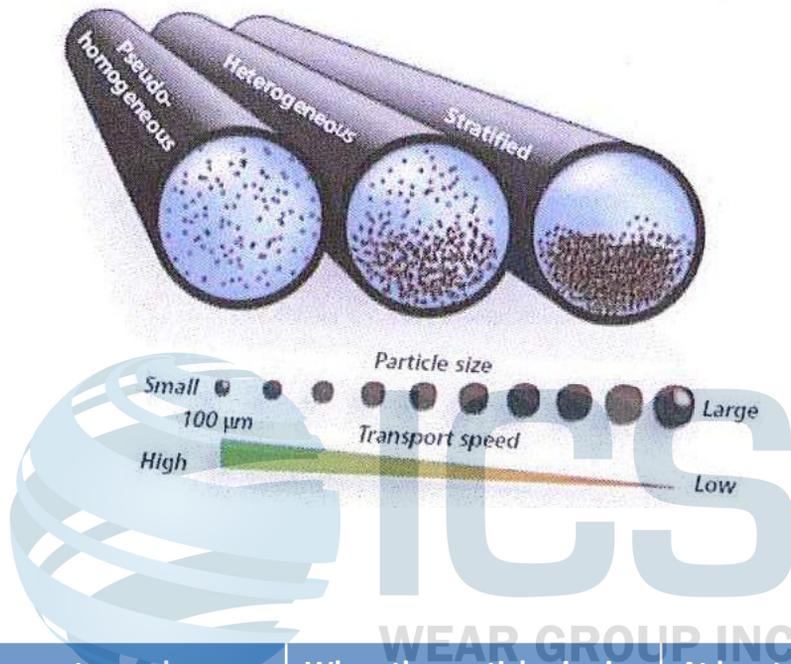


Heterogeneous mixture,  
Partly stratified



Heterogeneous mixture,  
Fully stratified

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-homogeneously

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

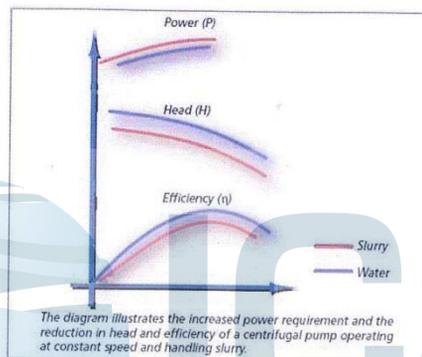
At low transport speeds and/or large particles, the slurry tends to collect/glide.

A slurry consisting of large particles can also move like a sliding bed.

## 6.0 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 (%). The differences between slurry and water are shown schematically in the curves below.



### a) 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, ICS and other experts in the field of pumping slurry, are particularly interested in the solids by volume being pumped.

### b) 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 concentrations by volume exceeds 20% have a greater drop in ER than the HR.

### c) 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.

## 7.0 System Design

### *a) 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 to the discharge point.

### *b) 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.

### *c) 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.

### *d) Total Discharge Head*

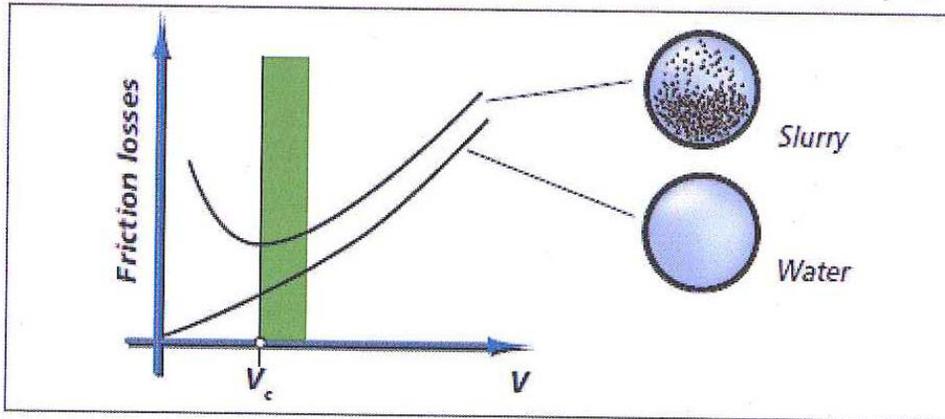
This value is used for pump calculations and comprises the static head plus friction losses plus pressure feed equipment needs caused by pipes and valves, converted to meters of water.

### *e) 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 following diagram, in which the critical velocity ( $V_c$ ) 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 ( $V_c$ ) 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.

## 8.0 Slurry Pump Types

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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 ICS specialize in and that this paper details.

### a) 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 flow rate. The most common types of PD pumps used to pump slurries are:

1. *Helical Rotor Pumps*. Also called 'Mono Pumps', 'Progressive Cavity Pumps'
2. *Air Operated Diaphragm (AOD) Pumps*
3. *Double Diaphragm Piston or Hose Diaphragm Piston*

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

### *b) Centrifugal Pumps*

Centrifugal pumps utilize 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.

#### *1. 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 ICS HD range falls into this category. They are sometimes called dry mounted, as the hydraulic end and the drive unit is located outside the pump, having a positive feed from a hopper. It is the main type of slurry pump 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.

#### *2. Vertical Centrifugal Slurry Pumps*

These types of pumps are called vertical slurry pumps as the shaft is located in the vertical plane. Our ICS HP.S 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 "*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.

## **9.0 Hydraulic Design**

Pumping slurry can cause a severe reduction in the hydraulic efficiency of a pump. ICS 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.

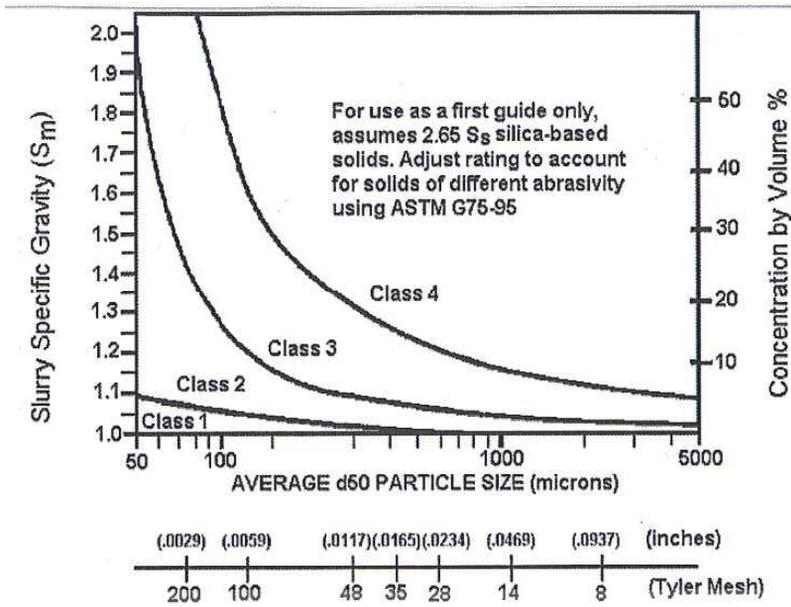
To achieve a long wear life, the vanes and shrouds must remain a heavier section than water pumps so they maintain their high efficiency during the slurry wear cycle. For optimum performance on slurries, impellers should also maintain the pump out vanes which reduces wear on the liners. For these reasons, 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 benefit is lost while the ICS impellers maintain their efficiency over the long term in even the most sever applications.

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

## **10.0 Selecting Slurry Pumps**

Slurry pumping can usually be separated into four categories which ANSI/HI Standard 12.1-12.6-2005 categorizes 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 the following figure.



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

#### a) 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 pump 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 and impeller materials that can be fitted in the same pump 'wet end'. This enables sites to maximize interchangeability throughout their plant, while 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	123	68	52
Feet	400	225	168	130
Maximum impeller peripheral speed: All Metal Pump				
	(m/s)	43	38	33
(ft/min)	8500	7500	6050	5500
Rubber Lined Pump				
	(m/s)	31	28	26
(ft/min)	6000	5500	5000	4500

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

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

Class 1 are often non-settling, comprising  $d_{50}$  particle size of less than 50  $\mu\text{m}$ . 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:* use standard water pumps such as the Southern Cross Sovereign or in heavy duty situations, the ISO-PRO pump fitted with 420SS wear rings and a suitable shaft seal arrangement.

*Class 2 Slurries:* If solids have relatively round edges and heads less than approximately 50m, use ICS slurry pumps fitted with natural rubber liners. When the  $d_{50}$  particle size is less than 100  $\mu\text{m}$ , use a urethane impeller and when larger, use a white iron impeller. If particles are sharp or head exceeds approximately 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 15mm, and the head is less than 40m, use ICS pumps with rubber liners. When the  $d_{50}$  particle size is less than 100  $\mu\text{m}$ , use a urethane impeller and when larger, use a white iron impeller. If the  $d_{50}$  particles size exceeds particles 1000  $\mu\text{m}$  or are sharp or the head exceeds 30m, use an all white iron pump or consider pumps in series.

#### *b) Duty Point Considerations*

Although not used by other pump companies, ICS 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:

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

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 the BEP is less important to the anticipated wear life.

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

Due to the previous parameters discussed, ICS recommends the following selection guidelines:

	Service Class			
Operating Limits	1	2	3	4
Recommended % of BEP Flowrate	45-120%	40-110%	35-100%	30-90%

## 11.0 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. ICS stock rubber lined pumps with 28% High Chrome White Iron (CrWI28) impellers as it will be found these meet the majority of general service slurry pumps. The design enables quick retrofits to other liners and impeller either in the ICS 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 ICS.

