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**INNOVATIONS – IMPROVING THE EFFICIENCY OF SLURRY TRANSPORT FOCUSSING ON IRON ORE**

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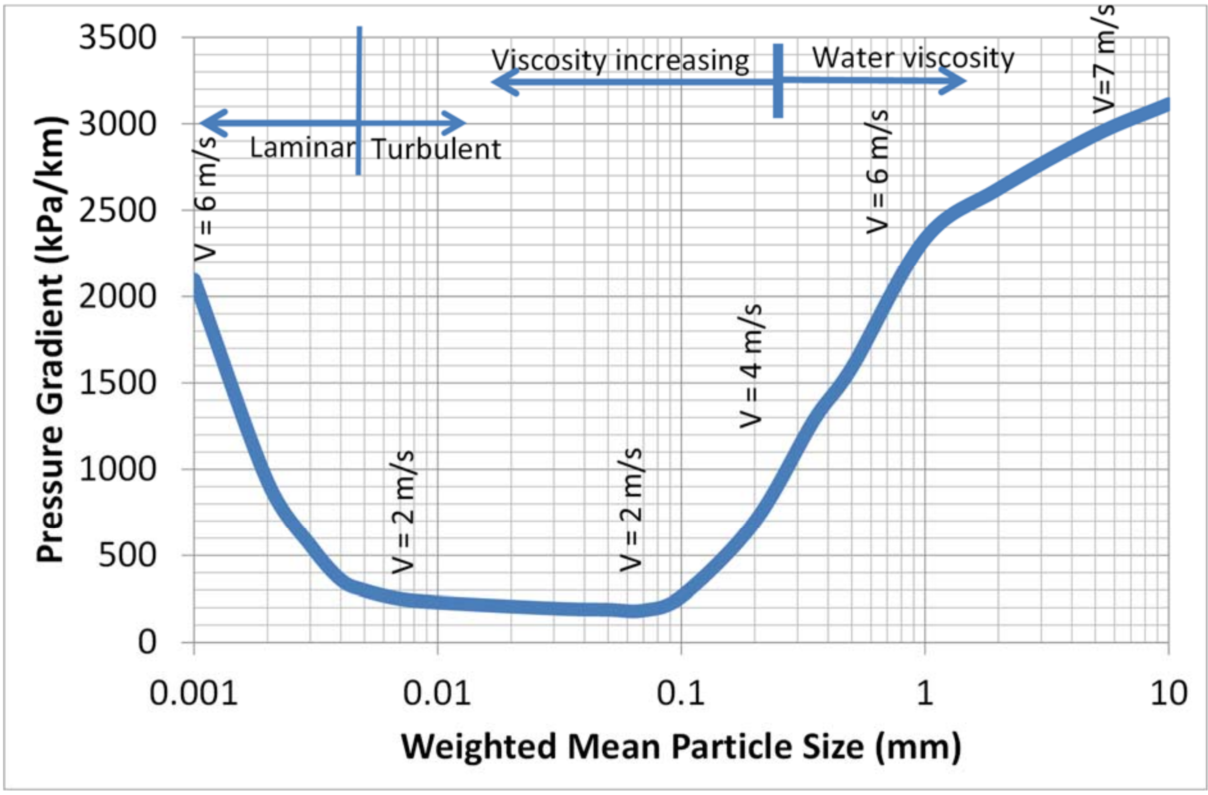
## 1. INTRODUCTION

From a pumping viewpoint the optimum slurry is one where the particle size is fine enough such that the slurry flows homogeneously but not so fine that high slurry rheology limits the maximum concentration. A lot depends on the exact slurry properties but as an indication for solids SG 5.0 the optimum slurry has a weighted mean particle size in the range 10 to 100 microns as indicated in Figure 1. The weighted mean particle size is obtained by splitting the size distribution into fractions and summing the product of fraction of solids in each times median particle size for each fraction. For a typical wide size distribution the $d_{50}$ size is about half the weighted mean size and the $p_{80}$ size is roughly 3 times the $d_{50}$ size.

Figure 1
Pressure Gradient versus Mean Particle Size
300 mm Pipe, 50% Concentration, Solids SG 5.0




The velocities shown in Figure 1 indicate suitable operating velocities for that particular particle size. As the particle size becomes finer than 0.01 mm (10 microns) the rheology starts increasing and the flow becomes laminar unless the concentration is decreased. If the concentration remains constant then the pressure gradient increases as indicated in Figure 1.

Under laminar flow conditions settling issues become important and the pressure gradient needs to be above about 2500 kPa/km or else there is the potential for the pipeline to block due to particles settling during transit. Laminar flow settling is discussed further in Section 5.

As the mean particle size increases above 0.1 mm (100 microns) the pressure gradient rapidly increases. The deposit velocity in a 300 mm pipe also rapidly exceeds 2 m/s as indicated in Figure 1 and in fact the velocity will need to be increased. At the high velocities required to transport coarse particles pipe wear becomes a serious issue. Because of the high velocities the concentration can be reduced and still maintain the same solids throughput. This will reduce the pressure gradient slightly but not significantly since the high velocities still apply.

Figure 1 shows that the particle size has to be quite fine for minimum pressure gradient and there is a relatively narrow range of particle size which is optimum. Unfortunately the hydraulics engineer generally doesn't get to choose what type of slurry he is required to pump. However there are sometimes ways to improve the pumpability. Some innovative methods which have been developed over the years to transport different materials by slurry pipeline are now discussed. In relation to Figure 1, many of these methods effectively extend the optimum low pressure gradient region to the right in the case of coarse particle slurries and to the left in the case of fine particle slurries.

## 2. USE OF A FINE SLURRY CARRIER

### 2.1 General

Pipeline transport of lump coal by pumping in water involves very high velocities with resulting high pressure gradients and high pipe wear and is only economic over short distances. To enable lump coal to be pumped over long distances Slurry Systems developed the Special Vehicle Slurry (SVS) concept, (Cowper et al, 2010). SVS makes use of vehicle slurry of higher density (magnetite and fine coal mixture) to transport coarse coal that simulates the successful fine coal slurry hydraulics proven in the Black Mesa slurry pipeline.

A similar approach can assist in the case of iron ore. However, whereas in the case of coal it is possible to achieve a vehicle slurry density equal to that of the coal and thereby achieve neutral buoyancy of the lump coal, this is not possible with iron ore. Nevertheless use of a high density vehicle slurry can reduce the pressure gradient for iron ore pumping but only in the case of relatively fine particles. For example there is little advantage for mean particle sizes above 1 mm. Even for 0.5 mm particle size the advantage is only marginal and pumping velocities and pressure gradients are still high. It is only when the weighted mean particle size is below about 0.3 mm that real advantages occur in use of a fine slurry carrier.

### 2.2 Transport of Heavy Mineral Sands (or Iron Sand) in Slimes

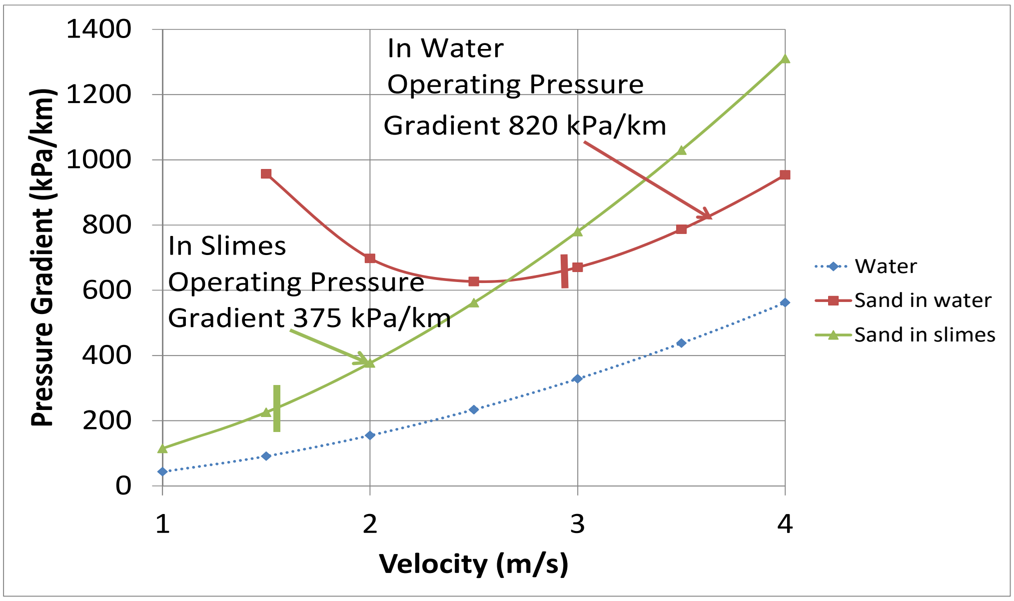
Mineral sands often occur in clay bands and the heavy mineral sand is separated from the slimes by washing before the sands are transported. Once washed, the mineral sands require high velocities and pressure gradients to pump, as for example occur in the New Zealand iron sand pipeline (Venton and Cowper, 1986).

An adaptation of the SVS concept to mineral sands involves pumping the sand in the slimes, separating the slimes at the pipeline terminal using conventional cyclones, then returning the slimes via a separate pipeline. Many slurry pipeline projects now require a water return pipeline so pumping the sand in the slimes achieves the same water recycling but with the added advantage that the slimes reduces the pressure gradient in the mineral sands pipeline.

Figure 2 compares predicted pressure gradients for the N.Z. iron sand (solids SG 4.75, $d_{50}$ = 115 microns) in water and in a 20% concentration slimes vehicle slurry in the 187 ID pipe. The deposit velocity in water is 2.85 m/s but this reduces to 1.6 m/s in slimes. The pressure gradient reduces by more than half. However to get the same solids throughput in the slimes the pipe size is increased to DN250 (ID 242 mm). The operating velocity is 2.15 m/s and the pressure gradient reduces to 320 kPa/km. Importantly the wear rate is much lower and depending on the corrosivity of the slurry, unlined steel pipe may be viable, or at least a much cheaper polyethylene liner may be used rather than polyurethane.

Whereas the previously discussed SVS system relied on magnetic separators to separate the recyclable magnetite from the fine coal portion of the carrier, separation of the mineral sands from the slimes carrier is achieved by cycloning, relying on the fact that the mineral sands have a narrow size distribution with particle sizes which do not extend down to the slimes range. The pressure gradient could be further reduced by use of a viscosity modifier to allow higher slimes concentration. Viscosity modifiers are discussed in Section 3.

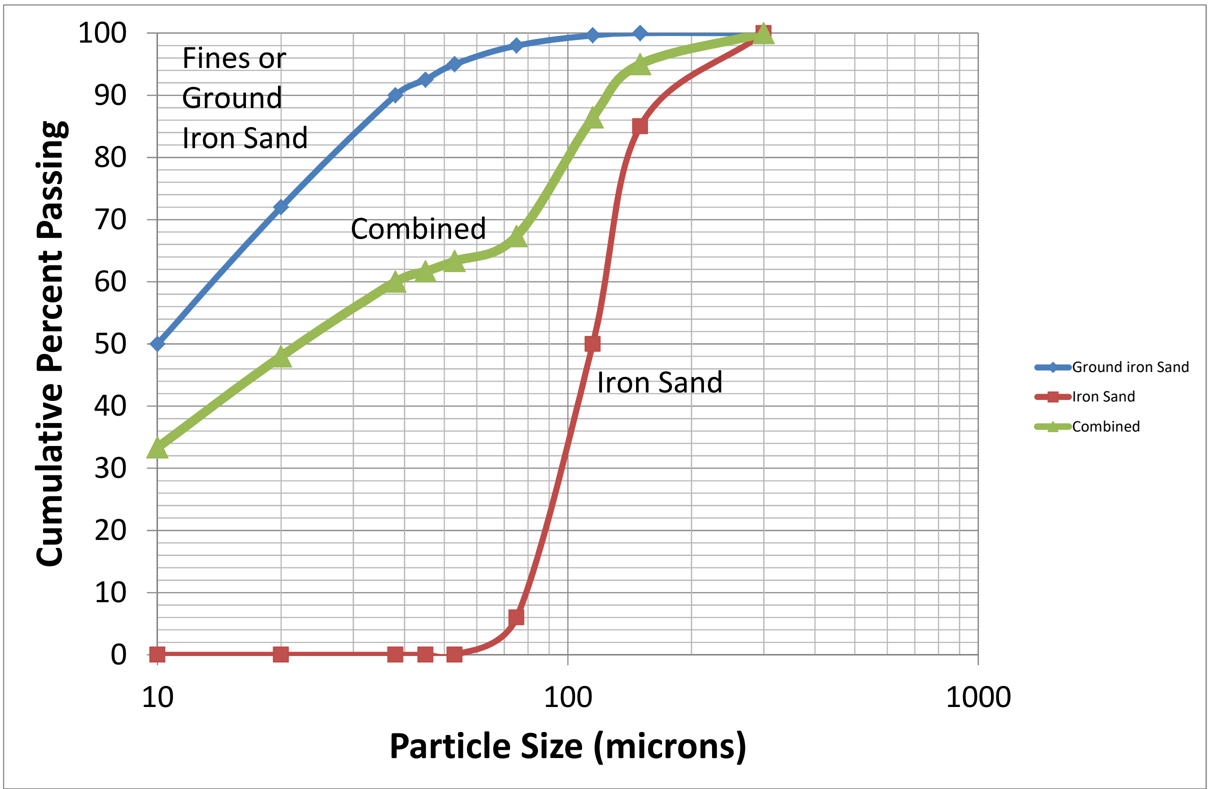
Figure 2
Comparison Iron Sand in Water and in Slimes



### 2.3 Transporting Iron Sand by Grinding Portion of the Iron Sand Finer

Instead of transporting the iron sand in slimes another option is to grind a portion of the iron sand and then recombine to reduce the overall particle size of the iron sand. Figure 3 shows the size distribution of the iron sand together with an assumed ground iron sand size distribution with a $p_{80}$ = 26 microns. Assuming a solids SG of 5.0 for both the iron sand and the fines the size distribution resulting from combining the two in the ratio 1 part iron sand to 2 parts fines is also shown.

Figure 3
Size Distribution Resulting from Combining Iron Sand with Fines in 1:2 Ratio



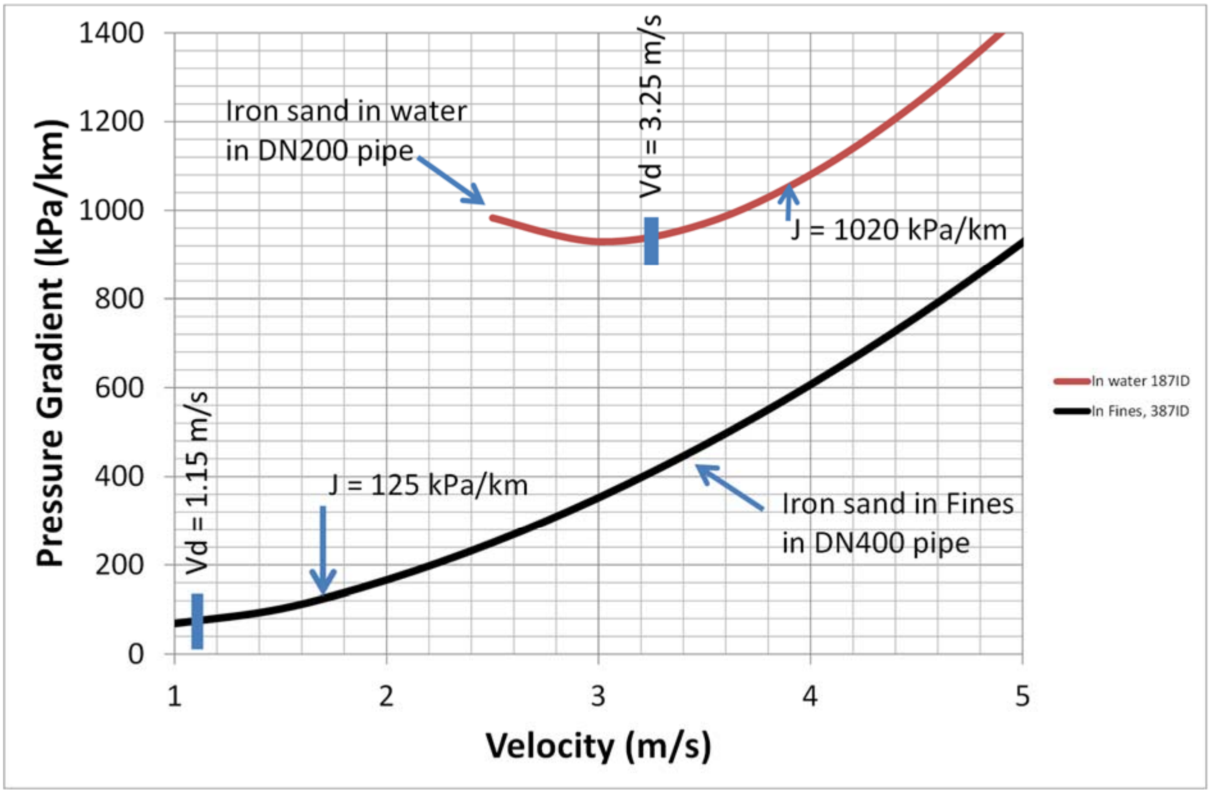

If the $d_{50}$ = 0.115 mm iron sand is transported in water in a DN200 pipe the design velocity is 3.9 m/s and polyurethane lining is required. By grinding 2/3 of the iron sand finer and then recombining the resulting overall finer particle size allows a lower design velocity of 2.1 m/s and bare steel pipe can be used. The concentration is increased from 48.5% to 63% to achieve the same solids throughput.

The pressure gradient is reduced to 1/3$^{rd}$ from 1025 kPa/km to 345 kPa/km and pump power reduced to 1/5$^{th}$ from 122 kW/km to 26 kW/km. The bare steel pipe is approximately $200,000/km cheaper than the polyurethane lined pipe. These savings in pumping power and pipe cost need to be compared with the added cost of grinding 2/3$^{rd}$ of the iron sand finer, taking into account the length of the pipeline.

## 2.4 Transporting Iron Sand in Fines in a Larger Pipe and Recycling the Fines

Another option to transport 307 tph of Iron Sand is to add available fines and pump the combined mixture in a larger pipe, separate the Iron Sand using cyclones at the terminal, and recycle the fines in a return pipeline. Assuming the fines have a solids SG = 5.0 and a size distribution as in Figure 3 two parts fines are added to one part Iron Sand to give a total solids throughput of 921 tph at a concentration of 63%. An unlined DN400 pipe is required. Figure 4 compares the predicted pressure gradients.

Figure 4
Comparison 307 tph iron Sand In Water and in Fines




By adding fines to the Iron Sand the velocity is able to be reduced to 1.7 m/s in the DN400 pipe. The pressure gradient is reduced to 1/8$^{th}$ of 1020 kPa/km to 125 kPa/km. Iron Sand in water would require a pump station about every 20 kms, whereas Iron Sand in fines in the larger pipe would require a pump station every 160 kms making it viable for long distance transport.

A similar DN400 pipe is required for the return pipeline recycling the fines with the pressure gradient being 75 kPa/km. Pumping power for the main pipeline is 28 kW/km and 14 kW/km for the return pipeline giving a total pumping power of 42 kW/km.

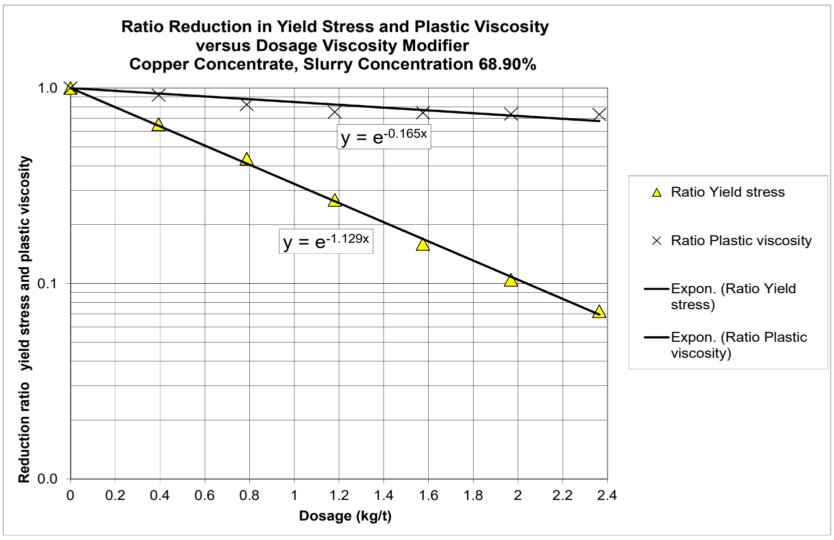
Even though the pipe size is DN400 and a return pipeline is involved, after taking into account the cost of the increased number of pump stations for the no fines case, the overall cost of the fines recycle system has the potential to be significantly cheaper than the once through, DN200 polyurethane lined system.

Sections 2.3 and 2.4 have compared alternatives with pumping Iron Sand in water in a DN200 polyurethane lined pipe. The Iron Sand is similar to that pumped in the New Zealand Steel pipeline and is of narrow size distribution as shown in Figure 3. The comparisons would be roughly similar if, instead of the narrow size distribution Iron Sand, a more typical wide size distribution iron ore was required to be transported although these would need to be considered on a case by case basis. However, as noted in Section 2.1, the particle size limitations of Figure 1 are still relevant and transport of particles of mean size 1 mm or larger is probably never going to be viable over long distances. Of course anything can be pumped over short distances.

## 3. VISCOSITY MODIFIERS

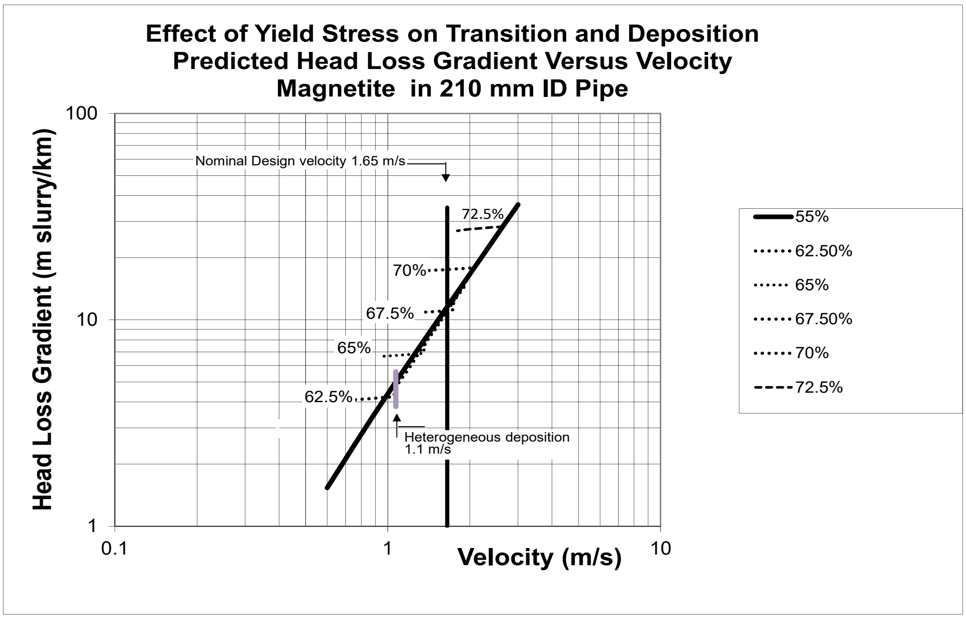
Viscosity modifiers are chemical additives which reduce the yield stress of a slurry, but generally have little influence on the plastic viscosity. This is illustrated in Figure 5 which compares the ratio reduction in yield stress and plastic viscosity for a particular viscosity modifier on a copper concentrate slurry.

Figure 5




The transition velocity between laminar and turbulent flow is largely determined by the yield stress so addition of a viscosity modifier allows higher concentrations to be pumped whilst still maintaining turbulent flow. The situation is illustrated by Figure 6 which is a plot of head loss gradient (metres of slurry per km) versus velocity for a minus 100 micron magnetite slurry in a 210 mm ID pipe.

Figure 6




The steep angled bold line represents the turbulent flow head loss gradient and is practically the same for all concentrations when expressed in terms of head loss gradient rather than pressure gradient. The flatter dashed curves on the left represent laminar flow predictions assuming homogeneous flow. These are largely dependant on the yield stress. The intersection of the turbulent and laminar flow curves represents the transition velocity. For any particular concentration, as the velocity is decreased the head loss gradient will follow the turbulent flow line down until the transition velocity after which the head loss gradient will follow the laminar flow curve shown but only assuming homogeneous flow, which in fact will not be the case for the concentrations shown in Figure 6. Deposition will actually occur as soon as the velocity falls below the transition velocity.

Operating velocities in the range 1.5 to 2 m/s generally provide the most economic balance between pumping costs and pipeline costs. For this particular slurry and pipe size, the selected operating velocity is 1.65 m/s as indicated by the vertical dashed line. For concentrations below 62.5% the predicted heterogeneous deposit velocity is around 1.1 m/s as indicated by the barred vertical line. For these concentrations deposition occurs under turbulent flow conditions although for 62.5% concentration the deposit velocity also coincides with the transition velocity.

The highest feasible concentration in Figure 6 is 65% for which deposition will occur at the 1.35 m/s transition velocity, 0.3 m/s below the operating velocity. It would not be desireable to operate at 67.5% concentration because transition coincides with the operating velocity, meaning that a stationary/sliding bed would be present with the potential to cause unstable operation and increasing bottom pipe wear.

Now suppose a viscosity modifier is added which reduces the yield stress by a factor of 4. The 72.5% laminar flow dashed curve would reduce by a factor of 4 to approximately coincide with the 65% laminar flow curve in Figure 6. The transition velocity would reduce from 2.65 m/s to 1.35 m/s and turbulent flow would be present at the operating velocity of 1.65 m/s. At 72.5% concentration the solids throughput is 356 tph compared with 279 tph at 65% concentration, an increase of 28%. The pressure gradient would increase by about 12% but pump pressure could increase by much less if there is significant static head advantage, due to the higher slurry density. In relation to Figure 1 viscosity modifiers are effectively extending the optimum low pressure gradient region further to the left.

## 4. TURBULENT DRAG REDUCTION USING DRAG REDUCING POLYMERS

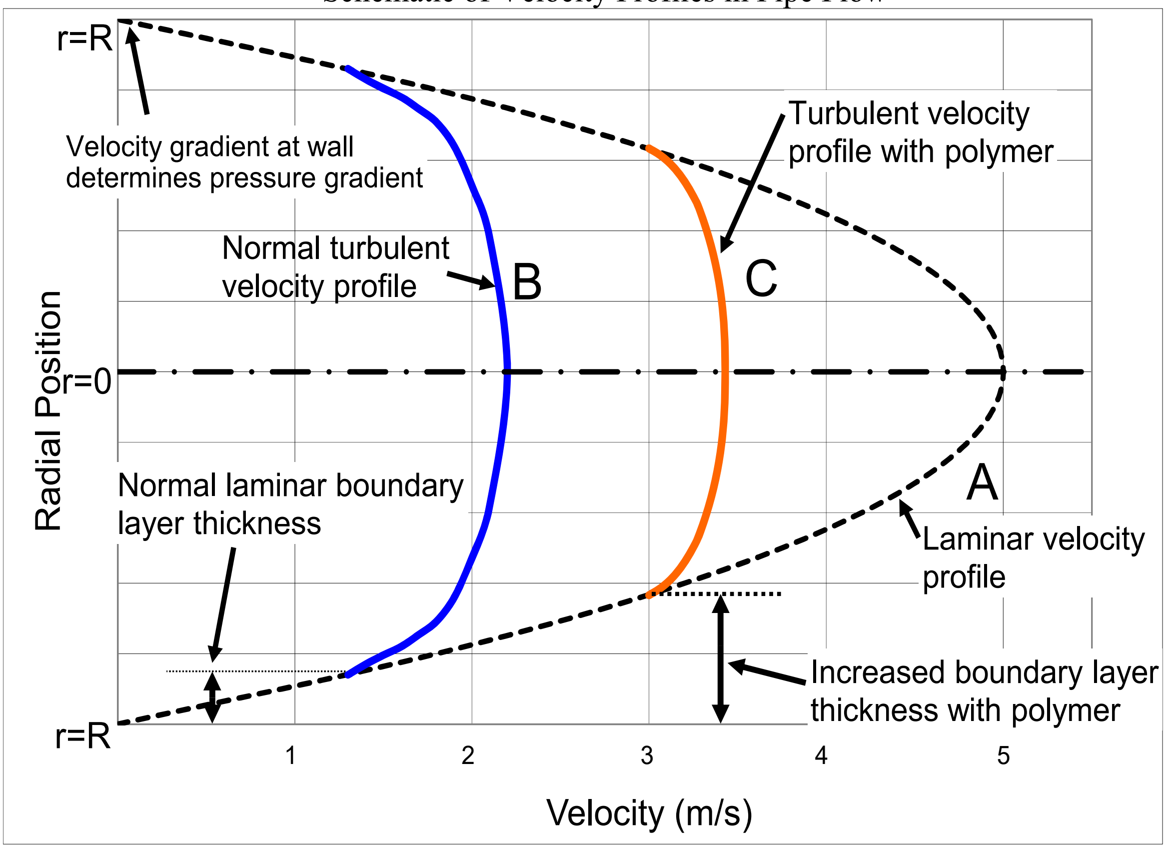
### 4.1 Introduction

The addition of certain long chain polymers to water has been known for many years to increase the flow rate by up to 80% with no change in the pressure gradient. The dosage rate required is very small, typically around 30 ppm. The polymers act by suppressing turbulence in the wall region thereby effectively increasing the thickness of the boundary layer. Such polymers are routinely used in oil pipelines such as the Trans Alaska pipeline. In PNG the Kutubu pipeline flow rate increased from 120,000 bbl/d to 200,000 bbl/d with drag reducer.

### 4.2 Drag Reduction due to Thickened Boundary Layer

Laminar and turbulent velocity profiles in pipe flow are illustrated schematically in Figure 7.

Figure 7
Schematic of Velocity Profiles in Pipe Flow



The dashed curve A represents the parabolic laminar flow velocity profile. The laminar flow pressure gradient, $\Delta P/L$, is determined by the velocity gradient, $(dV/dr)$ at the wall as per Eqn 1.

$$\Delta P/L = (4\,\mu\,/D)\;(dV/dr)_{r=R} \qquad (1)$$

where μ is the viscosity
D is the pipe diameter
V is the velocity at a particular radius, r, in the pipe
R is the radius at the wall = D/2

Equation 1 applies to laminar flow. Flow of water, except in extremely small pipes, is turbulent. Curve B in Figure 7 is a schematic of the normal turbulent velocity profile. In the laminar boundary layer region adjacent to the wall the flow is laminar and the profile initially follows the same profile as the laminar flow profile. But once the velocity in the boundary layer reaches a certain value, inertial effects cause turbulent eddies to develop and the profile B deviates away from the laminar profile and becomes blunter as indicated. Now, even though the pressure gradient, as determined by the velocity gradient at the wall, remains the same as per Eqn 1, the average velocity and hence flow rate is less than if laminar flow had persisted. In Figure 7 the average velocity for turbulent profile B can be visualised as being significantly less than the average velocity for the laminar flow curve, A.

Comparisons between Curves A and B illustrates how, for the same pressure gradient, the flow rate with turbulent flow is less than if laminar flow occurred throughout the pipe. Conversely, for the same flow rate, the pressure gradient for turbulent flow is greater than for laminar flow.

It must be emphasised that Figure 7 is purely schematic. In actual fact the boundary layer thickness is very small, just a few mm in a 200 mm pipe. Also, there is a buffer layer between the laminar boundary layer and the turbulent core region which is not shown in Figure 7.

### 4.3 Effect of Polymer Addition on Velocity Profile

Velocity profile C schematically illustrates the effect of addition of polymer. The long chain polymer suppresses turbulent eddies in the buffer layer thereby effectively increasing the thickness of the buffer layer although in Figure 7 this effect is indicated as an increase in the thickness of the laminar boundary layer.

Figure 7 shows how increasing the thickness of the boundary layer causes the turbulent velocity profile to move from Curve B to Curve C. The effect is to increase the average velocity, and hence flow rate, with no change in the pressure gradient which is still determined by the velocity gradient immediately adjacent to the wall.

### 4.4 Maximum Possible Drag Reduction

The maximum possible drag reduction occurs when the buffer layer thickness is increased to the extent that it reaches the centre line of the pipe. In Figure 7 the profile would then be the same as the laminar profile but in reality, because Figure 7 ignores the buffer layer, this is not the case.

Virk (1975) studied the maximum possible drag reduction and concluded that the theoretical maximum Drag Reduction Factor is 0.19, the Drag Reduction Factor being defined in Eqn 2.

Drag Reduction Factor (DRF) = [f additive / f no additive] (2)
(for the same velocity)

**4.5 Application to Slurries**

A number of early researchers have investigated drag reduction with slurries in small scale laboratory scale test loops. For example Poreh et al (1970) tested a 0.9 mm sand slurry, volume concentration 20%, in a 20 mm diameter loop. They found that energy savings up to 70% could be achieved by addition of small quantities of a complex soap (cetry trimethyl-ammonium bromide-1-Naphthol). Polymer solutions were not found to be as effective.

Sellin (1989) reviewed a number of earlier papers including the results of Fujimoto and Tagori (1974) who tested Separan AP30 with an iron ore slurry up to 40% by weight concentration in a 25 mm pipe. They found up to 50% drag reduction but the drag reduction reduced as the concentration increased. Sellin also notes Golda (1984) who tested a range of coal slurries in a 40 mm tube and obtained a maximum drag reduction of 40% with Separan AP-45. Limited tests were also conducted in a 254 mm pipe loop.

Sellin (1989) offers the general conclusion “that the longer the pipeline the more likely it is that polymers could be advantageous. It would appear that although most polymers are vulnerable to degradation in centrifugal pumps, the risk of them degrading in long pipe runs due to flow induced wall shear stress is low”

Large scale field trials were conducted by Interthal et al (1983). They tested a sand/water slurry with sand of $d_{50}$ = 0.23 mm at a concentration of 27% by wt in a 3.2 km long, 300 mm pipeline. They obtained what they described as an “astonishing” 44% increase in sand throughput with 40 ppm addition of a high molecular weight polymer drag reducer, due to the increase in flow rate and also because they were able to pump at higher concentrations with additive.

Because the dredge trial involved a centrifugal pump, the reduction in friction loss with additive allowed the system curve to move out on the pump curve resulting in an increase in flow rate which contributed to the increase in solids throughput.

The drag reduction measured by Interthal et al (1983) applies to a sand slurry in water with few fines, for which the boundary layer is almost pure water, and it is likely that drag reduction is most effective with this type of slurry. Wide size distribution, viscous mineral processing slurries, where the boundary layer will comprise very fine slurry, may be less amenable to significant drag reduction although Fujimoto and Tagori (1974) did observe drag reduction with a wide size distribution iron ore slurry.

## 5. HIGH CONCENTRATION TAILINGS DISPOSAL

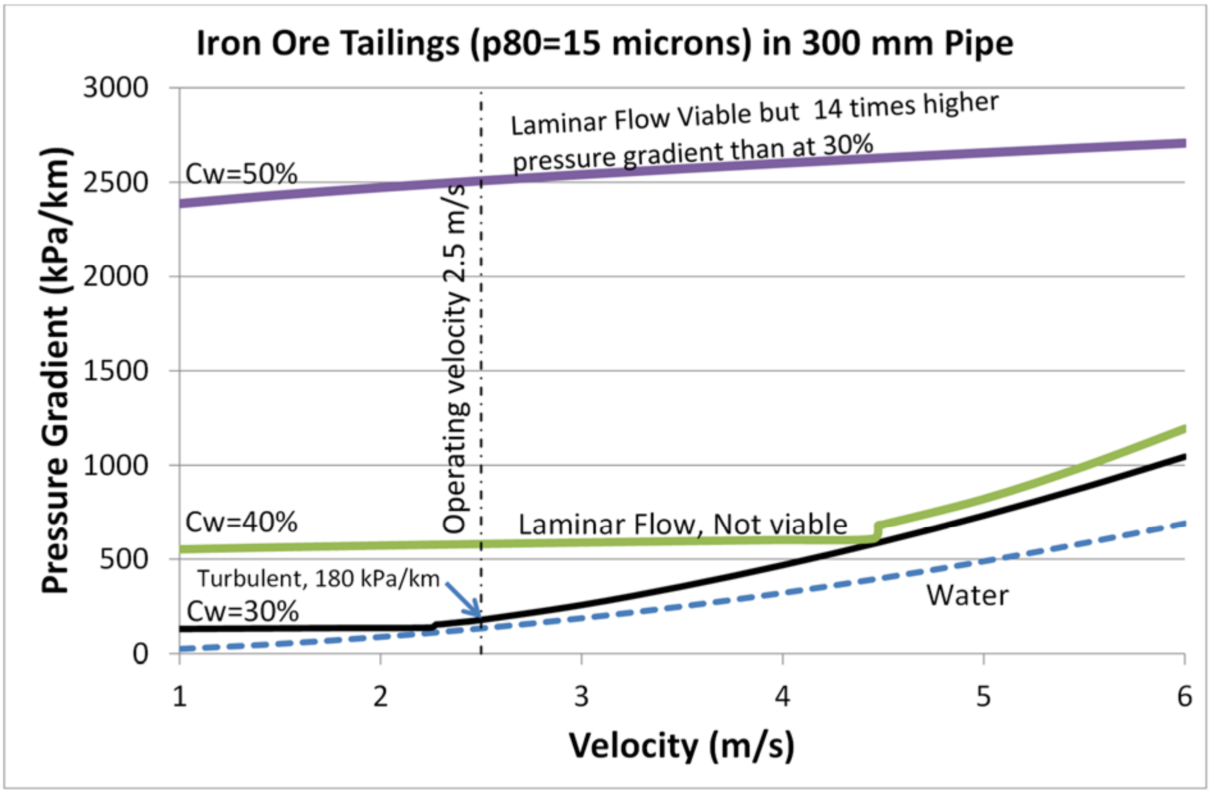
Tailings have traditionally been transported to the tailings disposal area at low concentration under turbulent flow conditions. There is now increasing interest in pumping and disposal of tailings at high concentration. The advantages of high concentration disposal include recovery of water directly at the plant, disposal on a slope hence increased storage for a given retaining dam height, better deposit drying, and improved rehabilitation of the disposal site. However high concentration pumping involves laminar flow and the limitations with regard to particle settling are not always fully appreciated.

Thomas (1979) was the first to note the potential problems of laminar flow operation in regard to settling and investigated the pipeline length for particles to settle. More recently laminar flow of tailings has been addressed. It is now accepted that settling of particles will occur during laminar flow of tailings. Once all particles have settled, a pressure gradient in the range 1000 kPak/m to 2000 kPa/km is required to maintain flow as noted by Cooke (2002). This pressure gradient range applies to tailings with a solids SG around 2.7. For iron ore tailings with a higher solids SG, the pressure gradient range is likely to be more like 2000 kPa/km to 3000 kPa/km. Currently there is still no method of predicting the pipeline length required for settling to occur for a wide size distribution tailings slurry. Hence it is very difficult to design a laminar flow pipeline other than to use the approach outlined by Paterson (2011) where either the slurry concentration is selected to give a pressure gradient in the range noted above or, if the pressure gradient is less, provision is allowed for regular flushing with water.

It is important to realise that even if laminar flow operation is viable, the pressure gradient will almost always be higher than turbulent flow operation. There is almost never justification for high concentration laminar flow purely from a pipeline economics viewpoint. There has to be another reason for wanting laminar flow, which for tailings is of course slope disposal with its associated benefits.

Figure 8 illustrates the large differences in pressure gradient required for turbulent flow and laminar flow operation. The predictions apply to an iron tailings with $p_{80}$ = 15 microns. Based on the measured rheology, for an operating velocity of 2.5 m/s the highest concentration for which turbulent flow operation is possible is 30%. Once the concentration exceeds 30%, laminar flow occurs at 2.5 m/s as illustrated for the case of 40% concentration. However at 40% concentration the pressure gradient is only 600 kPa/km, much less than is required for stable operation. Stable operation is not achieved until the concentration is increased to 50% as indicated. Laminar flow operation may be possible at concentrations below 50% but only for a short pipeline and with regular flushing.

Figure 8




## 6. FLOCCULENT ADDITION AT END OF TAILINGS PIPELINE

A new concept has recently been instigated at some Queensland coal mines and some Eastern States mineral sands operations. It may be in use elsewhere as well. High clay content tailings having very high rheology may be able to be thickened to a paste consistency but pumping pressures are then very high and there may be settling problems under laminar flow conditions. The alternative is to pump at lower concentration under turbulent flow, but then under normal circumstances the solids may settle extremely slowly in the dam.

This is overcome by adding flocculent at the discharge of the tailings pipeline. Large dose rates are employed, sometimes up to 1 kg/tonne, and the large flocs cause water to separate. This concept is currently used at the Ashton and Bulga coal mines in the Hunter Valley and at Wilkie Creek and New Acland coal mines, and the Stradbroke Island mineral sands operation in Queensland.

## 7. ON-LINE VISCOMETER (OLV)

Most mineral processing stages, including grinding and pumping, are currently controlled on slurry density whereas in fact it is the slurry rheology, and in particular the yield stress, which really determines the process efficiency. An On-Line Viscometer is a preferred method of control, especially during the initial years of operation when rheology may vary significantly. In later years, experience in blending and processing resulting in more uniform slurry properties may mean that density control is sufficient.

Slurry Systems markets an On-line Viscometer (OLV) based on the tube viscometer principle. The instrument is of rugged design and able to handle particles up to 2 mm in size. A number of instruments have been installed at mines in Australia and Africa. The OLV provides a continuous reading of Bingham yield stress and is ideal for pipeline control where the rheology of the slurry varies. The instrument is illustrated in Figure 9.

Figure 9

## 8. WHEELSTAND TEST RIG

The Wheelstand was believed first invented by Russian workers in the 1960's. SSE's Wheelstand test rig consists of 200 NB steel pipe bent into a circular shape to form a wheel supported by spokes. The wheel rotates in the vertical plane about a horizontal axis, driven by a variable speed motor. The diameter of the wheel at the pipe centreline is 2.685 m. The pipe ID is 206.3 mm. The rig is shown in Figure 10 in operation at the Maitland, NSW, ALS laboratories. The Wheelstand allows measurement of pipe wear, particle attrition and rheology changes over time. It has the advantage over a test loop in that it does not involve repeated passage through a pump and so is ideal for monitoring attrition and rheology changes. SSE has tested numerous slurries including various coals, both coarse and fine, coal rejects, magnetite, and various tailings. SSE has tested a coal slurry for an equivalent pipeline length of 500 kms. A particularly interesting test was on a nickel ore slurry for a potential 150 km pipeline in which the slurry rheology changed over time.

Figure 10

## 9. WELDED COUPLING FOR POLYURETHANE LINED STEEL PIPE

Pumping of heavy mineral sands, including iron sands, requires high velocities with consequent high pipe wear rates. Wear resistant lining is required for a long life pipeline. As an example Slurry Systems designed the 18 km New Zealand Steel iron sand pipeline in New Zealand transporting sand of median size 120 microns (Venton and Cowper, 1986). This pipeline operates at 3.6 m/s and requires two positive displacement pump stations supplying a total pressure of 18 MPa. Ordinary steel pipe was not suitable because of the high wear rate and the pipeline is lined with polyurethane. Special welded couplings were developed in conjunction with McConnell Dowell and the pipeline is buried and fully welded. It has operated successfully for 25 years. The coupling enables the polyurethane lined steel pipe to be welded which is more suitable for a long life buried pipeline than flanges. A photo of the coupling is shown in Figure 11.

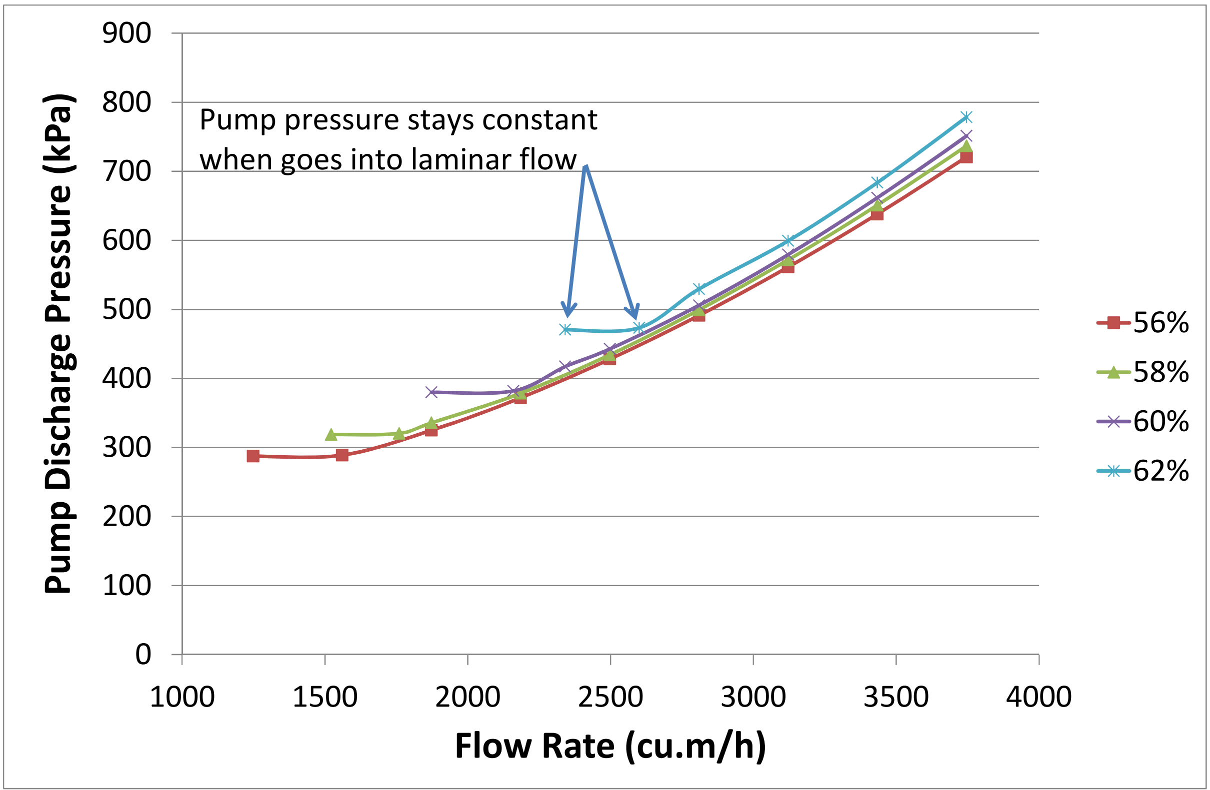
Figure 11
Welded Coupling

## 11. MAXSOLIDS CONTROL CONCEPT

The MaxSolids control concept is a method of ensuring a slurry pipeline operates at maximum concentration within the capability of the pumps. Operation at maximum concentration is especially attractive for tailings disposal.

Figure 12 shows predicted pump discharge pressure versus flow rate curves for a gold tailings in a 6.3 km, 745 mm ID pipe for four concentrations from 56% to 62%. The steeper curves to the right indicate turbulent flow whilst the change to a near horizontal curve at lower flow rates signifies the change to laminar flow. As we have seen in Section 5, stable laminar flow is generally not possible unless the pressure gradient is in the range 1000 kPa/km to 2000 kPa/km. Even discounting the fact that some of the pump head is static head, the pressure gradient for the highest (62%) concentration laminar flow region is only 470/6.3 = 75 kPa/km, far below that required for stable laminar flow. This means that once laminar flow occurs, particles will settle out almost immediately and form a stationary bed. Hence laminar flow is to be avoided. Note that at the onset of laminar flow the pump discharge pressure remains constant. This means that observation of the discharge pressure alone gives no indication that deposition is imminent.

Figure 12




The patented MaxSolids number, Y, is given by:

$$Y = \frac{K_1 \, \Delta P/L}{Q^a \, SG^b} \qquad (3)$$

Q is flow rate.

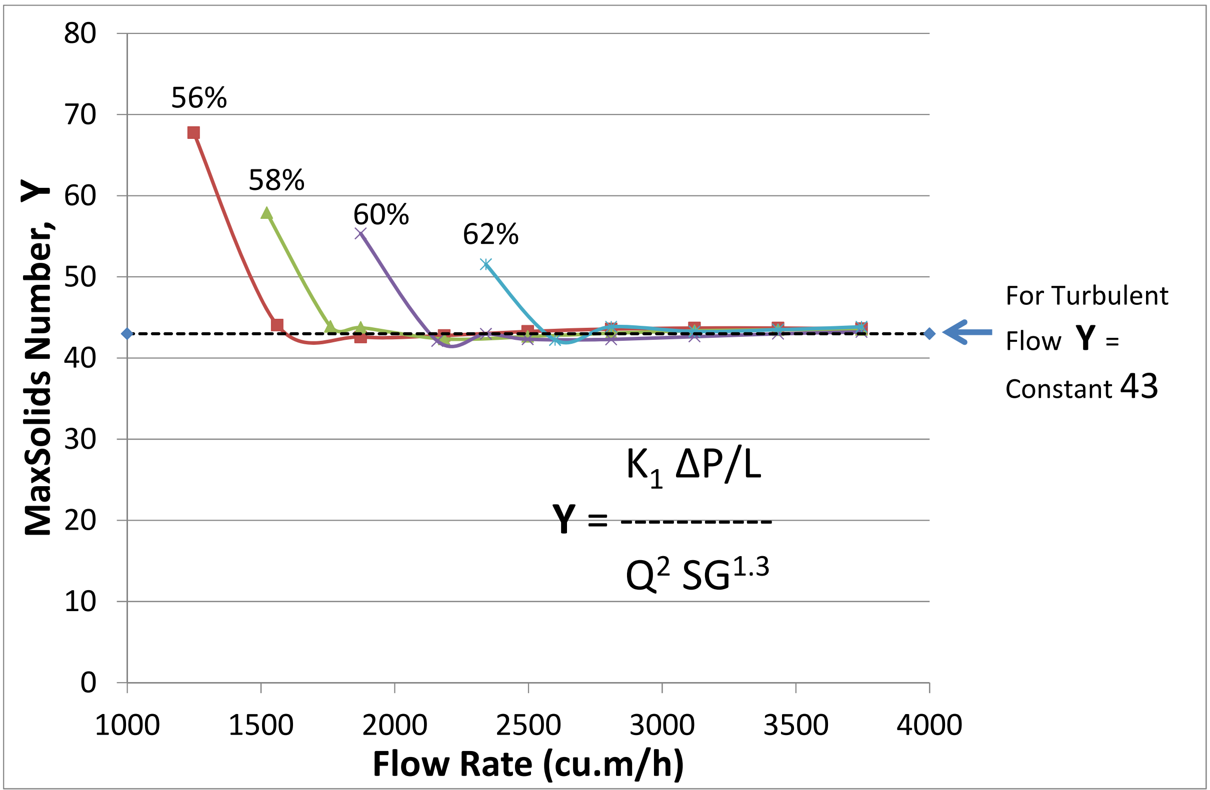
SG is slurry SG

$K_1$ is a constant for a particular pipe.

Exponents a and b depend on pipe diameter and slurry rheology and are determined for each slurry

The pressure gradient ΔP/L is measured by a differential pressure gauge over an initial length of the pipeline, with the measuring length ranging from 10 m to 100 m depending on pipe diameter. Figure 13 shows the MaxSolids number, Y, applicable to Figure 12, versus flow rate. Note that for turbulent flow Y is essentially constant. However once laminar flow occurs, Y increases markedly. The MaxSolids number provides a very sensitive indication of the onset of laminar flow. Sensitivity is enhanced by making the measuring length of pipe of slightly larger diameter than the main pipeline.

Figure 13




For any given solids throughput the solids concentration increases as the volume flow rate of slurry decreases. MaxSolids allows the pipeline to operate at the lowest flow rate consistent with staying above deposition regardless of variations in slurry rheology thereby maximising solids throughput and minimising power and water usage.

One method of MaxSolids operation would rely on the thickener producing slurry at a concentration higher than the pipeline can pump. MaxSolids is then used to control dilution water s uch that the pipeline transports at the highest possible concentration within the capability of the pipeline. Another method of operation is to integrate MaxSolids into the thickener control system such that the thickener then only produces the maximum concentration that the pipeline can transport, thereby optimising thickener performance and saving flocculent usage.

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