

Settlement in backfill pipelines: Its causes and a novel online detection method

Authors:

Peter Goosen, Paterson & Cooke Consulting Engineers (Pty) Ltd, South Africa (presenter)

Hartmut Ilgner, CSIR, South Africa, corresponding author, hilgner@csir.co.za

Stanford Dumbu, Stoner (Pty) Ltd, South Africa

Abstract:

Many predictive models exist for the calculation of the critical deposition velocity for settling slurries and pastes. However, unforeseen variability of backfill operations as well as changing properties of source materials used for a particular backfill recipe may result in unexpected pipeline blockages. Although quality control procedures are often in place to ensure consistency of the backfill recipe, the large number of factors influencing pipeline blockages and their interdependence cannot always be determined reliably.

This paper addresses what are considered to be the dominant parameters affecting backfill pipeline blockages. In particular, backfills with low water content and high cement content may undergo significant rheological changes during extended pipeline transportation, which may affect the settling characteristics.

Various methods and types of instrumentation are used in laboratories to measure the velocity and flow conditions at the pipe invert, but no simple instrumentation is readily available as an industrial monitoring tool. A novel method to detect the onset of a stationary bed with an all-metal pipe spool is presented. This instrumentation has been shown to detect the existence of a stationary bed at the pipe invert reliably over a wide range of slurry compositions and slurry densities. Its non-intrusive nature makes it an ideal tool for abrasive and coarse backfill types.

Keywords: Deposition velocity, detection of stationary bed, settled bed measurements, slurry flow control, deposition criteria.

1. Introduction

One of the most important parameters to be determined in the hydraulic design of a backfill distribution system, and yet often one of the most difficult to predict reliably, is the minimum velocity required to avoid the build-up of a stationary deposit of solids in the pipeline, i.e. the “deposition velocity”.

Given the potential operational risks associated with solids deposition in a backfill distribution pipeline system, particularly the potential for pipeline blockage and system overpressure, there is considered to be tremendous value in being able to detect directly the onset of solids deposition in the pipeline. Such an instrument to provide a warning signal at the onset of deposition, or even an alarm when a stationary bed has formed within the pipeline, is currently being developed by a consortium consisting of the South African Council for Scientific and Industrial Research (CSIR), Paterson & Cooke Consulting Engineers (Pty) Ltd and Stoner (Pty) Ltd. The instrument is based on a thermal slurry flow sensor to detect the local flow condition at the pipeline invert.

This paper summarises the authors' recommended approach for predicting the deposition velocity limits for typical hydraulic and paste fills, and highlights the challenges and uncertainties involved in this process. This provides a background against which to introduce the novel instrumentation which is intended for on-line monitoring and detection of the onset of a stationary deposit within a slurry or backfill pipeline. It is envisaged that this instrument will provide a useful early-warning signal or even an alarm to prompt appropriate corrective action.

1.1 Terminology and Definitions

For the purposes of this paper, a *backfill slurry* is considered to be any two-phase, solid/liquid mixture utilised as a mine fill. This encompasses the full spectrum of fill materials, from relatively low-density, uncemented, segregating and free-draining fill (often referred to as hydraulic fill), through to high-density, cemented and non-segregating fills (typically referred to as paste fill).

1.2 Test Work

Contrary to conventional slurry testing, where a constant flow rate is maintained to ensure steady-state conditions over a suitable time period to obtain the flow and settling parameters associated with that exact flow rate, it was found that the best way to characterise the response of the new instrumentation was to reduce the volumetric flow rate continuously and gradually. In that way, the instrument is able detect the change in the flow condition at the pipe invert from fully suspended flow to sliding bed and eventually to stationary bed condition.

The instrumentation output is not aimed at identifying the precise flow rate at which the first particles become stationary. While such information will always be required for exact modelling of slurry flow, the aim with this instrument is to provide a reliable tool to prevent pipeline blockages in operating pipelines. In other words, the instrument does not provide the exact deposition velocity, but indicates reliably the condition when a small bed has developed at the pipe invert. This small bed is regarded as insignificant in relation to the entire cross-sectional area of a typical industrial pipeline. More details are provided in Section 4.1.

2. Hydraulic Design of Backfill Distribution System

The hydraulic design of a backfill slurry distribution system (Cooke, 2001) relates primarily to:

- (i) The sizing (specification of required pipe bore) of all piping elements that make up the system for delivering the backfill from the preparation plant to the point at which it is discharged underground
- (ii) Specifying the pressure rating of all piping and associated elements in the distribution system
- (iii) Specifying the duty requirements for any pumps in the system (as in a pumped paste backfill system)
- (iv) Specifying the duty for any flow-restricting elements in the system (orifice chokes or other energy-dissipation devices (Wilkins et al., 2004))

In specifying all of the above, cognisance must be taken of:

- (i) Accommodating the required backfill delivery rate
- (ii) Accommodating the backfill distribution system routing to all current and future fill-discharge points, within the limitations of the pressure rating of the piping system components

- (iii) Ensuring that the velocity of the backfill within the distribution piping remains within appropriate limits during system operation.

2.1 Distribution System Operating Velocity Criteria

For the purposes of introducing the novel instrumentation described in this paper, point (iii) above is now further discussed. The risks associated with inappropriate velocities in a backfill distribution system are:

Velocities too high: The primary concern with excessively high velocities is the resulting abrasive wear in the distribution piping. In many cases, pipeline velocities in backfill distribution piping systems are significantly higher than would be considered acceptable in typical surface slurry pipeline systems (such as tailings pipelines or product-transfer pipelines). This is often a consequence of the significant elevation drop across the gravity-assisted backfill system or of a wide range in system duty requirements. Predicting and combating high backfill pipeline wear rates has been the subject of much previous research (Ilgner and Kramers, 1996).

Velocities too low: The concern with excessively low pipeline velocities in a backfill distribution system is the associated risk of a pipeline blockage. A blockage in a slurry pipeline has been succinctly defined by Shou (2004) as “a special pipeline operating condition when the moving resistance of a settled solids column (plug) is greater than the available driving force”. In other words, a blockage in a backfill distribution system typically occurs when a plug of settled solids forms (at some point in the system), and the pressure differential across the plug is insufficient to continue to drive the flow through the system. The flow stops and the system is then “blocked” or “plugged”.

The conditions which give rise to either reliable pipeline transport of a backfill slurry, or a situation in which solids may deposit in the distribution piping, are particularly complex. Designers of slurry pipeline systems (of which backfill distribution systems are a special case) will generally agree that a primary criterion that should be met is that the pipeline system should operate without any stationary deposit of solids in the pipeline (referred to in this paper as a “settled or stationary bed”). Such a settled or stationary bed will often create a point at which a plug or blockage may develop.

To put it simply, to ensure that the stationary bed condition in a backfill pipeline system is avoided during operation, the pipeline velocity must remain high enough to avoid solids deposition under all operating conditions. In other words, it must remain above the deposition velocity.

2.2 Slurry Characterisation and Deposition Velocity Criteria

When the flow behaviour of a backfill mixture, or any slurry for that matter, is considered, the slurry can be classified primarily according to the settling behaviour of the particles in the mixture:

Settling slurries: The solids are relatively coarse (particle diameter typically 75 micron and larger) and the solid and liquid components of the slurry remain clearly distinguishable. Turbulence in the fluid flow is relied on to suspend and transport the solids. When the flow is stopped, the solids quickly segregate from the liquid. A slurry of sand plus water would be a typical example of such a slurry.

Non-settling slurries: The solids are fine (particle diameter typically 10 micron and smaller) and form a mixture with the liquid component that does not readily segregate and exhibits viscous properties that are very different from those of the liquid alone. A slurry of cement plus water would be a typical example here.

Mixed-regime slurries: Most backfills can be considered to behave as mixed-regime slurries, exhibiting the characteristics of both settling slurries and non-settling slurries. Such slurries contain a wide range of particle sizes and/or densities. The fine particles mix with the liquid phase to form a “vehicle” with modified viscous properties. The coarser particles are transported in the vehicle and, depending on the flow conditions, are supported by the vehicle viscosity, turbulent mixing or a combination thereof.

A settled bed in a pipeline conveying a mixed-regime slurry is generally formed by one of two mechanisms:

- (i) Deposition of solids will occur under *turbulent flow conditions* when the flow velocity is below the limit of the driving force of the fluid on the particles and/or the intensity of turbulence is insufficient either to maintain all solids in suspension in the flow or, at least, to move the flow along the bottom of the pipe.
- (ii) Deposition of solids may also occur under *laminar flow conditions* (i.e. when the flow velocity is below the laminar/turbulent transition velocity). Solids will tend to settle at the bottom in the pipeline under laminar flow conditions as (by definition) there is no turbulence to maintain the coarse particles in suspension. This phenomenon is commonly referred to as “laminar flow settling” and has been described by Cooke (2002).

Note that it is only stated in point (ii) that deposition *may* occur in this case, i.e. under laminar flow conditions. Under certain conditions, laminar slurry flow can be maintained without solids deposition or risk of a pipeline blockage. In fact, high-density, high-yield-stress paste backfill is one example. However, this phenomenon and reliable prediction of the conditions under which a stationary deposit will or will not develop are not yet well understood and are the subject of much current research in the field of slurry pipeline system design (Sanders et al., 2004).

In the design of a mixed-regime slurry pipeline system, both of these criteria must be checked. The deposition mechanism that governs the design is dictated by the higher of the two values.

2.3 Prediction of Deposition Velocity for Backfill Pipeline Flow

Since predicting the conditions under which deposition will or will not occur in slurry pipelines (which includes backfill pipeline systems) is a critically important part of the design process, this topic has been the subject of significant amounts of research in the field of slurry flow behaviour. One of the early publications was by Carleton and Cheng in 1974. They identified 55 different correlations for predicting the design velocity, which included wide definitions such as: sliding bed velocity, saltation velocity, suspending velocity, deposit velocity, velocity corresponding to the minimum of the pressure gradient curve, velocity for homogeneous flow, standard velocity and laminar-turbulent transition velocity. A power law correlation was the usual form used to calculate the deposition velocity. They concluded that most correlations were simply based on dimensionless analysis; some were based on theory, but most relied on experimental results for their numerical constants. Therefore, confidence levels were low for applying those correlations outside the range of the measured data.

For purposes of backfill pipeline system design, the methods preferred and recommended by the authors are described here. The two deposition mechanisms to be considered are discussed under separate headings below.

2.3.1 Turbulent flow deposition

Sanders et al. (2004) suggested a method for predicting the deposition velocity for relatively fine settling slurries (typically particle size < 150 micron), which is considered to be appropriate for application to a typical backfill slurry composed of mill tailings, with or without binder addition. This analysis is based on the assumption that for these fine particles, the onset of deposition in the slurry pipeline is associated with the particles under consideration being contained entirely within the laminar sublayer at the pipe wall.

In this case, the deposition velocity is given by (equation requires iterative solution to determine V_{dep}):

$$V_{dep} = \sqrt{\frac{2}{f}} (0.76 + 0.15d^+) \left[\frac{g \mu_{mf} \left(\frac{\rho_s}{\rho_{mf}} - 1 \right)}{\rho_{mf} (C_{b\ free} - C_{V\ coarse})^{0.88}} \right]^{\frac{1}{3}} \quad [1]$$

Where:

- f = Fanning friction factor evaluated at deposition velocity
- d^+ = non-dimensional representative particle size
- μ_{mf} = fluid (slurry vehicle) viscosity (Pa.s)
- ρ_{mf} = fluid (slurry vehicle) density (kg/m³)
- $C_{b\ free}$ = freely settled concentration of coarse (+75 micron) fraction of the solids
- $C_{V\ coarse}$ = volume concentration of coarse (+75 micron) fraction of the solids

The fluid (slurry vehicle considered to be formed by the water and the -75 micron particles) density is determined from:

$$\rho_{mf} = \rho_w + C_{Vf}(\rho_s - \rho_w) \quad [2]$$

Where: C_{Vf} = volume concentration of the -75 micron particles in the slurry vehicle

and:

$$C_{Vf} = \frac{P_f C_V}{1 + C_V(P_f - 1)} \quad [3]$$

Where: P_f = "percentage fines" = fraction of the total solids falling into the -75 micron "fines" category

The non-dimensional representative particle size, d^+ , is defined by:

$$d^+ = \frac{d V_{dep} \rho_{mf} \sqrt{\frac{f}{2}}}{\mu_{mf}} \quad [4]$$

Where: d = mean particle size of the +75 micron "coarse" fraction of the solids

This method is applicable only for $d^+ < 5$

For coarser slurries to which this method cannot be applied, many other alternative methods for predicting deposition velocity are available, for example the method of Gillies and co-workers (2000) at the Saskatchewan Research Council in Canada.

2.3.2 *Laminar flow settling*

When deposition under laminar flow conditions is being considered, the deposition velocity is the velocity at which the transition between laminar and turbulent flow occurs (frequently referred to as the “critical velocity”). There are a number of methods for predicting the laminar/turbulent transition velocity, for example based on assessment of the Reynolds number at transition, based on equivalence of the pipeline friction pressure gradient under laminar and turbulent flow conditions or, for slurries that can be considered to behave as Bingham plastic fluids, the convenient method of Slatter and Wasp (2000).

Methods for predicting *whether or not a stationary deposit will develop* in the laminar flow regime and determining the associated risk of blockage under laminar flow conditions are very much less well developed than is the case for turbulent flow as described above.

A criterion that the authors have applied with success is that proposed by Shook and Sumner (2001): provided that the friction pressure gradient associated with the slurry flow is greater than approximately 1 to 2 kPa/m, then any solids that do tend to segregate or settle under laminar flow conditions will still be transported along the bottom of the pipe in the form of a sliding bed. This is the mechanism by which the coarse particles in a paste backfill are transported, since the high slurry yield stress associated with a paste backfill typically results in pipeline friction pressure gradients exceeding this pressure gradient range.

2.3.3 *Example analysis output*

The application of the deposition velocity criterion described above is illustrated here based on an assessment of a typical tailings-based fill slurry. The physical properties of the tailings which are required as inputs to the calculations (particle size distribution, solids density and slurry viscous properties as a function of slurry density) have been measured in the laboratory. The three key criteria to be considered, namely turbulent flow deposition velocity, laminar/turbulent transition velocity and the pipeline friction pressure gradient, are plotted as a function of slurry density in Figure 1. Referring to Figure 1, the following can be noted:

- At slurry densities of less than 1.44 t/m^3 , the governing deposition criterion is deposition under turbulent flow conditions. If the backfill system is to be designed to operate in this (low) density range, then the pipeline velocity must be maintained above the limit labelled “turbulent deposition velocity criterion” on the chart.
- In the slurry density range 1.44 t/m^3 to 1.70 t/m^3 , the governing deposition criterion is deposition under laminar flow conditions. If the backfill system is to be designed to operate in this (intermediate) density range, then the pipeline velocity must be maintained above the limit labelled “laminar/turbulent transition velocity” on the chart.

- At slurry densities greater than 1.7 t/m^3 , the analysis shows that although the governing deposition criterion is the laminar/turbulent transition velocity, the pipeline friction pressure gradient for this (high) density range exceeds 1.5 kPa/m and thus it is expected that the pipeline can be operated safely at velocities well below the laminar/turbulent transition.

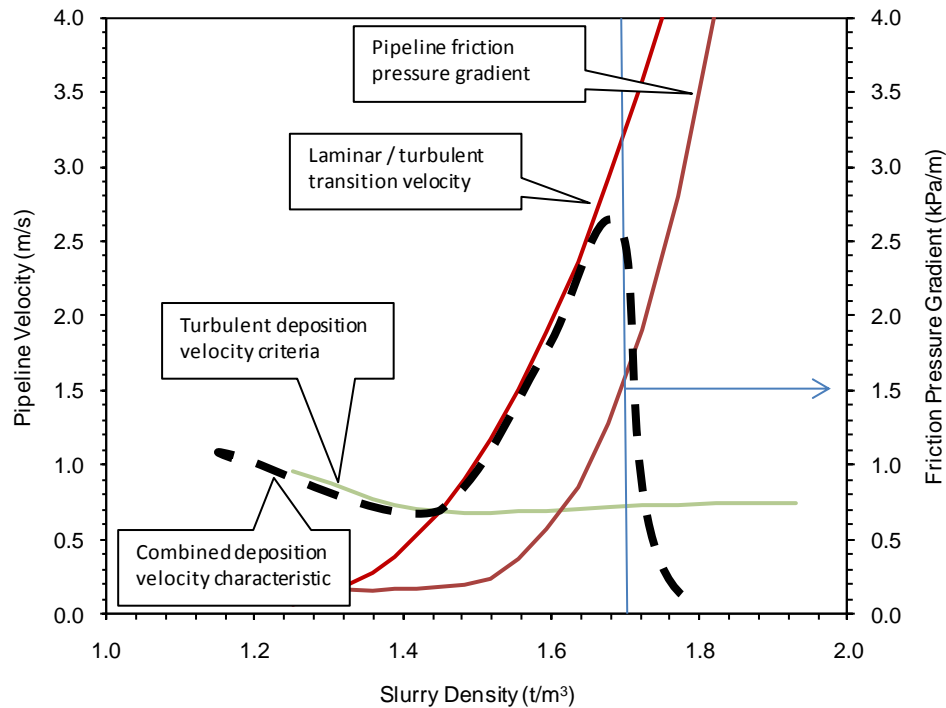


Figure 1: Graphical Output of Assessment of the Risk of Solids Deposition for a Given Pipe Diameter

Based on the results of the assessment described above, the area below the dashed line in Figure 1 indicates the backfill system operating region (in terms of slurry density and pipeline velocity) that is at risk of solids deposition and should thus be avoided. This example highlights a challenge that is frequently encountered in the design of backfill distribution systems: there is an intermediate slurry density range where the governing deposition criterion is the laminar/turbulent transition velocity, and where the pipeline friction pressure gradient is insufficient to ensure transport of settled solids. This region requires the highest pipeline velocities and is considered to be most at risk of unexpected deposition of solids in the pipeline.

3. Example of Operational Problems Associated with Solids Deposition

Notwithstanding the available analytical methods for identifying the conditions under which deposition in backfill distribution piping is expected to occur, there are still many cases where backfill systems have experienced operational problems associated with solids deposition and blockage (De Souza et al. 2003). One example with which the authors have had first-hand experience is given briefly here:

Fehrsen and Cooke (2006) have described operational experience with a paste fill preparation and distribution system at Lisheen Mine in Ireland. Based on the properties of the cemented paste produced during pre-design test work, pipeline friction pressure gradients greater than 2 kPa/m were anticipated. It was accepted that the paste fill, which comprises mill tailings with cement binder, would be in the laminar flow regime in the distribution piping. Given the high pressure gradients, however, it was expected that any solids deposited in the pipeline would be transported.

On commissioning of the system, however, inspection of the pipe bore revealed a progressive build-up of the cemented paste in sections of the piping. This deposit hardened and even aggressive pigging was unsuccessful in clearing the pipe. Investigation of possible causes of this build-up pointed to deposition under laminar flow conditions, with the pipeline pressure gradients found at times to be very much lower than initially anticipated (pressure gradients lower than necessary to maintain movement of the settled solids). The deposit did ultimately reach a stable condition, thought to be at the point where the reduced pipe bore resulted in sufficiently high pressure gradients to prevent further stationary deposits in the pipe (see Figure 2).



Figure 2: Cemented Paste Fill Deposit under Laminar Flow Conditions

4. Novel Instrumentation for Detecting Onset of Pipeline Deposition

Given the potential operational risks associated with solids deposition in a backfill distribution pipeline system, particularly the potential for pipeline blockage and system overpressure, there is considered to be tremendous value in being able to detect directly the onset of solids deposition in the pipeline. The instrumentation described here, which will provide a warning signal at the onset of deposition within the pipeline, has been under development for some time, and this process and initial prototypes have been documented in previous papers (Ilgner, 2006; Ilgner et al., 2010).

4.1 The Concept of the “Stationary Bed Detector”

Traditionally, settling is observed in a laboratory situation through transparent viewing sections to identify the flow rate at which particles become stationary at the pipe invert. This flow rate relates to the deposition velocity (V_{dep}). Some early developments of instrumentation, probes and related techniques to detect stationary beds – most of them in direct contact with the slurry – were reviewed by Ilgner (2004). However, there is no instrumentation readily available in the market that can replace the skilful interpretation of the complex interactions of settling, slow sliding or erratically stationary particles at the pipe invert. The stationary bed detector (SBD) is a novel instrumentation method which can detect the existence of a stationary bed at the pipe invert to trigger a warning when stationary conditions are imminent, or raise an alarm when a small stationary bed has developed. The instrumentation provides an analogue signal (4–20 mA). This is useful for practical engineering control purposes as corrective interventions can be initiated either by the operator or by the integrated process control.

The stationary bed detector is based on the thermal anemometer principle, with the measuring section focused at the invert of a metallic pipe. The instrumentation is not in contact with the slurry, as all necessary components are on the outside of the pipe wall. The recent developments and results with various novel thermal prototypes were reported previously (Ilgner et al., 2010). Good thermal coupling between the sensor head and the pipe wall is ensured by providing a thermal contact compound. The instrumentation is therefore non-intrusive and can be retrofitted to existing pipelines without the need to insert spool pieces. There is no upper limit to the pipe diameter as the transducer is simply attached to the pipe wall. Test work on a stainless steel spool piece with a 15 mm thick pipe wall showed good response times within 1 minute to changes of the settling flow behaviour at the pipe invert.

Figure 3 shows the temperature profile at the invert of a spool piece pipe with an internal diameter of 150 mm prior to its installation in the test loop. The inside of the stainless steel pipe was sprayed with matte black paint to eliminate any reflection from external heat sources, e.g. the human body, which would impair the infrared image. The visible square around the “hot spot” is a thin metallic marker used to enable manual focusing of the infrared camera and to allow for scaling of the temperature field.

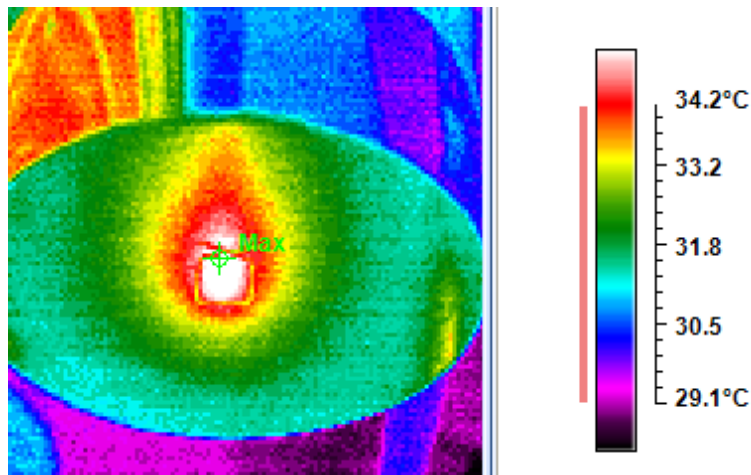


Figure 3: Elevated temperature field at pipe invert of 150 mm ID spool piece

The instrumentation provides an analogue signal (4–20 mA) for convenient signal processing. The results of comprehensive test work to evaluate the performance of this novel instrumentation are given in section 5.1.

4.2 Video Tracking Software to Verify Actual Bed Width

As mentioned above, a definite bed width has to be established at the pipe invert so that the stationary bed detector can trigger a warning or an alarm. In order to correlate the actual bed width with the event of the stationary bed detector triggering the alarm, a video tracking methodology with the associated hardware and software was developed. The idea is that an online signal for the actual bed width can be obtained from online video images. This optically-obtained bed width is then correlated with the online signal from the stationary bed detector attached to the metallic pipe. In this way, the observable and video-tracked bed width (obtained from a transparent pipe section adjacent to the metallic pipe section to which the settled bed detector is attached) can be used to infer the actual bed width in the metallic pipe section. Figure 4 shows the configurations for combining actual observation and video-tracking with the signal from the stationary bed detector.

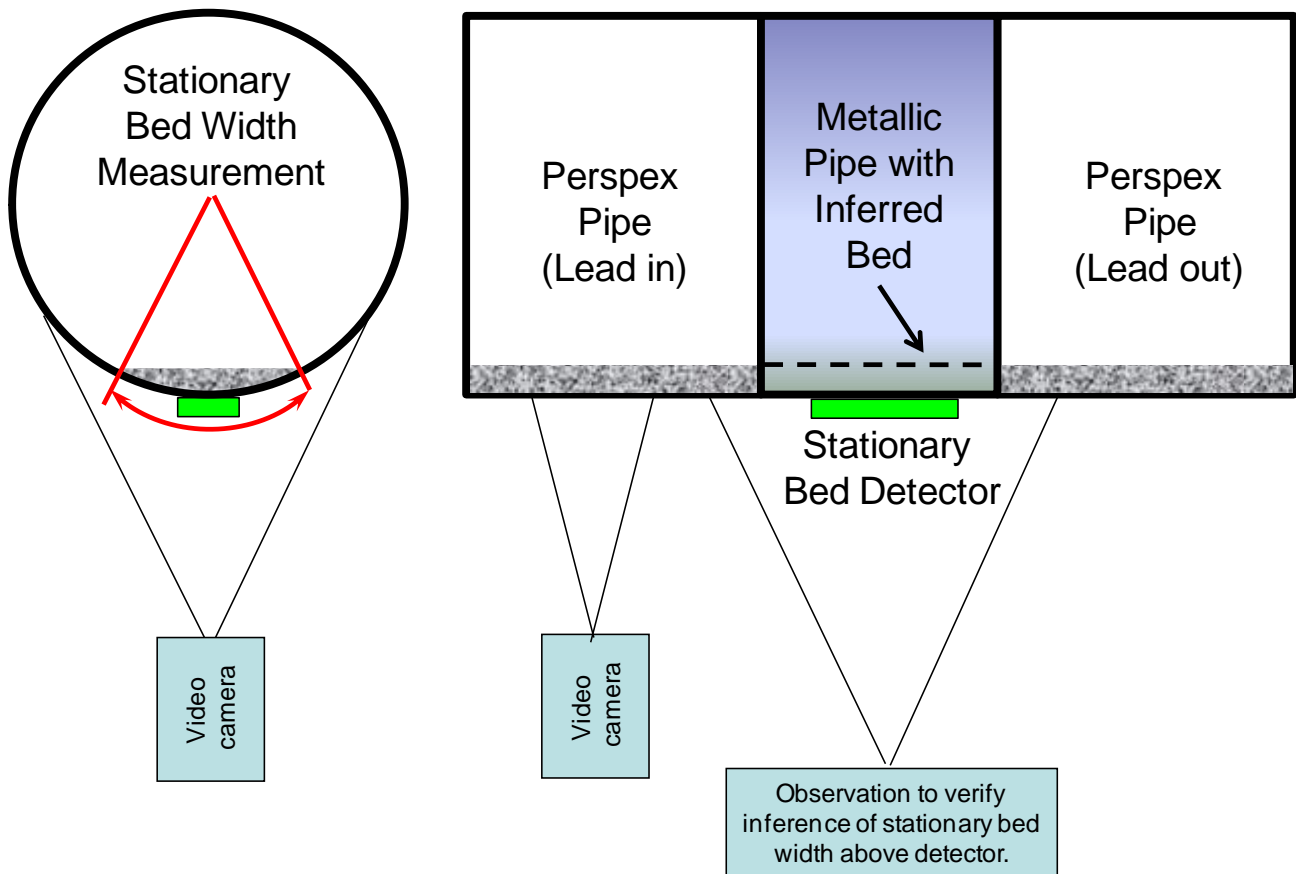


Figure 4: Instrumentation to quantify the inferred bed width in the metallic pipe section above the stationary bed detector

Transparent Perspex viewing sections are situated at the inlet and outlet of the metallic pipe section, with the transitions being carefully machined to be absolutely smooth to avoid any obstruction to the delicate sliding of particles at the pipe invert. The metallic pipe section is kept as short as possible to minimise any potential deviation. The pipe wall roughnesses of the metallic and Perspex sections have to be absolutely equal to bring about exactly the same sliding or settling behaviour of the solids. In that way, the bed width observed in the Perspex pipe section can be inferred to be the same as in the metallic spool piece.

The video-to-analogue processing is based on a modified technique described by Ferreira (2006), with sophisticated calibration and other features from Open Source libraries, such as histogram equalisation, noise filtering and luminescence tuning, to accommodate a wide range of sliding particles' optical properties and image dynamics. Up to 12 rectangular segments can be superimposed onto a live video-capturing screen which must include the area where the stationary bed will develop. Each segment is continuously assessed in terms of how much change takes place between the individual frames. The frame rate can be adjusted up to a maximum of 25/s. This is sufficient, as the slurry sliding process is relatively slow. In fact, the slower the comparison rate of the individual segments is, the more likely it will be that the software will indicate a change. As soon as a stationary bed covers the segment, there is no longer a change in the consecutive images. The output state of this segment will then change from "green" to "red". The outputs of all 12 segments are continuously uploaded to the segments superimposed onto the live video images. This enables fine-tuning of calibration and triggering of parameters for each particular slurry type and optical appearance. The assessed area of 12 equally sized segments can be scaled to suit small and large pipe diameters alike, in accordance with the viewing field selected by the camera. The 12 digital states are then combined into a single analogue signal for data logging. Figure 5 shows all 12 segments superimposed onto the video image, which includes a stationary bed. A fuzzy

interface of minor movement is visible between the stationary bed and the fully suspended area in the image. In this instance, four segments are red, equivalent to an actual bed width of nearly 3 mm.

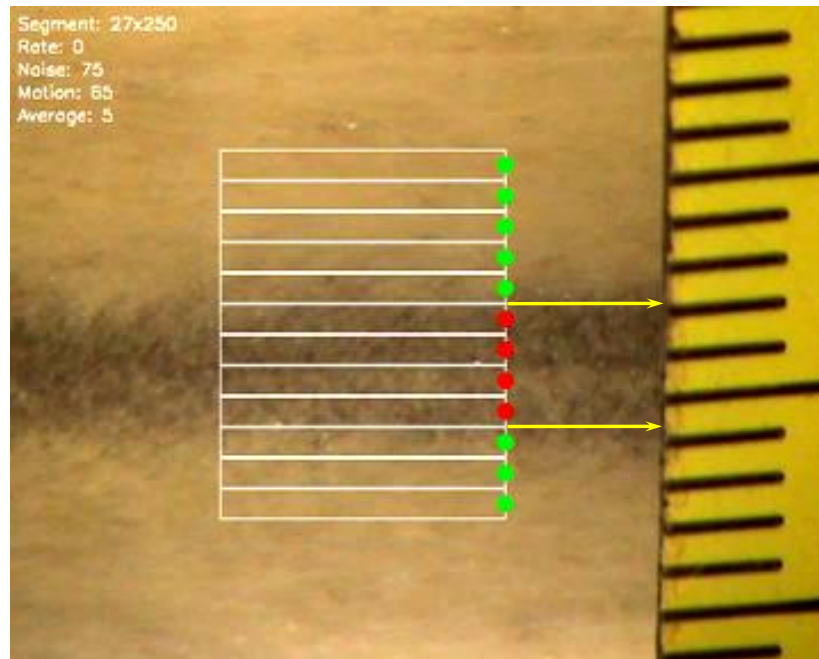


Figure 5: View upwards towards the pipe invert with small stationary bed and online results of video analysis of segments – flow (green) and no-flow (red)

The actual bed width at which the stationary bed detector triggers the initial warning and then the alarm can be determined in small and large pipe diameters during test work by using this video analysis tool. This enables an exact correlation of the instrumentation output with the actual bed width. Preliminary indications are that the stationary bed detector output can even indicate the thickness of the stationary bed up to about 20 mm, depending on the backfill properties and pipe wall thickness.

5. Particle Size Distributions and Pump Test Loops

The particle size distributions for the laboratory tests were classified gold plant tailings, fly ash material originated from a South African power station and classified tailings from a South African platinum mine. Their differences are shown in the distributions in Figure 6. The smaller sizes up to 20 micron were determined by the hydrometer method and the larger sizes by conventional sieve analysis.

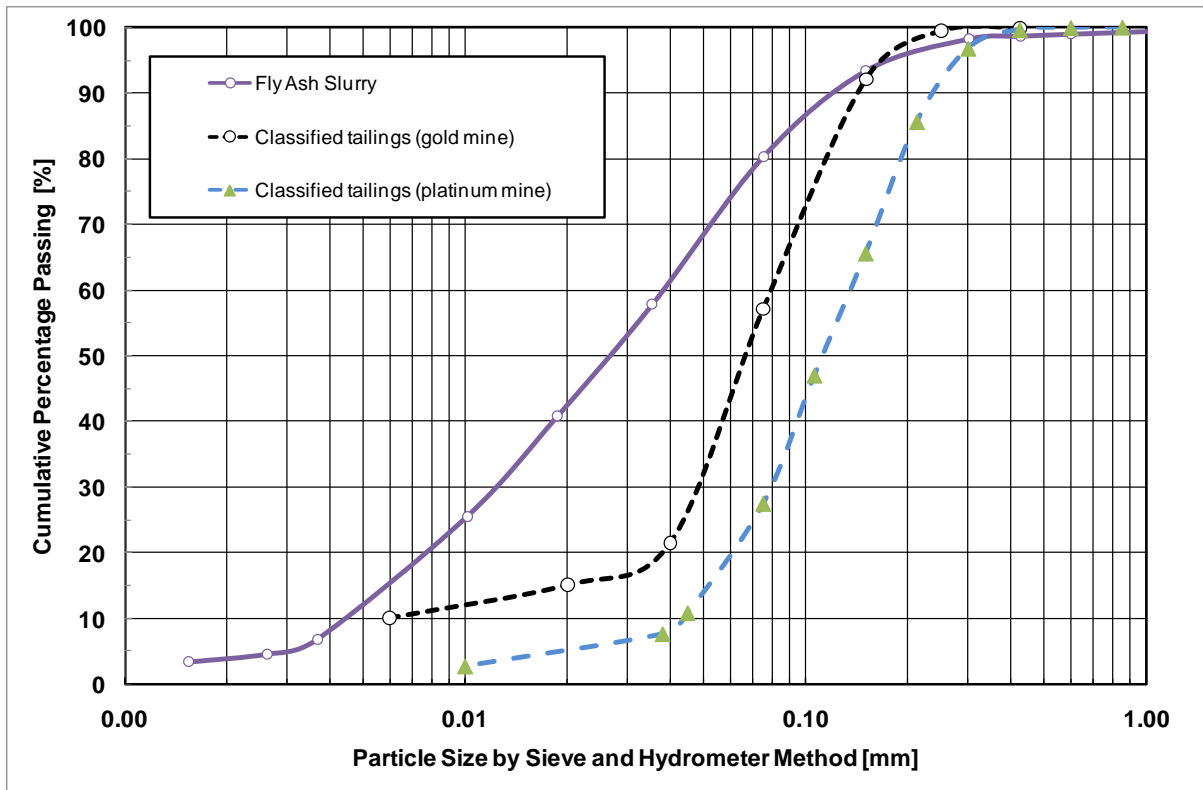


Figure 6: Particle size distributions of different slurries

The pump test loops include variable speed drives to reduce the flow rate linearly and slowly to obtain a continuous profile of the output of the stationary bed detector attached to the invert of a length of steel pipe in the pipe loop. The flow rate, measured with Endress & Hauser’s Slurry Pro electro-magnetic flow meter in both loops, was reduced well below the critical deposition velocity to obtain a characteristic profile for a given backfill type at a particular slurry density. Horizontal viewing sections were used to visually observe the flow condition and the established bed width in order to relate the observations with the instrumentation output.

5.1 Results for Detecting the Stationary Bed over a Large Backfill Density Range

5.1.1 Classified tailings (gold mine)

The backfill flow rate was reduced continuously to detect the transition from fully suspended particle flow to the development of a stationary bed. The responses of the stationary bed detector for seven selected backfill densities are shown in Figure 7.

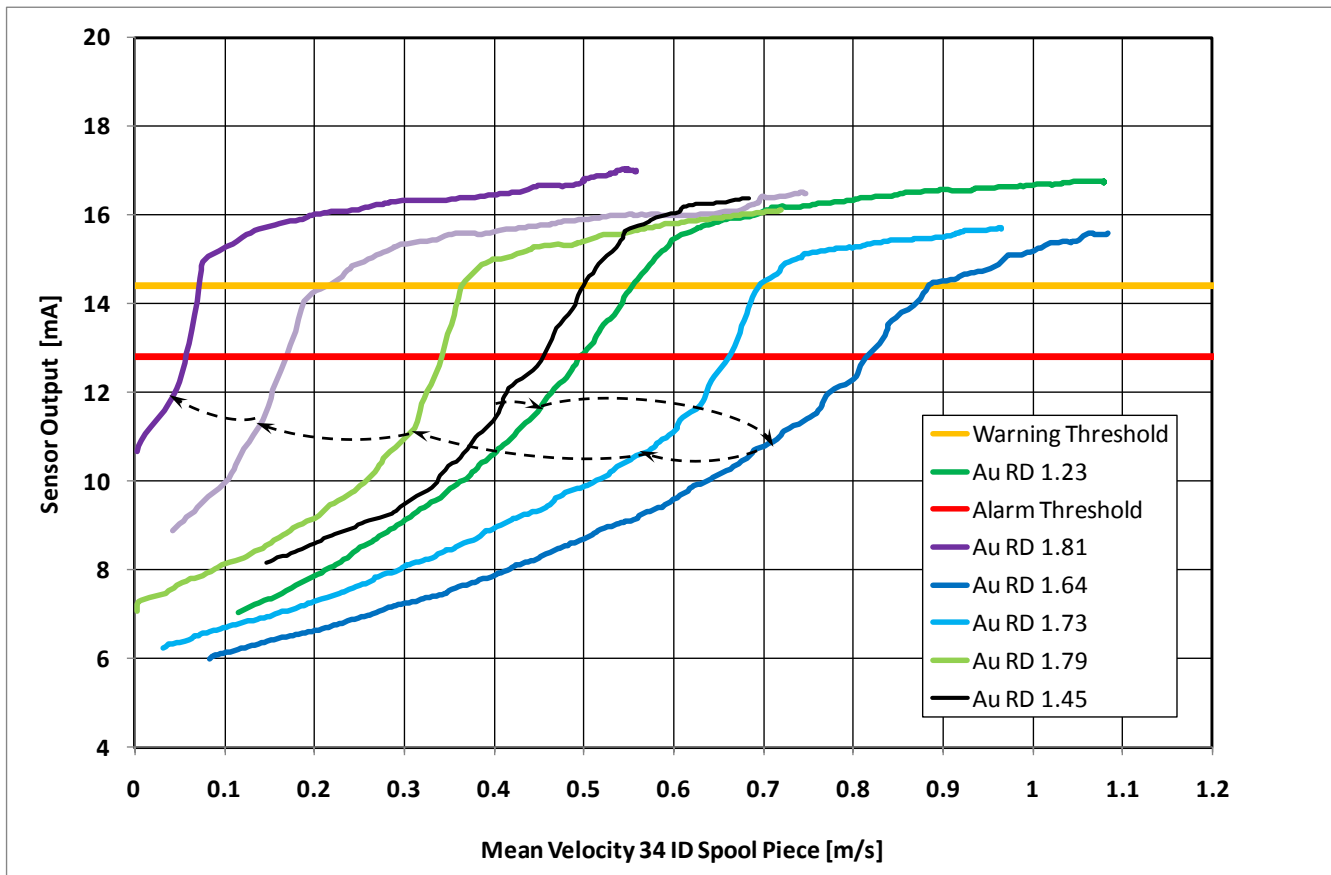


Figure 7: Responses from the settled bed detector in 34 mm ID piping for classified tailings (gold mine)

The response at the lowest density of 1.45 t/m^3 is in the middle of the array of data sets on the chart. With increasing backfill densities, the bed forms at higher flow rates. This trend is indicated by the dashed arrows in Figure 7. The maximum deposition velocity was observed at a backfill density of 1.64 t/m^3 for this slurry at a flow rate of about 0.81 m/s in the 34 mm ID pipe loop. The shift of the deposition velocity due to density increases can be seen in Figure 7 for densities greater than 1.64 t/m^3 . A very sharp transition is evident at higher densities due to the abrupt stoppage of an already high-density sliding bed.

5.1.2 Classified tailings (platinum mine)

This backfill has a high solids density of 3.2 t/m^3 compared with the density of 2.7 t/m^3 for gold tailings-based backfills. As with previous tests, the flow rate was reduced continuously to obtain the characteristic curves and the velocity at which the sensor would detect the stationary bed and trigger an alarm. Figure 8 shows the instrumentation output for six different backfill densities.

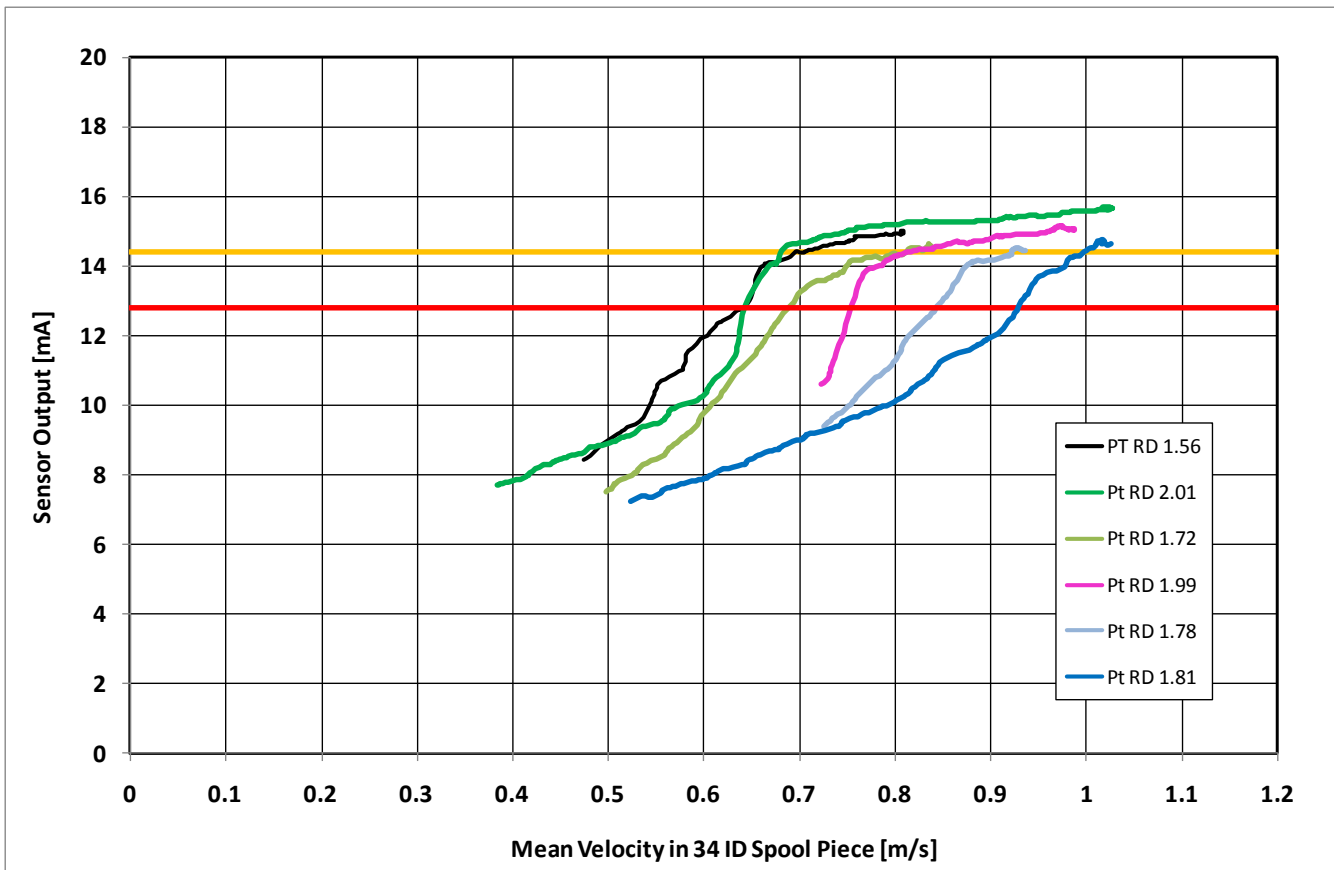


Figure 8: Output of stationary bed detector for classified tailings (platinum mine) with 2 thresholds, 34 mm ID

As with the gold tailings-based backfills, there is again a significant shift of the deposition velocity with increasing slurry density up to a point. Interestingly, a stationary bed is detected for both the lowest and the highest densities measured (1.56 t/m^3 and 2.01 t/m^3 slurry density) at the same low velocity of about 0.61 m/s . At the backfill densities in between those two, velocities had to be as high as 0.92 m/s for a slurry density of 1.81 t/m^3 to avoid settling and development of a stationary bed at the pipe invert.

5.1.3 Fly ash slurry

The most complex results were obtained when testing fly ash slurry due to its high ultrafines content and its low solids density of 2.1 t/m^3 . Although the fly ash settled reasonably quickly, it could easily be resuspended after 24 hours without any formation of larger conglomerates. When the pump tests were repeated after the material had been left in the pipeline for a day, the establishment of a stationary bed was not found to be time dependent. On the second day of testing, backfill densities were increased by decanting supernatant water from the mixing tank after 1 hour of settling between tests. Figure 9 shows the various responses due to slurry flow regime changes over a wide range of densities.

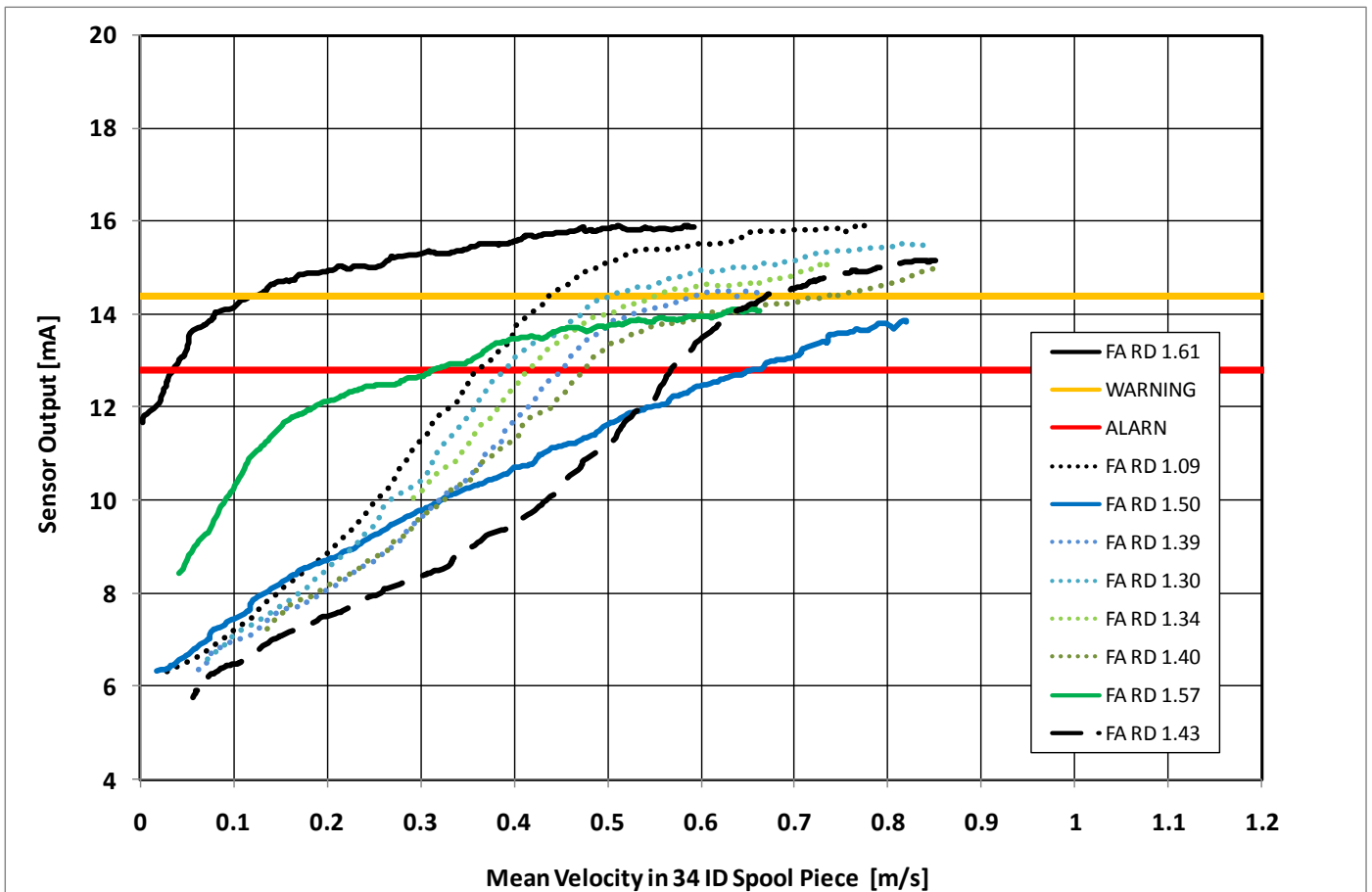


Figure 9: Output of settled bed detector for fly ash slurry, 34 mm ID piping

The fly ash material displayed significant changes when the density was increased from as low as 1.06 t/m^3 to 1.60 t/m^3 . The same threshold of 12.8 mA was used again to indicate that a small stationary bed had developed at the pipe invert. The five dotted curves represent the low fly ash densities from 1.09 t/m^3 to 1.40 t/m^3 . They indicate that when the slurry density increases, the flow rate must also increase to avoid the development of a stationary bed. The dashed curve (FA RD 1.43) symbolises the approaching change in flow behaviour associated with entering the region where deposition is suspected to be occurring under laminar flow conditions. The maximum deposition velocity was observed at a density of 1.50 t/m^3 .

5.2 Comparisons of Critical Bed Flow Rates for Different Backfill Types

The material-specific and slurry density-dependent deposition velocities for a small 34 mm ID pipeline are compared for a wide range of backfill densities in Figure 10. The data for the curve in Figure 10 were obtained from the alarm threshold during the volumetric “ramp down” test shown in figures 7, 8 and 9.

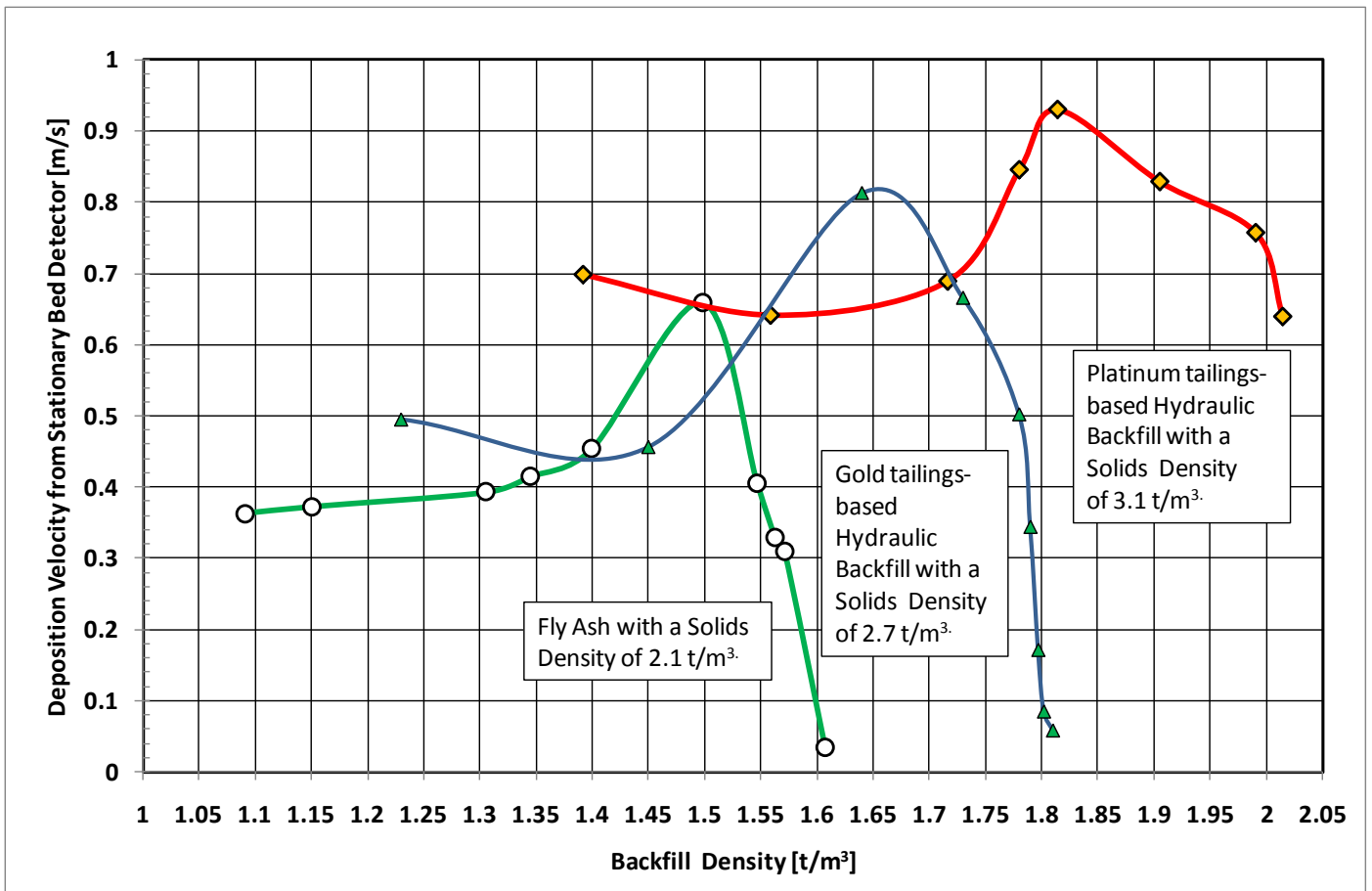


Figure 10: Deposition velocities for three backfill types in 34 mm ID spool piece

All three backfills follow an initial flat trend where settling is governed by deposition under turbulent flow conditions (see description in Section 2.3.1 and in Figure 1). The second region, that of steeply increasing deposition velocity with increasing slurry density, is associated with the onset of laminar flow conditions as described in Section 2.3.2. A significant peak of the deposition velocities is visible for all three backfill types. At this density the risk of particle settling is greatest. In the third region, the deposition velocity decreases with increasing density. This is the region where stationary deposition is governed by the friction pressure gradient criterion of a minimum of 1 to 2 kPa/m . Typically, this flow is characterised by a high-density sliding bed, sometimes associated with erratic stoppages. Deposition to the right of the peak velocity is associated with laminar flow conditions and ever-increasing pressure losses.

6. Potential applications of the stationary bed detector in backfill systems

The cost-effective and non-invasive nature of this novel instrumentation, coupled with its ability to detect motion or no-motion through thin- and thick-walled steel pipes and other backfill-handling equipment, offers various potential applications in addition to the obvious use as a stationary bed detector in horizontal pipes. The instrumentation provides not only pre-settable alarms, but also a flow-proportional analogue 4 mA to 20 mA signal for integration within the plant PLC. Due to the online signal provided, which can be routed to either an operator or a control room, further advantages are the identification of:

1. “Dead zones” within slurry handling equipment, e.g. mechanically agitated storage tanks, thickener discharge pipes, etc.
2. Flow or no-flow conditions for individual binder addition lines in backfill preparation plants or for open-channel or launder flow in transfer chutes
3. Full-flow vs. free-flow conditions in vertical shaft columns, particularly at the shaft collar
4. Slack flow in inclined pipes by using two sensors opposite each other (Ilgner, 2005)
5. Scaling of pipelines due to accumulation of cemented backfill at the pipe invert
6. Filling durations for manually operated backfill pipe ranges from an underground storage dam
7. Interfaces between backfill and flush water to reduce flush water consumption after filling
8. Flow problem areas when using it as a portable inspection tool for troubleshooting

7. Conclusions

Although various empirical and theoretical models exist in the literature to predict the deposition velocities for settling slurries and backfills, based on numerous influencing parameters, an analysis has shown that different mechanisms dominate the onset of stationary beds. Although these mechanisms of settling during turbulent or laminar conditions depend largely on the backfill density and the particle size distribution, they are also influenced by solids density, particle shape and the pipeline pressure gradient.

A novel online instrument has been developed and tested which can indicate the deposition of solids at the invert of a metallic pipe. This instrumentation is non-invasive as it is attached to the outside of the pipe wall. It can provide an alarm to initiate corrective action either by the operator or by integrated process control to avoid potential pipeline blockages. Measurements for fly ash, platinum and gold tailings-based backfills reflected the expected dependence of the deposition velocity on the backfill density. Each backfill type displayed a maximum deposition velocity in the slurry density range studied, which poses a high risk of blockage. This point corresponds to the transition between the region where stationary deposition occurs under laminar flow conditions, and the region where the pressure gradient under laminar flow conditions is sufficient to avoid stationary deposition. Further increases in density resulted in a visible decrease in deposition velocities due to significantly increased pressure gradients.

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