PASTE FILL PIPELINE DISTRIBUTION SYSTEMS – CURRENT STATUS

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ABSTRACT

Despite the technology for designing backfill distribution systems being mature, a recent review (De Souza *et al*, 2003) of Canadian backfill operations reveals that 70% of backfill system failures relate to the distribution system (blockages, fill sloughing, pipeline bursts and hammering). The primary reason for these failures is a lack of understanding of the flow behaviour of hydraulic and paste fills.

This paper presents a basic overview of the design process for backfill distribution systems. Two backfill case studies are discussed to illustrate aspects of backfill pipeline system design:

- Boulby Mine, United Kingdom
- Lisheen Mine, Ireland.

1 INTRODUCTION

While the majority of South African backfill operations utilise un-cemented classified tailings, many North American, European and Australian operations have opted for paste fill. Paste fill typically comprises dewatered total tailings with cement and/or binder added. Aggregate is added to the paste for applications where high strengths are required.

The primary advantages of paste fill are:

- The fill has little or no bleed water, simplifying mine dewatering.
- As total tailings are used, the surface disposal problems are reduced.
- Paste can be "engineered" to provide the required strength for different parts of the mine.

The primary disadvantage is the high cost of using paste fill. The capital costs are high due to the plant requirements to de-water the tailings (usually using filters) and then to prepare a paste with a particular rheology or consistency. The operating costs are largely dictated by the cement costs. Grice (1998) notes that cement typically accounts for 75% of the operating cost of a paste fill system.

Not all paste systems fully realise the benefits of paste due to operating problems associated with inadequate design, engineering and implementation. De Souza *et al* (2003) note that many of the operating problems are due to the poor performance of the underground pipeline distribution systems. This paper discusses design considerations for paste distribution systems and reviews two paste distribution system case studies.

2 PASTE FILL DISTRIBUTION SYSTEM DESIGN CONSIDERATIONS

This section reviews issues to be considered when designing a paste fill distribution piping system for an underground mine.

2.1 Distribution System Pipeline Routing

The distribution pipeline routing is largely defined by the mine layout. However, there are usually some opportunities for optimising the piping layout and the following issues should be considered:

i.) Ideally the slope of the piping should reduce along the distribution system, i.e. vertical down sections should be at the start of the distribution system, with horizontal piping towards the end of the system.
ii.) It is preferable to have a series of vertical piping sections instead of a single vertical section. This reduces the pipeline operating pressures.
iii.) Pipes may be installed in shafts to reduce installation costs, although this is generally not preferred due to safety considerations.
iv.) Inter-level boreholes can be used to reduce the total pipeline length.

2.2 Paste Flow Properties

The standard 300 mm concrete slump cone has become the industry standard for communicating paste properties (e.g. 150 mm or 6" slump paste) and for paste plant quality control. High slump values indicate low rheology or "viscosity" while low values indicate a "stiff" paste. The typical range of slump values used in paste fill applications is 150 mm to 250 mm as illustrated in Figure 1.

Together with an empirical test data base, the slump test can provide a preliminary assessment of the paste pipeline flow behaviour for conceptual designs. However, the accuracy is not suitable for final design, specification and control of a pipeline system.

Figure 2 compares measured pipeline pressure gradients for cemented pastes produced using total tailings from three base metal mining operations. The following points are noted:

- The paste from Mines A and B have similar slumps and similar pressure gradients, although it could be expected that the pressure gradients for Mine B would be lower than the data for Mine A due to the higher slump. For both these pastes, the pipeline pressure gradient is relatively insensitive to flow rate. This has important implications for the hydraulic design of the distribution system.

- The Mine C paste has significantly higher pipeline friction losses which are sensitive to relatively small changes in slump. If the system had been designed using an empirical correlation based on data from Mine A or B, the system would not meet its design duty.

An important point to consider is the effect of shear on the paste properties. Figure 3 illustrates the slump of a paste produced using a thickener before and after shearing. Any test work for the design of paste distribution system should be conducted using fully sheared material.

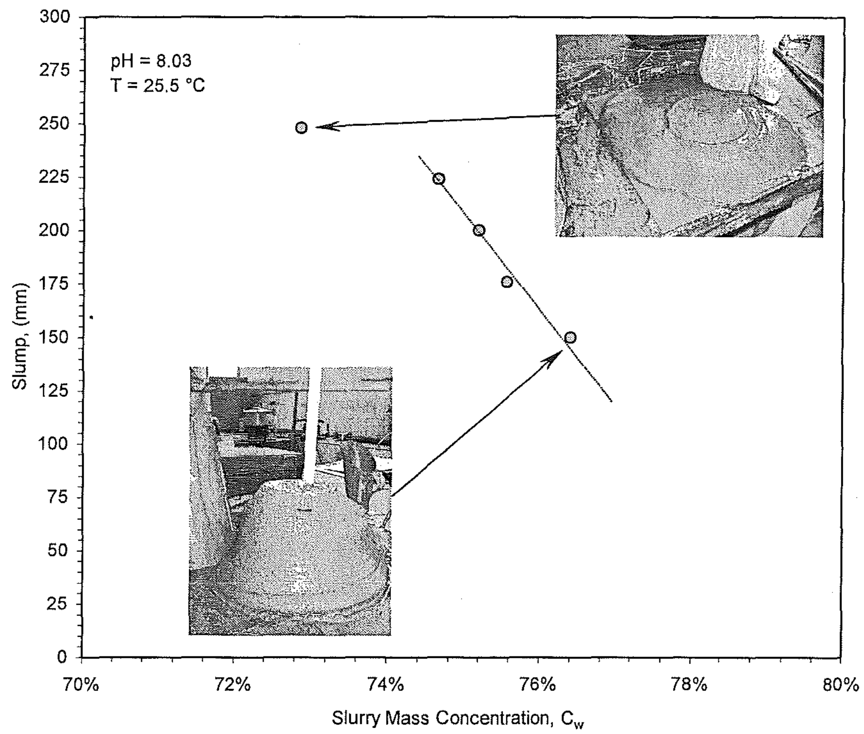

Figure 1: Slump versus Concentration (Gold Tailings)

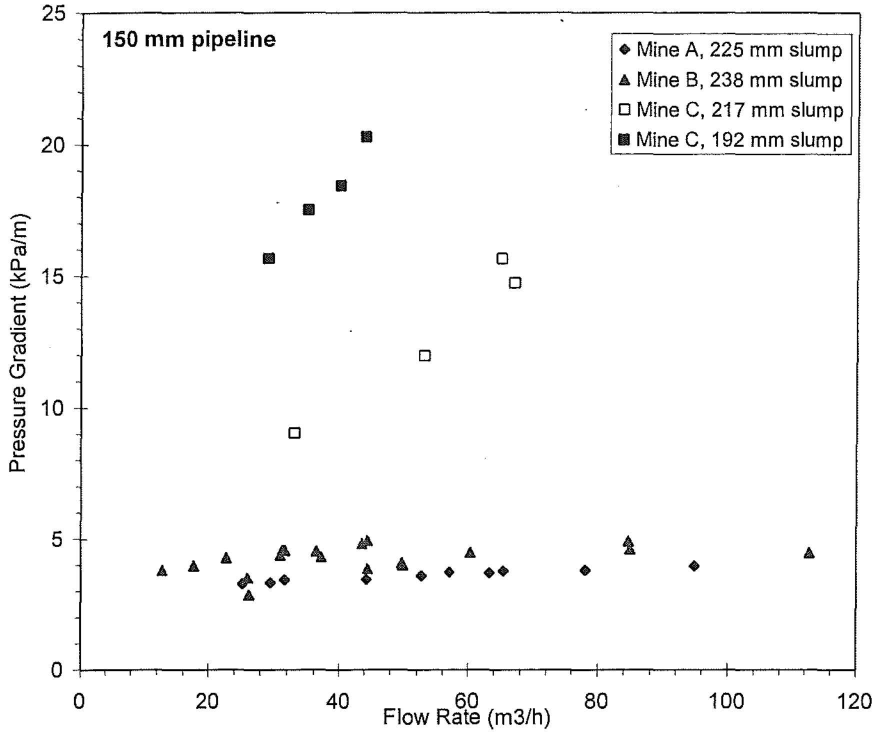

Figure 2: 150 mm Pipeline Pressure Gradient Data

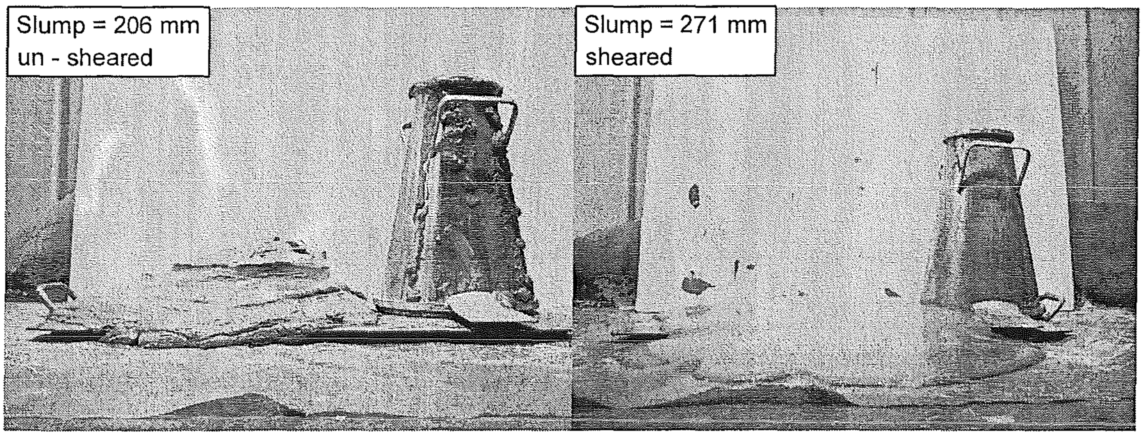

Figure 3: Effect of Shear on Paste Slump

2.3 Test Work

Test work is required to establish the flow behaviour of paste mixtures. For preliminary investigations, this work can be conducted in laboratories using slump tests, viscometers and small scale pipe loops. However for final engineering and specification of the system, pipe loop tests should be conducted on site. The following points should be considered:

i.) The pipe loop tests should be conducted in at least two pipe diameters, three is preferable, so that slip effects can be quantified. One of the pipe diameters should be the size anticipated for the distribution system.
ii.) The paste should be as representative as possible. This includes tailings sampling, production method (sedimentation dewatering or filtration), flocculant type and dosage, cement/binder type and dosage and shear state as discussed above.
iii.) Ideally, to minimise particle degradation effects, once through pipe loop tests should be conducted instead of using a recirculation system. This is more important for coarse particle paste and tailings-aggregate mixtures.

2.4 Rheological Characterisation, Friction Losses and Pipeline Diameter Selection

Details of rheological characterisation and the determination of pipeline friction losses for paste mixtures are discussed by Cooke (2006).

Due to the viscous nature of paste mixtures, most paste distribution systems operate in laminar flow. This introduces potential problems associated with laminar flow settling (Cooke, 2002). To avoid the risk of laminar settling, the current guideline is that the pipeline pressure gradients should be greater than 2 kPa/m.

2.5 Hydraulic Components

In addition to the piping, a paste distribution system may also include the following components:

i.) Pumps to provide additional energy to overcome pipeline friction losses and, in some cases, to control the flow rate delivered to the distribution piping. Hydraulic piston type pumps with a maximum operating pressure of 8 MPa are typically used.
ii.) Many systems have an excess of gravity energy available and so localised energy dissipaters are used to absorb excess energy. This function can also be performed using small bore choke piping.
iii.) Pressure rupture devices protect the distribution components from excess pressures that may be generated under fault conditions.

2.6 Hydraulic Analysis

The hydraulic analysis of a paste distribution system entails the following:

i.) Steady state analysis to balance the pipeline friction losses with the gravity head available (plus the pump head if applicable). The system must be designed such that "free-fall" or slack flow conditions do not occur as this will cause rapid pipeline failure (Cooke, 2001).
ii.) Analysis of flow conditions during start-up and shut down. Ideally slack flow conditions should also be avoided during non-steady state operation if possible.
iii.) Transient flow analysis to establish suitable over pressure allowances due to water hammer events.

2.7 Mechanical Piping Design

The mechanical design of the piping system is usually done in accordance with ASME B31.3 or B31.11.

For high pressure systems, a pipeline and support system stress analysis is performed using software such as Caesar II. Care should be taken when using software packages to do the analysis as many assumptions have to be made regarding support models, friction, etc. when compared to modelling of petrochemical piping installations. Particularly as dynamic loads, such as pump pressure pulses, of often of the most concern.

2.8 Operating Procedures

An important part of the system design is the specification of the normal, flushing and emergency operating procedures.

3 CASE STUDY 1: BOULBY BACKFILL SYSTEM

3.1 System Overview

The processing of potash ore at Cleveland Potash Limited's Boulby Mine gives rise to two waste products: centrifuge (salt) and filter cake (salt, calcium sulphate and insoluble clays). Historically all process waste has been discharged into the North Sea. Due to traces of heavy metals in the insoluble clays, the permitted amount of insoluble waste that can be discharged into the sea will be substantially reduced over the next few years.

In May 2003, a 200 000 t/y backfill system was commissioned at Boulby Mine. The backfill system uses the gravity head available (between 908 m to 1 100 m) to transport the backfill down the shaft and then horizontally to old workings between 5 500 m to

11 000 m from the shaft bottom. The design, commissioning and operation of the system is described in further detail by Wilkins *et al* (2004).

The system reduces the mine's environmental impact and allows the mine to operate at its maximum potential and even increase the tonnage milled in line with strategic operational planning.

3.2 Backfilling for Environmental Reasons

The backfill is required at Boulby Mine purely for environmental reasons and not for support, pillar extraction, improved ventilation or any of the other typical reasons that backfill systems are implemented. At Boulby this influenced the design of the distribution system as follows:

- Rheology, system flow rate and placement density could be selected to minimise the cost of the system to avoid the cost of high pressure paste pumps either on surface and/ or booster pumps underground.
- The addition of cement was not required.

3.3 No Flushing

The underground roadways at Boulby are in the salt layer and thus it was desirable to avoid flushing the pipeline between batch placement pours during normal operation. During the test work phase the possibility of restarting the system after a delayed shutdown was investigated. Subsequent operation has shown that the system can be shutdown for up to 3 weeks and still be re-started without difficulty.

3.4 Rheology Control

Due to the varying placement distances and the relatively constant gravity head available, the pipeline pressure gradient must be varied to ensure:

- Full flow conditions at all times.
- Maintain turbulent flow to avoid laminar settling problems in the long horizontal piping section.
- Driving head required must not exceed the gravity head available.

Due to variations in the filter cake properties, the backfill rheology is not constant for a given backfill density. A rheology control system was provided to ensure that the filter cake was mixed with the required water quantity to optimise the backfill rheology rather than the backfill density.

Thus each batch of backfill is prepared to the required rheology (and thus required pressure gradient) to utilise the available gravity head without the need for paste pumps.

3.5 Large Bore Shaft Column

The backfill is transported down the shaft in a 1 100 m long 200 NB high pressure steel column. The shaft column has some unique features:

- It was designed to operate in laminar flow to reduce friction losses and maximise the available driving head.
- Due to poor ground conditions at the shaft bottom, the column is not supported at the base of the column, but from a hanging support about 25 m above the shaft bottom.
- Due to the variations in operating and ambient temperatures, compensators were installed to allow for controlled expansion and contraction of the shaft column.
- The top of the shaft column has a substantial support to counter upward pressure loads during emergency flushing conditions.

3.6 Valve Station

As discussed above, cement addition is not required at Boulby. This made it feasible to install a valve station at the bottom of the shaft column (shown in

Figure 4) to keep the shaft column full when the system is not operating thereby avoiding the following potential problems associated with draining the column after placing each batch:

- Free-fall conditions would occur during start-up operations if the backfill was allowed to drain from the shaft column. This would result in excessive wear rates due to free-fall in the shaft column and high impact loads on both the shaft column and the bend at the bottom of the shaft.
- Isolating the shaft column at the bottom of the shaft limits the magnitude of the cyclic loading due to pressure variations on start up and shut down. The operational times of the shaft column isolation valve and associated bypass valves are carefully specified to limit the magnitude of any transient pressure wave.

To minimise pressure transients on start-up and shutdown of the system, the flow rate through the valve station is controlled using two banks of energy dissipaters operating in parallel. The first bank of energy dissipaters controls the flow through the valve station to an approximately 10 m^3/h with a 1 000 m differential head. The second bank shown in Figure 5 is rated for 115 m^3/h with a 200 m differential head.

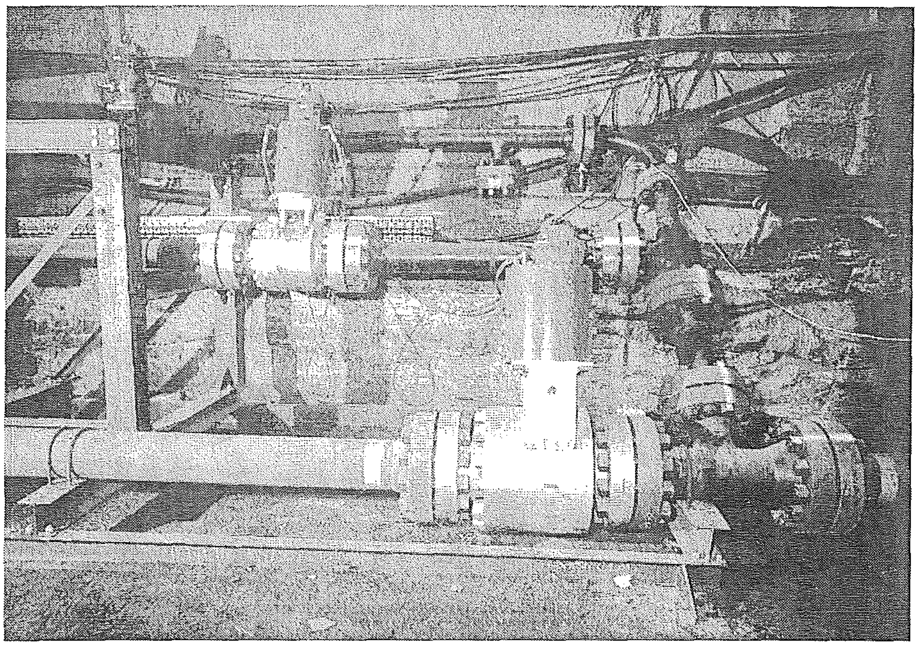

Figure 4: Underground valve station

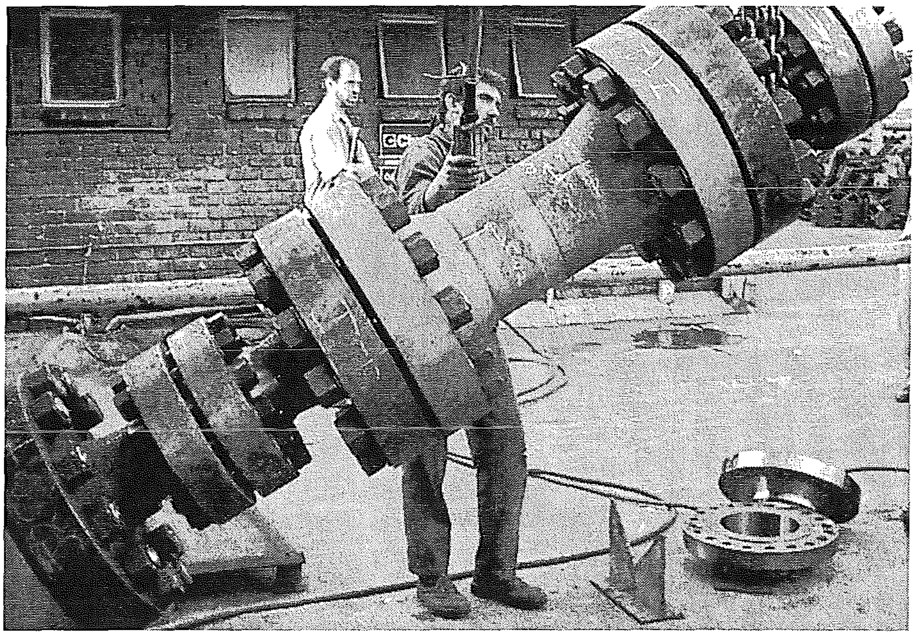

Figure 5: Energy dissipater during pressure testing

4 CASE STUDY 2: LISHEEN PASTE SYSTEM

4.1 System Overview

Lisheen Mine in Ireland is a zinc and lead operation. The floatation tailings were historically deposited on surface in a Tailings Management Facility (TMF). Lisheen Mine commissioned a paste fill system to place thickened cemented floatation tailings underground as backfill:

- For support to enable the extraction of pillars.
- To reduce the tonnage sent to the TMF to increase its operating life.

In October 2004, the paste fill system was commissioned at Lisheen Mine. A paste pump is used to pump the cemented paste between 1 900 m to 3 200 m to the underground areas between 136 m to 215 m below the surface.

4.2 Laminar Settling

Currently Lisheen Mine is experiencing laminar settling problems as shown in Figure 6. The pipeline is designed to operate in laminar flow as test work conducted by a third party predicated pressure gradients significantly greater than the guideline value of 2 kPa/m to avoid laminar settling problems (as discussed in Section 2.4).

Operating experience has shown that the pressure gradients are significantly less than predicted. The paste plant is able to produce paste with close to the design concentration, but the paste rheology is significantly less than expected. In addition the paste concentration and rheology produced is not consistent due to variations in the ore.

It is suspected that during the test work the paste was not produced in manner to satisfactorily simulate the envisaged paste plant production process as discussed in Section 2.3.

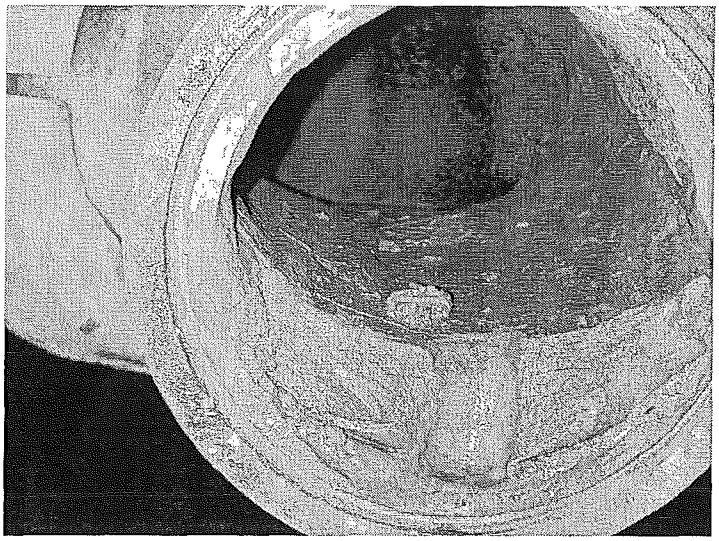

Figure 6: Laminar flow settling

4.3 Pump Control

The lower than expected rheology caused problems with the paste pump. Although there were some pump control problems, the low pumping pressures highlighted a common problem in the design of high pressure pumping systems. Often the system is design to account for the high pumping pressures and the minimisation of pressure pulses at the high pumping pressures. It is important to also consider the pump control at lower pumping pressures as often upset conditions, shorter pumping distances, etc. will result in low pumping pressures. Pressure pulses at these low pressures can do significant damage to piping as was experienced during commissioning of the system (fortunately the damage was not to the underground line, but a temporary surface commissioning pipeline).

4.4 Paste Thickeners

Lisheen Mine is unique in that the current paste plant does not use any filtration equipment to de-water the floatation tailings. Although there are problems with the paste rheology, if these problems can be resolved, this will be a significant step towards reducing the capital cost of paste plants. The possibility of using no filtration equipment does depend on the material characteristics.

4.5 Air Scour and Water Flush

Many North American operations use an air scour to flush the backfill pipeline following a pour. Many of these operations have a sufficient gravity head available to assist the air in driving a short air/ water mixture behind the paste. The velocities reached are sufficient to scour the pipeline clean.

Lisheen Mine's distribution piping, however, has a very flat profile and the route to many of the stopes in fact rises for the last 1 000 m. Analysis showed that the air scour would not be successful to these areas. Although laminar settling problems has meant even a water flush with an aggressive pig has not completely cleared the pipeline of the partially set cemented paste, inspections following air scours showed that in areas where low air scour velocities were predicted, very little removal of the partial set cemented paste had occurred.

In addition care should be taken to ensure that there are no areas where air and water plugs can be trapped due to the pipeline profile. This can lead to potentially dangerous incidents as were experienced during operation.

Using an air scour to clean the pipeline after a pour should be done with care and due consideration must be given to the pipeline geometry and operating conditions.

4.6 Pipeline and Piping Support Analysis

A stress analysis of the pipeline distribution system and supports was conducted using the Caesar II software package.

Of particular interest was the proper modelling of the hydraulic support loads on the pipe supports on the long decline. Loadings need to be carefully considered to ensure that the support system and anchors were not over designed.

4.7 Slack flow

Due to the lower than expected rheology, slack flow has occurred in the pipe at the top of the decline. This has resulted in "water hammer" occurring. Although the pressure pulses in this case were not excessive, it highlighted the importance of ensuring full flow conditions to prevent this phenomenon. Not always is the "water hammer" problem tolerable.

5 CONCLUSIONS

The key aspects to designing a successful paste fill distribution system are:

- The paste flow behaviour must be properly characterised. Ideally this is done by conducting on site pipe loop tests.
- The distribution system must be designed to operate without slack flow. This requires a sound understanding of pipeline hydraulics.

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