Deploying Oil & Gas drilling techniques with Dewatering Well Placement technology (DWPt) in open pit and underground mines

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Abstract

Dewatering of mining operations brings many advantages including improved access, increased stability of pit slopes, reduced cost of ore haulage and more cost effective blasting. In many cases dewatering is achieved through the use of vertical in-mine wells. The presence of these wells within the pit can however cause operational issues, while space constraints often mean that the wells cannot be sited in the optimum location from which to achieve dewatering impacts. In order to overcome these issues SWS has developed Dewatering Well Placement technology (DWPt), which applies oilfield directional drilling and completion approaches to implement dewatering wells which can be drilled from outside the final pit footprint, and place the well in the optimum production zone based on the final pit floor. The ability of these wells to target key hydrogeological structures, together with their improved operational run times, means that improved drawdowns are achieved when compared to vertical in-mine wells. Engineering design of these wells requires a comprehensive technical evaluation and cost benefit analysis to be undertaken in order to determine whether DWPt is the appropriate dewatering approach for any mining operation. SWS has developed a comprehensive workflow for implementation of DWPt, and the application of this workflow at the Sishen iron ore mine, South Africa, is presented as a case study of the evaluation process.

Key words: Dewatering, Well Placement technology, well trajectory, rate of penetration

Introduction

The majority of large open pit and underground mines require dewatering as part of the mining operation. The dry mining conditions that dewatering is aiming to achieve provides a number of operational benefits (Figure 1) which include:

- Unrestricted access to mine benches
- Dry pit slopes have a reduced risk of failure
- Dry ore has a lower cost of haulage
- Dry blast holes enable the use of lower cost explosive and generally achieve enhanced fragmentation
- Dry conditions help reduce the health and safety risk.

Figure 1 *Operational impacts of wet mining conditions*

In most cases dewatering is achieved through the use of vertical in-mine wells which are pumped to reduce groundwater levels ahead of mining, thus creating the dry working conditions. However the use of in-mine vertical wells can face a number of challenges, including:

- Well infrastructure, including power supply lines and pipelines, may interfere with mining operations
- Access restrictions due to mining activities to the dewatering infrastructure can result in significant downtime when trying to schedule repairs
- Space constraints within the pit mean that it may not be possible to site dewatering wells in the optimum location from a hydrogeological perspective
- Dewatering wells may result in the sterilization of ore, or as more often occurs mining of that ore will result in the destruction of the dewatering well.

The impact of these operational constraints on dewatering programmes mean that:

- Dewatering wells are frequently mined out and new wells need to be drilled, and dewatering infrastructure (pumps and pipelines) is repeatedly moved around the operation
- Dewatering wells do not operate at their optimum efficiency and therefore the dewatering programme is not as effective as it could be, resulting in wet operating conditions
- The use of vertical wells means that vertical structures, which may be controlling groundwater flow, are not intersected thus reducing the effectiveness of the dewatering programme.

In order to address the issues highlighted above Schlumberger Water Services (SWS) has developed its Dewatering Well Placement technology (DWPt). The approach integrates Schlumberger technology and expertise in subsurface characterization and well placement, developed through its position as the world's leading service provider to the Oil and Gas industry, with SWSs industry recognized expertise in mine dewatering (McCartney and Anderson 2015). Dewatering Well Placement technology has been developed over a 5 year period, backed by both SWS and industry funding, and has taken the approach from pilot trials, through proof concept and into operational implementation.

Directional Well Placement technology

Although directional well placement is commonplace in the oil and gas industry, it has been little used in mining apart from some specific coal mine fluid management applications, general related to Coal Bed Methane extraction. Its application in the hard rock geologic environment associated with most ore deposits provides many new challenges which need to be addressed. Central to development of DWPt has been the evaluation of the applicability of different drilling, surveying, measurement and well completion technologies to the mechanical and hydraulic constraints of different ore deposit settings. In order to ensure that DWPt offers the best dewatering solution for a given mine, SWS has developed an evaluation workflow which is implemented prior to initiation of any drilling programme. The workflow includes:

- A hydrogeological assessment of the suitability of DWPt to dewater the mine. This assessment reviews:
    - Ability of DWPt to intersect the main water bearing horizons and/or structures. DWPt provides a hydrogeological advantage where either vertical structures or lithologies act as conduits for groundwater flow, or where groundwater is compartmentalized by low permeability barriers to flow, such as dykes or sealed faults
    - A key advantage of DWPt is that the dewatering well is placed outside the final pit shell. However the well must be able to dewater the current pit and therefore understanding the hydrogeological connection between the current mining level and the DWPt trajectory is vital
- The directional well trajectory is designed with the objective of attaining the best possible hydraulic contact between the well and the ore deposit and is based on review and analysis of permeable fracture distributions inferred from fracture frequency, RQD and water strike data for the mine (Figure 2)
- The technical feasibility and cost associated with drilling and completing different trajectories needs to be assessed:
    - The time required to drill the well is a key control on overall costs as it will determine the time that the drill rig, plus associated directional drilling equipment and key staff, are onsite. Selection of appropriate drill bits and motors to help maximize Rate of Penetration (ROP) is a key element of the design
    - The design build up rate (BUR) of the well trajectory needs to balances the requirement to intersect specific hydrogeological targets and/or achieve a specific Total Vertical Depth (TVD) against the ability to install the completion, particularly the Electrical Submersible Pump (ESP), within the well
    - Measurement while drilling (MWD) is key to the ability to steer the well and to ensure that it intersects the horizons/structures that have been identified as controlling groundwater movement in the pit and reaches the targeted position beneath the final pit
- A comprehensive cost benefit and risk analysis is undertaken comparing both CAPEX and OPEX of the traditional in-mine approach to DWPt, as well as the risks associated with implementing a new drilling and dewatering approach at a particular mine site.

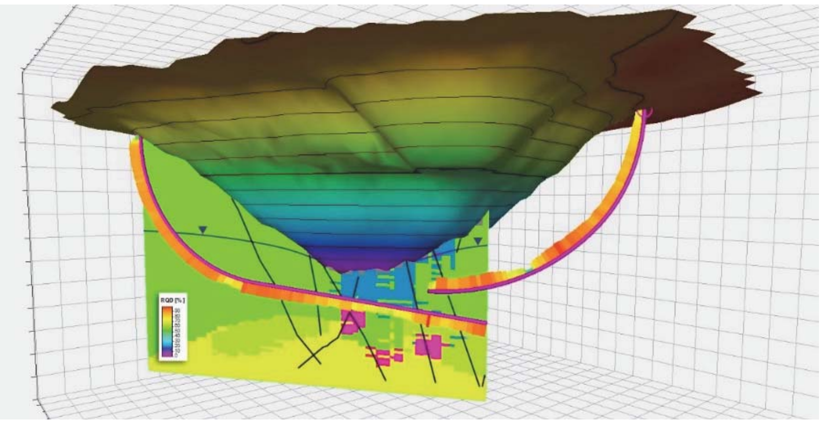

Figure 2 *Sub-surface geo-mechanical and fracture evaluation and simulation as part of dewatering well placement design process*

To date DWPt wells have been implemented at open pit mines in the USA and Mexico, while evaluation of its use is currently underway in a number of varying geological and geographical settings across the globe. Dewatering benefits that have already been reported from the first DWPt well include (Dowling and Rhys-Evans 2015):

- The well yield is five to ten times greater than previously installed in-mine wells
- The well was immediately commissioned into the active dewatering program and utilisation during its initial year was close to 100%
- The combination of its high production rate and year-long uninterrupted operation meant that it effectively produced two orders of magnitude more groundwater than any of the pre-existing in-mine vertical wells and it exceeded the combined groundwater production from the rest of the dewatering system, comprising six vertical production wells
- Drawdown of water levels was significantly enhanced in the pit area in response to operation of the DWPt well (Figure 3).

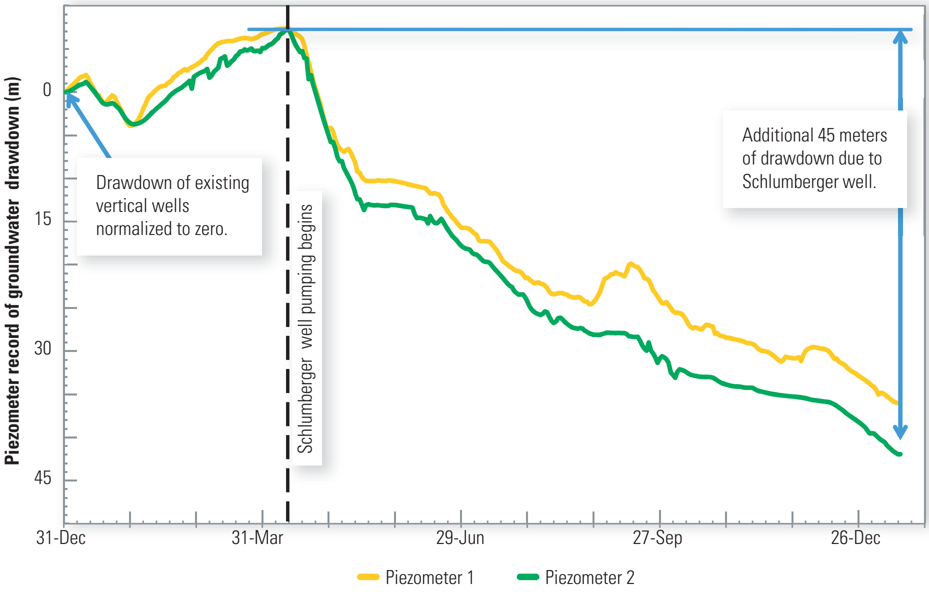

Figure 3 *Enhanced drawdown associated with implementation of a DWPt well at an open pit copper mine in North America*

Case study of DWPt evaluation: Sishen Mine, South Africa

GR35 project

The use of DWPt for dewatering the GR35 pit at Kumba Iron Ore's (KIO) Sishen Mine in the Northern Cape Province of South Africa was assessed from an initial pre-feasibility assessment of its hydrogeological benefits through to a fully costed design for implementation, with associated cost benefit and risk analysis. Application of the DWPt evaluation workflow to Sishen Mine allowed a number of aspects of the workflow to be further developed, including:

- The mine sites at which DWPt had been implemented in the USA and Mexico were located close to areas of O&G activity and therefore the service support required for implementation of DWPt was close at hand. The GR35 project tested the technical and cost risk associated with implementing DWPt in a mining area which is remote from O&G bases
- Specific "lessons learnt" from implementation of DWPt at other sites were evaluated within the Sishen project, in particular design elements around ROP/drill bit selection and borehole cleaning.

Background

Iron ore in the GR35 pit lies below the water table and is effectively sterilized without dewatering. Based on the mine plan the pit floor was to be lowered by 100m in approximately 15 months. The GR35 pit has been dewatered using vertical in-pit wells, however operational constraints meant that dewatering well utilization was approximately 60-80% (Nel 2015). The constrained nature of the pit also meant that wells are mined out quickly and there is limited space to site new wells, an issue which would become more prominent as the pit deepens and the pit floor area decreases.

An analysis of available hydrogeological data showed that:

- The size and frequency of water strikes was highly variable across the lithologies onsite
- Faults and diabase dykes result in compartmentalization of the groundwater system with stair stepping of water levels occurring across structures
- Major water strikes are associated with subvertical faults.

Dewatering wells target vertical faults but 2-4 dry wells were being drilled for each well that intersected a high yielding structure.

The aims for the DWPt well were:

- Placement of the wellhead on the pit rim and outside the final pit footprint
- Development of a DWPt trajectory that intersected permeable fractures beneath the final pit shell
- Placement of the pump at a depth below the final pit elevation such that water levels could be drawdown below the final pit floor.

Schlumberger's Petrel software was used to investigate the feasibility of different well trajectories for dewatering the GR35 pit. A hydro-geological conceptual model of the GR35 pit was developed in Petrel using:

- The Sishen geological block model
- The structural model for the GR35 pit, which showed the location of the main faults within/adjacent to the pit
- Water strike flow rate data; RQD data: An RQD block model, based on the same block size as the geological model, was developed for the GR35 pit using data from the Sishen geotechnical database.

A Petrel "plug in" allowed different well trajectories to be developed within the block model by varying the azimuth, inclination/BUR and metres drilled for different sections of the proposed borehole. The location for the wellhead, which was sited outside the final pit rim, was selected in consultation with the mine to optimise access to surface infrastructure including power and water pipelines. The well trajectory was then modified to review its feasibility with respect to a number of criteria, including:

- A maximum BUR of <6° per 30 m
- The production zone should extend below a final pit floor elevation of 862.5 masl
- The trajectory should avoid drilling along lithological contacts where possible as core data shows the rock quality to be poor along these boundaries
- Maximise drilling within the dolomite (DOL) units over the harder/more abrasive chert (MM/CH)/banded iron formation (BIF)/hematite (HEM) units
- Maximise the intersection of the well with zones of known or probable high groundwater flow, based on measured water strikes and RQD.

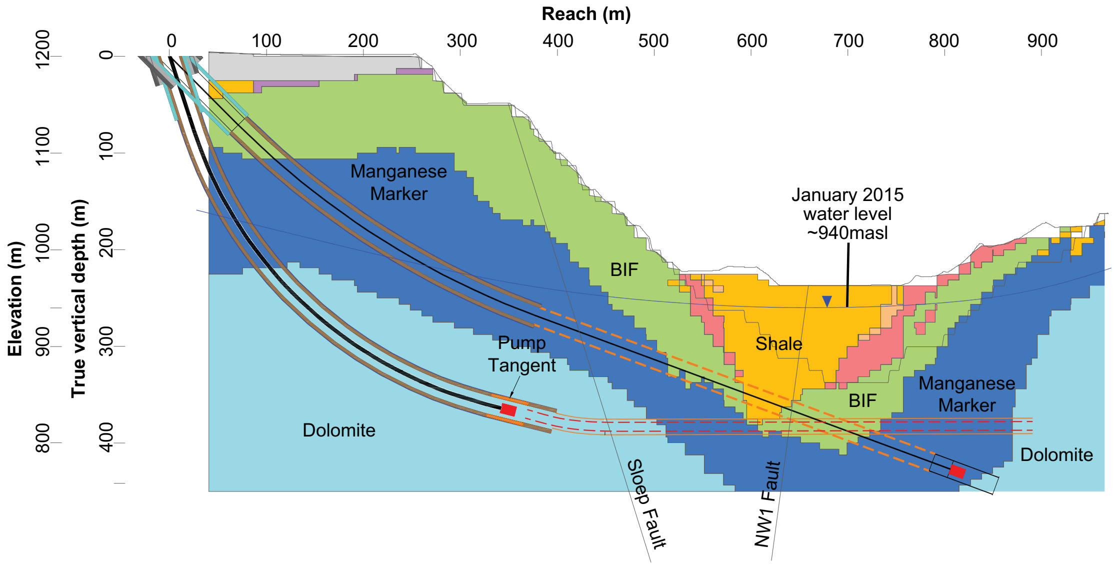

Figure 4 *DWPt well trajectories evaluated for dewatering of GR35 pit, Sishen Mine, South Africa*

The lithologies present at Sishen have UCS values which are significantly higher than those typically encountered during directional drilling in the oil and gas sector, or those encountered in previous DWPt projects executed in copper and gold mines in North America. As a result it was identified that selection of appropriate drill bits was a key project risk, as low Rates of Penetration (ROP) caused by use of inappropriate bits would significantly increase the time required to drill the well, and therefore the costs associated with rig and personnel hire.

In order to minimize the risk associated with this element of the programme the Smith IDEAS Laboratory in Houston, Texas was commissioned to carry out a series of tests on representative lithological samples from the Sishen mine in order to have site specific data available which could be used to evaluate the likely performance of different designs of drill bits. Samples of BIF, HEM, together with core samples of DOL and CH were sent to the testing laboratory (Figure 5). A series of tests were carried out to provide data on the effectiveness of standard Tungsten Carbide Inserts (TCI), commonly used on rollercone bits, and Grit Hot-pressed Insert (GHI) elements, commonly used on full-face Impreg bits. Drilling tests were carried out in the laboratory to assess the impact on ROP of varying the diamond size, concentration and substrate hardness in the GHI Insert.

Figure 5 *Laboratory drill bit testing of Sishen lithologies*

The laboratory test data were input to the Schlumberger Integrated Drillbit Design Platform (IDEAS) simulator to model ROP and select bits based on the lithologies and drilling diameters for the planned well trajectory. It should be noted that ROPs decrease by up to 70% during directional drilling (when building angle and sliding) and a correction factor is required to be applied for directional drilling sections when estimating total drilling time.

Cost benefit analysis

A cost benefit analysis was carried out to compare the cost associated with ongoing use of vertical in pit wells, and the cost associated with developing a dewatering programme based on implementing the DWPt well as designed for GR35. The cost benefit analysis compared both the Capex and Opex costs associated with implementation of the two different approaches, and also aimed to put a cost on the intangible benefits that will result from being able to implement the dewatering programme from outside the operational pit. The direct tangible costs compared for both approaches to include:

- Drilling costs associated with a DWPt well and the cost of drilling vertical wells which will provide the equivalent dewatering rate
- The cost of completing the two dewatering options, including the cost of casing the wells, installing pumps, connecting the pumps to both a power supply and into the water reticulation network
- Electricity costs for operation of both types of dewatering network
- Wet mining costs associated with ineffective dewatering based on site experience and data, including potential loss of revenue where benches cannot be mined.

Key intangible benefits which would result from implementing a DWPt approach to dewatering include:

- Reduction of interference to the mining operation and improvement of pit traffic movement due to removal of dewatering operations from the pit
- Improved in-pit operational conditions and ore recovery due to dewatering occurring in advance of mining
- Reduction in step outs, drilling pads and general space preparation and maintenance for in-pit dewatering infrastructure

- Simplified mine planning due to removal of the need to incorporate dewatering infrastructure and maintenance in pit
- Addition of 'ore body knowledge' gained from the information gained from the directional well trajectories, particularly with respect to the ore body beneath the current pit floor.

Although direct costs were easily compared, with those for the existing dewatering programme being available from the mines annual budget, and the costs for implementing the DWPt being compiled as part of evaluation workflow, intangible benefits are less easy to assign a cost saving to.

Conclusions

Implementation of DWPt at mines in the USA and Mexico has shown that these wells can provide a step change in dewatering impact through both increased yields from individual wells and utilization rates which approach 100%. The ability to site DWPt wells outside the final mine footprint, while at the same time placing the well production zone such that it can dewater the final pit shell, provides additional benefits in terms of reduced interference with mining from dewatering activities and development of dry conditions ahead of mine development.

The applicability of DWPt for dewatering the GR35 pit at Sishen iron ore mine, South Africa was evaluated using the workflow developed by SWS. The project provided the opportunity to assess the technical and financial challenges associated with implementing DWPt outside of North America, while specific aspects of the engineering design, including drill bit selection, were focused on based on "lessons learnt" from DWPt implementation at other sites.

Evaluation of DWPt showed it to be an appropriate approach for dewatering the GR35 pit, while the engineering design also demonstrated that it was technically feasible to complete the DWPt well within the high strength rocks present at Sishen. The risk analysis indicated that the mine location required significant contingency to be built-in to the availability of drilling equipment which had an associated impact on the cost of implementation. The cost benefit analysis indicated that the DWPt provided a viable alternative to the use of vertical in-mine wells. The cost benefit of DWPt was shown to increase the longer it operated, and was therefore considered to provide the greatest benefit where a greater Life of Mine remained.

Acknowledgements

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