

## **DEVELOPMENT OF HYDRAULIC FRACTURING IN HIGH STRESS CONDITIONS IN AUSTRALIAN UNDERGROUND COAL MINES**

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### **ABSTRACT**

Hydraulic fracturing has been used extensively in the petroleum and coalbed methane industries as a means of improving access to the reservoir and thereby enhancing production. In the Australian coal mining industry there has been an aversion to the use of hydraulic fracturing. One of the main reasons for the lack of application of this technology has been the perceived risk of damage to the strata and the resulting impact on future mining operations. A number of Australian mines are progressing toward areas where gas drainage is becoming increasingly difficult and these mines are seriously considering the use of hydraulic fracturing. In several cases where the use of hydraulic fracturing was trialled in mines operating in the Southern Sydney Basin the technique was found not to be effective due to the impact of wellbore damage. The damage caused by the high insitu stress conditions prevented the use of borehole straddle-packers, used to isolate sections of the borehole to enable hydraulic fracturing to be undertaken. This paper discusses the development of a method of borehole casing that enabled the application of hydraulic fracturing.

### **INTRODUCTION**

Hydraulic fracturing (HF) is a method of stimulating gas production through the injection of fluid under pressure into the coal formation to create fractures. The fractures, that are typically held open through the use of a proppant material, carried into the fractures by the injected fluid, increase the effective surface area of the borehole and improve the connection to the gas bearing reservoir.

The application of HF to coal mine gas drainage improvement is not commonly used in Australia, with the majority of gas drainage being achieved through the use of underground-to-inseam (UIS) and more recently, the development of surface-to-inseam (STIS) drilling technologies. A number of Australian mine sites have been involved in the trial and development of HF stimulation through vertical wells. These mines include Central (QLD),

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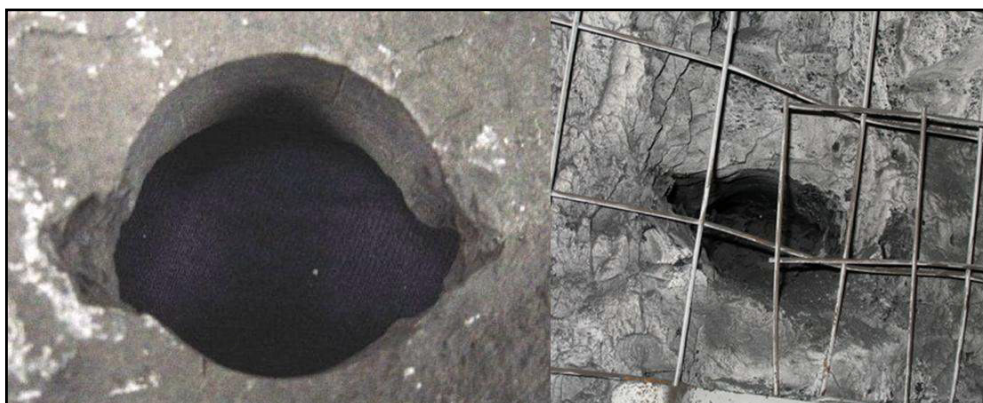
Appin (NSW), Munmorah (NSW) and Dartbrook (NSW) mines (Jeffrey *et al.*, 1992 and 1998).

Concerns have been raised by Australian mine operators regarding the impact of HF on future mining conditions. There have however been many investigations into the impact of HF on mining, primarily in the US, with several investigations in Australia. Jeffrey *et al.* (1998) found that mining was not adversely affected in areas that had been hydraulically fractured at Appin, Munmorah and Dartbrook. Diamond (1987) discusses the results of mine-troughs of twenty-two separate stimulation treatments at mines in the US. From these assessments it was concluded that, although in some situations the injection fluid had penetrated overlying coal beds through pre-existing joints and openings, there were no roof falls or adverse mining conditions attributable to the stimulation treatments. Diamond further concluded that although it was not possible to guarantee no adverse mining impact from stimulation treatment, the use of pre-stimulation strata characterisation testing and informed treatment design, along with controlled implementation, significantly reduces the chance of creating adverse mining conditions.

A number of trials have been carried out to extend the application of HF to horizontal boreholes. The Queensland Department of Mines undertook trials of HF underground at the Haenke Colliery in 1979-80 however no successful fractures were created (Croft, G. A., 1980). A hybrid system was trialled at Central Colliery in 1996 which involving HF equipment located on the surface, injecting fluid and proppant into a horizontal borehole via a vertical borehole connected to the underground workings. Due to problems associated with coal strength and stress, the injection fluid bypassed the packers and no fractures were successfully created (Jeffrey, R.G., 1999). Further trials at Dartbrook Mine in 2002 resulted in the successful initiation of fractures and increased gas production. This successful demonstration led to the operational deployment of HF at Dartbrook for enhanced gas drainage ahead of mining (Jeffrey, R. G. and Boucher, C., 2004).

Based on the success of the Dartbrook application, a trial of HF was undertaken at Tahmoor Colliery, which mines the Bulli seam in the Southern Sydney Basin at a depth of approximately 500 metres. The high stress conditions encountered at the mine were found to cause wellbore damage, referred to as “borehole breakout”, resulted in the failure of the trial due to the inability to effectively set the straddle-packers used to isolate sections of the

borehole to enable fracturing (Jeffrey, R. G., 2005). Figure 1 illustrates the effect of borehole breakout.



**Figure 1: Examples of borehole breakout.**

## **PHASE 1 – CONCEPT DEVELOPMENT**

The objective of the initial work carried out at the Appin West Colliery (formerly Tower Colliery), as described by Mills *et al.* (2006), was to develop a system capable of successfully casing, cementing and slotting the installed casing to enable conventional HF treatment to be carried out using open hole straddle packers.

This development phase involved the drilling of six separate 50 metre long boreholes using a downhole motor at a nominal diameter of 96mm. At the completion of drilling five of the six holes were logged using the eight arm calliper logging system developed during ACARP Project C12021 (Jeffrey *et al.* 2005). The calliper logs confirmed that the boreholes had broken out horizontally by more than double the as-drilled diameter, for a substantial portion of the measured length, hence supporting the need for casing.

Three separate casing materials were sourced for trial:

- PVC – 84mm OD with 6mm wall thickness;
- Fibreglass – 85mm OD with 8mm wall thickness; and
- Steel – 76mm OD with 3.5mm wall thickness.

The main criteria considered in the selection of the casing material include, cutability by mining equipment, handling and separation in the coal handling and preparation plant, ease and robustness of handling, and the ability to resist external collapse during grouting and hydraulic fracturing.

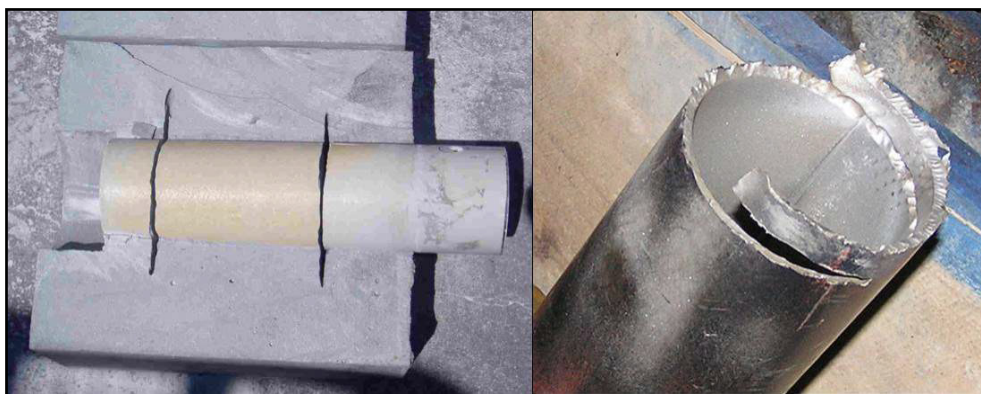
Using a cementing system, designed by Schlumberger Oilfield Services, incorporating an antifoaming agent, a dispersant and a gas block agent the cement mixture was pumped into

the casing at the collar of the hole and pumped down the holes using water. A displacement plug positioned between the cement and the water served as a barrier to separate and prevent mixing of the two fluids. A control valve located at the collar provided a means of maintaining back pressure on the cement during injection to ensure maximum filling of the free space between the casing and the formation was achieved and to limit gas entry into the cement before it cured. Figure 2 shows the displacement plug and the cement head used during the cementing process. Testing of the cementing effectiveness in several cases did confirm the presence of channelling, which is effectively an open void, extending for some distance along the length of the borehole that had not been filled by the cement. The presence of such a channel would provide a path for fluid to pressurise the outside of the casing and allow the HF to initiate some distance from the intended location. Fluid can also flow along such a channel and back into any open slots in the casing, bypassing the packers set inside the casing. Additional cement, reinjected through the casing, successfully filled these remaining voids.



**Figure 2: Displacement plug and cement head used during cementing.**

Following completion of the casing installation and cementing process connection to the coal seam was to be achieved through the creation of a number of separate slots positioned along the length of the casing. High pressure sand-water slurry was used to cut slots through the casing and cement, to create access to the coal seam. Figure 3 provides an example of the slots created through the use of the abrasive jet tool.



**Figure 3: Test slots cut using the abrasive jet cutting tool**

## **PHASE 2 – OPERATIONAL TRIAL**

Following the success of the initial trials support was given to extend the development to include an operational trial of HF incorporated into a standard underground to in-seam (UIS) production drilling program.

### **Trial Site**

The trial was conducted in an un-drilled area of the mine (Mine A) that was off the critical path for drilling and mining operations and had previously experienced gas drainage difficulty. The site was located at the inbye most point of the current mine workings was at a depth of around 500 m below ground and was also the most down-dip point in the panel. It was later realised that the location was problematic and had significant impact on the project in terms of flooding in both the roadway and gas range, ventilation, as the site was inbye of the operating longwall and logistics, due to the site being the maximum distance from pit bottom, and restricted storage work and storage areas. The regional permeability had been determined from step-rate and injection-falloff testing during exploration drilling to be in the order of 2.5mD. The maximum stress is horizontal and orientation in the area of the trial site was approximately 70° from north. This was favourably oriented for HF as the general layout of the trial holes was approximately perpendicular to the stress direction with fracture growth expected to be normal to the borehole axis.

### **Drilling**

A total of four boreholes were planned for drilling in the trial area, however during the trial the standpipe of Hole 4 was damaged, the hole was deemed not viable for HF testing.



A minimum period of 40 days was allowed for the collection of baseline borehole flow readings prior to setting up for, and completing, the HF treatment

**Table 2: Results of coal core gas analysis from UIS boreholes in HF trial zone**

Core Reference	Location Reference	Hole No.	Distance from collar	Content (m3/t)	CO <sub>2</sub> (%)	CH <sub>4</sub> (%)	Date	CH <sub>4</sub> /(CH <sub>4</sub> +CO <sub>2</sub> )	Q <sub>1</sub> (m <sup>3</sup> /t)	Q <sub>2</sub> (m <sup>3</sup> /t)	Q <sub>3</sub> (m <sup>3</sup> /t)	Q <sub>3</sub> /Q <sub>T</sub> (%)	Desorption Rate (ml/min <sup>0.5</sup> /kg)	IDR 30 Index (m <sup>3</sup> /t)
WE1185	519 A33-2	2	40	10.55	86.89	12.62	18/01/07	12.68%	1.05	2.85	6.65	0.63	185.36	1.13
WE1191	519 A33-2	2	80	13.91	54.83	36.42	31/01/07	39.91%	1.55	4.74	7.62	0.55	253.22	1.54
WE1197	519 A33-2	2	120	13.31	60.44	4.91	6/02/07	7.51%	1.61	2.45	9.25	0.69	240.07	1.46
WE1199	519 33A-2	2	160	14.24	55.10	43.86	7/02/07	44.32%	2.44	4.86	6.94	0.49	317.79	1.93
WE1201	519 33A-4	4	40	10.56	58.76	3.03	13/02/07	4.90%	1.17	4.00	5.39	0.51	256.22	1.56
WE1202	519 33A-4	4	80	12.19	72.88	25.65	14/02/07	26.03%	0.88	1.94	9.37	0.77	155.48	0.95
WE1203	519 33A-4	4	120	13.93	59.89	37.91	16/02/07	38.76%	1.31	2.16	10.46	0.75	235.76	1.43
WE1209	519 33A-4	4	179	13.84	75.96	23.60	28/02/07	23.70%	1.11	2.34	10.39	0.75	192.42	1.17
WE1210	519 33A-4	4	200	14.12	79.87	18.59	1/03/07	18.88%	2.73	3.18	8.21	0.58	303.72	1.85

## Fracture Design

A hydraulic fracture is normally initiated when the pressure of injected fluid overcomes the stress concentration and rock strength at the borehole. The length of the fracture is extended by continuing to inject fluid at a pressure that exceeds the minimum principle stress of the formation being treated. Given the high strength and stiffness of the roof and floor rock and the higher stresses which exist above and below the seam it was expected that the fractures produced in the Bulli seam would be completely contained within the coal seam. Also, due to the stress conditions vertical fractures were expected. Through the use of hydraulic fracturing models, CSIRO proposed a treatment design for trial that included a schedule of injection rates, volumes, fluid types and proppant concentrations. The initial treatment schedule proposed by Jeffrey, (2007) for the trial is provided in Table 3.

**Table 3: Proposed initial HF treatment schedule.**

Stage	Volume (litres)	Rate (litres/min)	Duration (minutes)	Sand Concentration (grams/litre)
1	1500	240	6.25	0
2	360	240	1.5	100
3	480	240	2.0	0
4	360	240	1.5	100
5	480	240	2.0	0
6	360	240	1.5	100
7	480	240	2.0	0
8	0	0	2.0	Shut in
<b>Totals/Ave</b>	<b>4020</b>	<b>240</b>	<b>18.75</b>	<b>108 kg added</b>

It should be noted that the cyclic nature of the proppant (sand) injection was dictated by the design of a Sand Adder unit, used to inject proppant on the high pressure end of the fluid injection pump. In this trial a single prototype sand adder was used, which necessitated

regular refilling during the injection process. Throughout the course of the trial, data was collected by logging the injection pressure and manually recording the volume of sand added. This data allows history matching of the treatments with the models in order to check and recalibrate the model to develop a more optimal design.

## **Operational Phase**

### *Hole No.1*

An attempt to install a piezometer in Hole No 1 was unsuccessful. The conduit carrying the grout split a short distance inbye of the standpipe and the installation failed. This resulted in the borehole being abandoned. No further attempts were made to install a piezometer to monitor the trial.

### *Hole No.3*

Allowance was made in the program to test the operation of the equipment in a hole. Hole 3, a short 50 metre hole, was a sacrificial hole that was used to carry out system testing for a complete cycle of casing installation, cementing, slotting, and fracturing. The objective was to ensure that all of the equipment and processes were operating to plan, prior to moving into the full operational testing on Holes 2 and 4.

The testing in Hole 3 was considered successful, with all equipment functioning satisfactorily. It was however necessary to reinject cement into the borehole to address some channelling which had resulted from the initial cement injection. The cement mix quality was adversely affected by lumps in the dry cement and this affected the overall performance of the cementing operation. This problem was solved by using fresher cement for the remaining holes, with much improved cement quality.

### *Hole No.2*

At the completion of Hole 3 the drill rig was repositioned in line with Hole 2 and the hole was flushed for the full 160 metre length to remove any accumulated fines. The casing was then inserted into the borehole, followed by cementing. A total of 2,100 litres of cement was used in the cementing of this borehole. After curing, the end of the borehole was drilled out followed by well-testing and step-rate testing. The following reservoir data was determined from this testing:

- Permeability ~ 0.6mD

- Fracture initiation pressure ~16-18MPa
- Fracture extension pressure ~8-10MPa

Slots were then cut through the casing at 142.7 m and 87.7 m using the abrasive jet tool. Two fractures were then created through these slots. Details of these fractures are listed below:

- HF#1 142.7 m – 22 MPa injection pressure, 140 kg sand deposited
- HF#2 87.7 m – 27 MPa injection pressure, 90 kg, sand deposited

At the completion of the fracturing at 87.7 m the hole was effectively blocked preventing the packer set from being advanced inbye of this point.

Additional slots were then cut through the casing at 82.7<sup>c</sup>m, 77.7<sup>a</sup>m, 72.7<sup>c</sup>m, 67.7<sup>a</sup>m, 62.7<sup>c</sup>m and 57.7<sup>a</sup>m. Fracturing was then completed through the slots at 82.7m and 77.7m. The details of these fractures are:

- HF#3 82.7 m – 27 MPa injection pressure, 70 kg sand deposited
- HF#4 77.7 m – 31 MPa injection pressure, 40 kg sand deposited

Following the fourth fracture the packer set became stuck in the borehole at 77.7 m and was not able to be recovered.

The investigation into the blockage concluded that the casing had deformed such that it effectively locked the packer set in the borehole. Finite element modelling of steel casing with 3.5 mm wall thickness determined that an unconfined casing of this type has a collapse pressure of 12.7 MPa.

The following actions arose from the investigation:

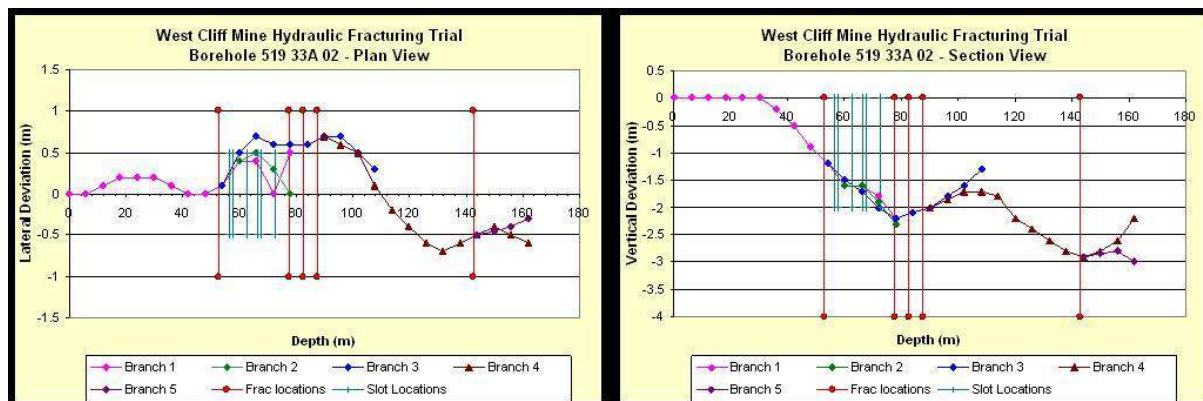
- No further axially oriented slots to be cut through the casing and all existing axial slots shall be abandoned and not used for HF;
- Only circumferentially oriented slots to be cut through the casing;
- Injection pressure to be limited to less than 30 MPa; and
- Controlled flow back and pressure release at the completion of HF treatment.

Additional circumferential slots were then cut at 66.4<sup>c</sup>m, 56.4<sup>c</sup>m and 52.7<sup>c</sup>m. Fracturing was then completed at 52.7 metres, requiring 26 MPa injection pressure with 100 kg of sand deposited. The casing was found to be damaged at 53.9 metres, preventing access to treat the inbye slots. Hole 2 was then abandoned.

A thicker walled casing was sourced for use in the second HF trial hole to reduce the risk of casing failure and to allow successful HF treatment and assessment of potential drainage

improvement benefits. Figure 5 provides details of Hole 2, as surveyed, along with the location of the various slots and fractures created in the borehole.

A summary of the fractures created in Hole 2 are listed in Table 4.



**Figure 5: Hole 2 details and slot / fracture location**

**Table 4: Hydraulic fractures created in trial hole 2.**

Number	Position (m from collar)	Date	Water Volume (litres)	Pumping Time (minutes)	Sand (kg)	Average Pressure (Mpa)
1	142.7	6/06/07	8,500	40	140	22.0
2	87.7	12/06/07	4,800	20	90	27.0
3	82.7	15/06/07	8,000	40	70	27.0
4	77.7	18/06/07	6,800	30	40	31.0
5	52.7	5/07/07	9,000	70	100	26.0

Note: Water volume for fractures in hole 2 is approximate since pump did not produce full 240 lpm during entire frac period because of recirculation through pressure relief valve fitted.

### *Hole No.4*

The presence of water in boreholes has for some time been thought to be a significant impediment to effective gas drainage, particularly in zones of increased CO<sub>2</sub> composition. Clark, D. *et al.* (1983) investigated a range of factors for the purpose of increasing gas drainage at Metropolitan Colliery. Clark emphasised the point that suitable dewatering systems must be provided and maintained to protect the boreholes from blockages in order to achieve optimum flows to the gas range.

During the period of treatment in Hole 2, a dewatering system was established in Hole 4, to clear accumulated water, and assess the impact of water on gas drainage performance.

Whilst the cement was curing in Hole 2, the drill rig was repositioned in line with Hole 4 and used to clear accumulated fines and install a dewatering pipe into the borehole.

In the course of working in Hole 4 the standpipe was damaged. An assessment of repair options concluded that Hole 4 was no longer viable for use in the HF trial. Hole 4 was then set up for ongoing dewatering and gas flow monitoring to assess the relative benefit of borehole dewatering.

There were many occurrences throughout the trial where the gas range was found to be full of water. This water not only filled the gas range but also flowed through the connecting hoses and filled the drainage boreholes at the trial site. The water impact was not isolated to the trial site and many other drill stubs at the inbye end of the panel were affected in the same way. Investigation into the source of the water determined that the primary source was from UIS drill rigs, where drilling fluid was being lost into adjacent boreholes which were open and connected to the gas range.

### *Hole No.5*

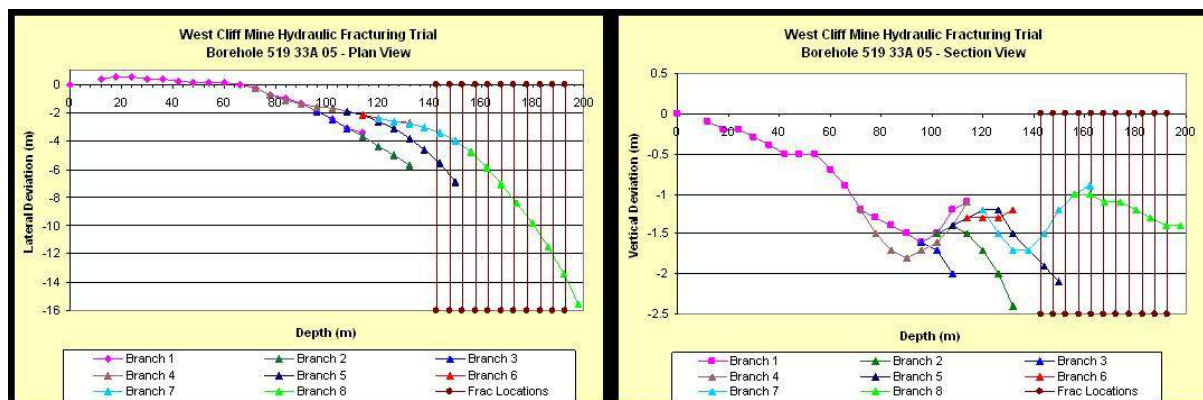
At the completion of work in Hole 2 the drill rig was repositioned in line with Hole 5 and the hole was flushed for the full 210 metre length to remove the accumulated fines. Casing, with an increased wall thickness of 6.5 mm, was installed in Hole 5 in an attempt to avoid any recurrence of the problems encountered in Hole 2. Finite element modelling determined that the unconstrained collapse pressure of the 6.5 mm wall thickness casing was in the order of 29 MPa. Following the insertion of the casing, the borehole was cemented. A total of 2,900 litres of cement was used in the cementing of this borehole.

Slots were cut through the casing, using the abrasive jet tool, followed by hydraulic fracturing. Fractures were then created in the coal seam through each of these slots. Details of the fractures are listed in Table 5.

**Table 5: Hydraulic fractures created in Hole 5.**

<b>Number</b>	<b>Position (m from collar)</b>	<b>Date</b>	<b>Water Volume (litres)</b>	<b>Pumping Time (minutes)</b>	<b>Sand (kg)</b>	<b>Average Pressure (Mpa)</b>
1	172.5	9/08/07	8,400	35	165	23.5
2	152.7	10/08/07	8,400	35	100	23.2
3	192.7	14/08/07	11,500	48	125	22.5
4	182.9	15/08/07	10,100	42	140	23.2
5	162.7	15/08/07	8,900	37	130	23.5
6	142.7	16/08/07	9,400	39	110	23.0
7	187.67	27/08/07	8,400	35	65	21.0
8	177.67	28/08/07	8,400	35	90	25.0
9	167.67	28/08/07	6,700	28	70	27.0
10	157.67	28/08/07	6,700	28	70	25.5
11	147.67	28/08/07	5,500	23	5	23.5

Figure 6 provides details of Hole 5, as surveyed, along with the location of the various slots and fractures created in the borehole.



**Figure 6: Hole 5 details and slot / fracture location**

## DISCUSSION

Throughout the course of this project the trial site was adversely impacted on many occasions by inundations of water that resulted in flooding of both the face area, where the equipment was positioned, and the gas reticulation range and drainage boreholes. Significant time was lost recovering from these occurrences. Improvements were made which reduced the frequency and severity of such events in the latter stages of the project.

The impact of the water and fines, which flooded the drainage boreholes, is not yet fully understood. It is however known that the reservoir in the trial area is significantly undersaturated and it is therefore necessary for the water within both the borehole and surrounding formation to be removed before any reasonable gas flow can be expected.

### *Borehole Casing*

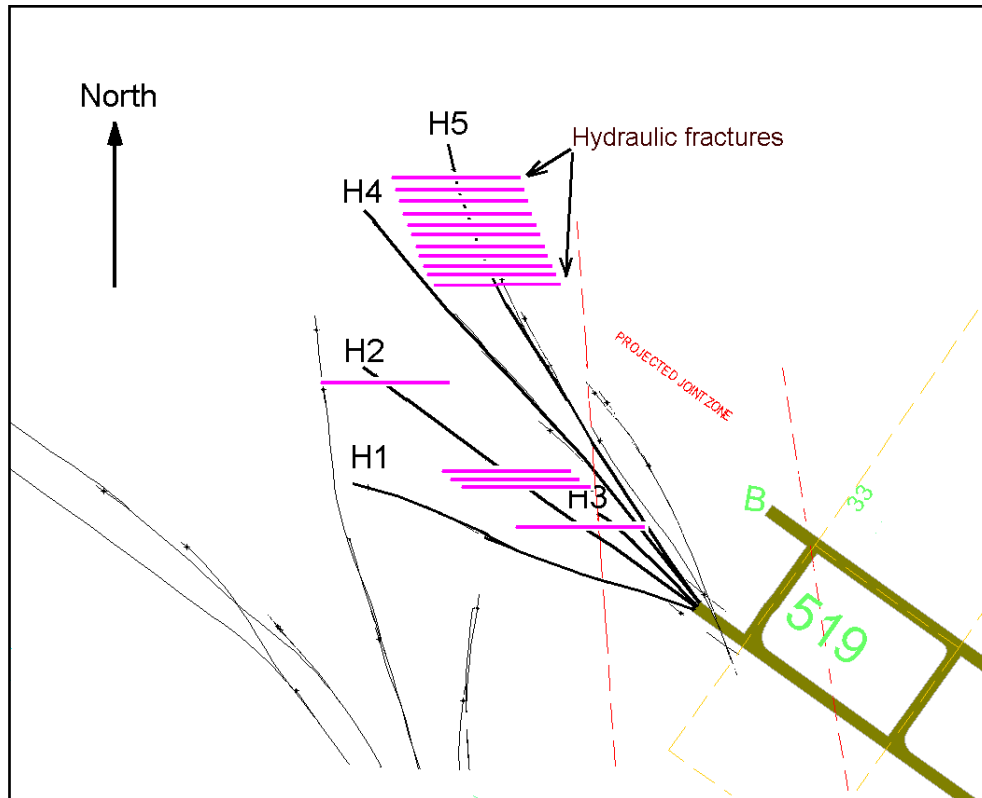
The project was successful in developing and refining a system for installing and cementing casing into a borehole which had sustained substantial breakout and internal failure.

By casing the borehole, a condition was provided that enabled the use of straddle packers to isolate sections of the borehole for HF treatment.

Initially a steel casing with 3.5 mm wall thickness was used to case Hole 2. Problems were encountered during the fracturing of Hole 2 which ultimately resulted in the loss of a packer set in the borehole which could not be recovered. Although the exact reasons and mechanism for failure are not known it was decided to increase the wall thickness of the casing to 6.5 mm to reduce the risk of further casing failure.

## Hydraulic Fracturing

A total of 16 fractures were created during the trial, 5 in Hole 2 and 11 in Hole 5, as shown in Figure 7.



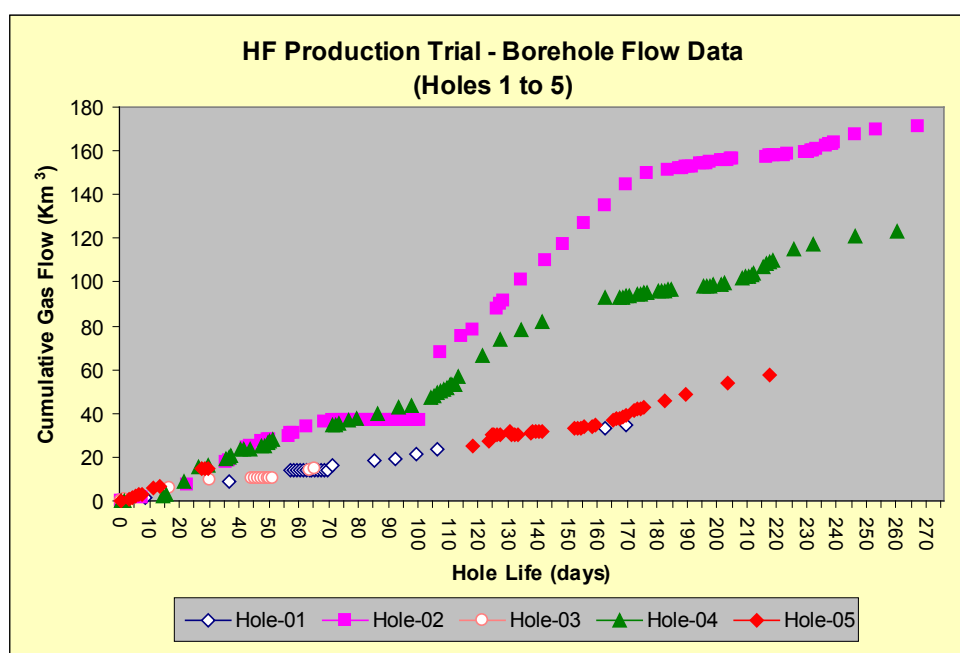
**Figure 7: Location of fractures created in trial boreholes.**

Initial gas flow rate measurements, using orifice plate meters, from the boreholes prior to casing and fracturing found that an average flow rate of 560 m<sup>3</sup>/day was sustained for 50 days, after which the rate began to slow. The installation of casing and the HF treatment in Hole 2 began 97 days after the drilling of the borehole had been completed. The preparation and treatment of Hole 2 continued for 61 days during which time slotting and fracturing was undertaken. At the completion of work on Hole 2, which ended prematurely due to several casing failures and eventual loss of a packer set in the borehole, flow monitoring resumed. Post treatment, the gas flow rate increased to 1,223 m<sup>3</sup>/day, more than double the pre-treatment rate. This flow rate was sustained for approximately 70 days before reducing to approximately 200 m<sup>3</sup>/day.

Following the drilling of Hole 5 flow monitoring commenced and it was soon found that a lack of physical separation between Hole 5 and the adjacent Hole 4 was resulting in the cross-flow of gas and water between the 2 boreholes. The pre-treatment gas flow rate from Hole 5

and Hole 4, following the commencement of drilling in Hole 5 until the casing of Hole 5 was complete, was therefore deemed to be unreliable and not representative of actual borehole flow. The installation of casing and the HF treatment in Hole 5 began 78 days after the drilling of the borehole had been completed. The preparation and treatment of Hole 5 continued for 49 days during which time slotting and fracturing was undertaken. At the completion of work on Hole 5 flow monitoring resumed. The average post treatment gas flow rate from this borehole was 342 m<sup>3</sup>/day, less than the average initial rate observed from other holes during the first 50 days of production.

The results of the gas flow monitoring from the boreholes in the trial, shown in Figure 8, show a large difference in post-treatment production between Hole 2 and 5. Some concern has been raised regarding the accuracy of the flow measurement due to the regular water inundations at the site and within the boreholes. However, within the constraints of the site and the equipment, the measurement process remained relatively consistent and the results are considered to provide an indication of the difference in drainage rate prior to and following HF treatment.



**Figure 8:** Gas flow monitoring results from Mine A HF production trial site.

### *Borehole Dewatering*

An attempt was made in Hole 4 to determine the impact on gas drainage performance by dewatering the borehole. Initially, the drill string was inserted into the borehole and used to drain water accumulations. Later, a steel conduit was sourced and inserted into the borehole to

replace the drill string, which was required for use in the attempted redrilling and recovery of Hole 1.

Due to the site not being manned every shift the hole refilled regularly with water. Dewatering of the local gas reticulation range, all connecting hoses and Hole 4 was carried out by the project team daily, whilst the site was manned, during the trial.

The results of the gas flow monitoring show that following the casing installation in Hole 5 and separation of the two holes that the production rate increased to 1,200 m<sup>3</sup>/day, more than double that recorded pre-treatment and similar to the post-stimulation flow measured in Hole 2. This increased rate was only sustained for some 30 days prior to reducing to an average 533 m<sup>3</sup>/day, as measured at the end of the HF trial. Although flow measurements have continued post-trial, no dedicated site resources were available to continue the regular management and clearing of the water accumulations from the gas range, hoses and borehole. The results do however show longer term flow rates greater than both of the stimulated boreholes.

## CONCLUSIONS

This project has demonstrated the ability to successfully case and cement a number of UIS gas drainage boreholes, which had sustained significant wellbore damage due to the high vertical stress conditions. Contrary to expectation, HF stimulation of these boreholes, through slots cut through the casing, did not yield the significant gas production increases.

The use of casing to overcome borehole integrity problems effectively halts gas drainage from the borehole until such time as connection to the formation is re-established, through slotting and fracturing.

Of the two boreholes cased and fractured during this production trial, one achieved a gas production rate more than double that recorded prior to the treatment, whereas the second hole recorded a post-treatment flow less than that recorded prior to treatment.

Casing collapse, slot orientation, fluid pressure release rate at completion of injection and injection pressure were found to impact the HF process. Changes made to the injection pressure (maximum 30 MPa), casing wall thickness (3.5mm to 6.5mm), slot orientation (circumferential instead of axial) and controlled pressure release rate post-treatment improved the HF treatment.

The relatively remote location of the trial site within the mine created challenges to the project in terms of men and materials transportation, as well as available storage locations for the many pieces of equipment and materials required to undertake the casing, cementing and fracture work.

The trial site itself presented some inherent challenges. The lower point location of the trial site presented problems in terms of water management, both from water flowing into the working area, and into the drainage boreholes through the gas reticulation range. The same challenges may present similar problems in future UIS HF operations.

For many mine the design of the UIS drilling program incorporates holes spacing of less than 25m. In such cases, HF becomes far less efficient as only short fracture distances (maximum fracture half-length of 25m) are able to be achieved. The impact is far more pronounced in situations where borehole breakout occurs and the borehole requires casing and therefore prevents drainage of water and gas from the formation into the borehole until slots and fractures are created.

To achieve maximum benefit from the use of UIS-HF there is a need for specific drilling patterns, which essentially consist of increased spacing between boreholes, which are parallel and oriented approximately normal to the direction of maximum horizontal stress. HF will not be successful in areas that have been previously drilled with a high density UIS pattern.

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