REVIEW OF INSEAM DRILLING PRACTICE

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Review of Inseam Drilling Practice

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Summary

It has long been recognised that current inseam drilling practice in Australia has serious limitations and likely results in higher than necessary costs to mining operations. Failed boreholes due to “boggy ground” and poorly performing individual borehole drainage are a common feature of the current inseam drilling scene. Major weaknesses associated with current practice include:

- Lack of balance control during drilling.
- Limited geosteering and logging capability.
- High ‘lost-in-hole’ risk.
- Limited ‘well completion’ approach to optimise drainage.
- Safety issues associated with manual rod handling.

A number of these issues can be addressed by removing the predrainage function ‘out of the pit’, to surface using medium radius directional drilling technology (MRD SIS). Although this methodology has proved popular in recent years, a commitment to MRD SIS will not preclude many operations from doing supplementary inseam drilling, and for others, surface access issues will mean that the vast majority of inseam drilling and drainage will still need to be carried out underground. It is clear that inseam drilling will remain an important part of mine gas drainage for safety and production purposes for the foreseeable future.

In addition, the problems associated with current inseam drilling practice are only likely to be exacerbated by higher reservoir pressures, and “softer” structurally disturbed coal, all of which can be expected as mining goes deeper, and works in more challenging terrains.

A step change approach is required for inseam drilling practice that addresses the major issues listed above. The best and most practical solution with a chance of fast tracking appears to be Coiled Tubing Systems (CTS), which may be adapted from mature conventional oil and gas practice. The CRC Mining is already advanced in developing a CTS prototype for underground inseam drilling and drainage, and it is recommended that this project be further supported by industry.

Development of a newly developed CFD model for simulation of gas release from coal through inseam horizontal boreholes has been achieved using the common CFD code FLUENT. The model operates as a two phase flow regime and the gas phase is considered compressible. Instead of treating gas flow as concentration driven diffusion (the conventional approach) gas release is dealt with as a mass source. A relatively simple but innovative equation is derived to describe the generation rate for the gas source according to the gas content – pressure isotherms. The simulation illustrates the procedure of gas release and the development of flow variables within the coal seam and the borehole, which assist in providing an improved understanding of the mechanism of gas release and borehole flow.
1 Introduction

This project's objectives are twofold: to critically review the state of the art in underground inseam drilling practice and improve the understanding of key aspects of gas flow performance from individual boreholes. The project also aims to identify potential solutions to underground drilling practice problems as a pointer towards future research directions. The need for such a project is predicated on the recognition that inseam drilling practice in Australia:

- Has changed little in the past 20 years,
- Represents a major cost to those underground operations mining gassy coals,
- That this cost is likely to increase as seams are mined in deeper and more challenging geological environments,
- May be only partially effective in draining gas, due to issues related to drilling practice and completion (including the issue of “over-drilling” and redundancy).
- In current form is inappropriate for solving problems of soft coal,
- Will (generally) be likely required from underground to supplement Surface to Seam drilling operations
- Is not currently quantitatively assessed in terms of individual borehole performance.

It is recognised that despite its limitations, current Australia underground inseam drilling technology still represents ‘international best practice’ and that any developments or strategic imperatives that emerge from this study are likely to further enhance Australia’s international competitiveness in underground mining, and lead to international export opportunities for new technology and methods.

As inseam drilling is the frontline mitigation technique for dealing with hazardous gas, the project addresses the issue of “Improving the management of core underground mining hazards such as gas, fires and explosions”, an ACARP priority in the Improved Health and Safety Program. In addition, it addresses “improving the efficiency and effectiveness of characterising ground conditions using innovative methods of drilling and remote sensing”, an ACARP priority in the Management of Mining Conditions Program. It also will identify suitable drilling methods for trial in “techniques that could potentially overcome difficult drilling conditions”, a further ACARP priority in the same program. The project also has relevance in the Greenhouse Gas Mitigation category, under the Capture of Mine Gas program, and will assist in “reducing gas drainage costs”.

The deliverables from the program are as follows:

- Provide an objective evaluation of current inseam drilling practice, including identification of key issues, and an improved understanding of the major weaknesses inherent in current practice.
- The development of a potentially commercial gas flow and hydraulic model specifically designed for analysis of inseam boreholes.
• Identification of future technology options including a summary of the state of readiness for adaptation to Australian inseam drilling and drainage.

• Recommendations for improvements and the delivery of a road map for the future of inseam drilling in Australia.

2 Background to Inseam Drilling Practice in Australia

2.1 Historical background and context

Directional drilling methods used for gas drainage are effectively modified and adapted from conventional oilfield technologies. The US Bureau of Mines and some of the large US coal mining operations pioneered the early work adapting this technology for coalfield in-seam drilling. The demise of the USBM and structural changes to the US coal mining industry effectively resulted in the baton passing to Australian coal companies, technology groups, and contract drilling operations. Today, Australian coal seam directional drilling techniques are among the most advanced, and equipment and expertise has been effectively exported throughout the world.

In-seam gas drainage in Australian coal mining is dominated by simple directional techniques using a downhole motor and electronic survey tool. This was not always the case; gas drainage was commonly carried out by rotary drilling methods – with mixed success - during the 1980’s to early 1990’s (see Gray, 1995 in Lama (ed.), 1995). In some instances, rotary drilling is still used in Australian coal mining but extremely rarely for systematic drainage associated with longwall mining predrainage. Over the past 10-15 years, directional drilling has steadily predominated, mainly due to the exacting demands on accuracy required in gas drainage programs.

Since the growth in directional drilling, there has been little incentive for change in Australian inseam directional drilling practice. The method clearly works, and has played a major role in safety improvement particularly concerning outburst mitigation. The cost of inseam drainage represents a (generally) manageable operational cost at most mines, and is perceived as an undesirable, but necessary part of mining practice.

As a result, it may be argued that this has resulted in a complacent outlook and almost certainly, most operations are paying more for drilling and drainage than they probably need to or should. Key factors that support this perspective include the following:

1. There is currently a monopoly in the supply of electronic survey technology to the underground inseam drilling industry. A lack of competition and an overall small market for this technology increases costs.

2. There is an oligopoly in terms of service companies with the skills and equipment to carry out inseam drilling and drainage. This is a markedly different situation to surface
exploration drilling (for example), and as a consequence, costs are likely to be higher than they could be.

3. The advent of transfer of the risk of lost survey technology to the operators, and away from the service suppliers. This means that lost equipment risk is now the mine’s problem.

4. Generally favourable coal and geological conditions that suit this type of drilling approach have been enjoyed to date, however increasingly challenging conditions can be expected with increasing reservoir pressure and increasingly structured terrain. This will result in more failed boreholes due to “boggy ground” and increased costs to individual mine sites.

5. A lack of direction and drive (also funding) from mining operations for further research. Clearly, mine operators are satisfied with the status quo and it is not a top priority. There is a culture of acceptance of the current cost structure even though it may not be optimal.

6. A similar lack of incentive amongst drilling contractors to change a profitable status quo.

7. A disconnect between underground gas drainage and exploration, and an absence of logging-while-drilling (LWD) technology. Geological interpretation and gas drainage are largely separate functions at most operations.

8. The advent of Medium Radius Drilling (MRD) from the surface has provided an alternative approach in some cases, and thereby reduced the focus on underground inseam drilling issues.

9. No fatal outbursts has been perceived (rightly) as a response to current inseam drainage practice, so why change?

10. The Illawarra has provided most of the underground inseam drilling and drainage experience to date. This is a very mature coalfield with entrenched practices. Current practice (generally) works there and there is little perceived incentive to change (see point 9).

### 2.2 Current practice

#### 2.2.1 Equipment

In an ideal geological environment in-seam directional drilling (Figure 1) is possible to distances of about 1600m. In reality, boreholes greater than 1000m in length are extremely rare in Australian (and international) coalfield drilling. The majority of predrainage degasification drilling holes are drilled to a maximum depth of ~500m. Borehole diameter is usually 96mm.

In principle, the equipment limits the distance the hole can be drilled. The thrust / pull back capacity of the rig (usually around 12 tonnes) is important but the major limiting factor is the frictional forces acting on the drill rod string with depth. The act of directional drilling involves the use of a downhole motor with a bent sub (Figure 2 and Figure 3). The continual process of correcting the path of the borehole by modification of the orientation of the bend angle (slide drilling) results in a borehole path that is tortuous. The stiff NQ rod string fights a constant battle with the borehole walls and ultimately the frictional forces negate the ability of the drill machine to push the rods further. Soft or fractured ground may further limit the depth capacity
of the directional-drilling project. Borehole collapse is a frequent cause of abandonment of an inseam drilling exercise.

**Figure 1:** Underground inseam drilling rig setup, drilling under a conveyor belt into the rib.

**Figure 2:** Downhole assembly typical for underground inseam drainage, consisting of 96mm PCD bit, downhole motor with bent sub, and survey unit.
Figure 3: Schematic representation of standard practice directional drilling downhole equipment.

Very little variation in equipment configuration exists in Australian in-seam drilling between the major contracting companies and in-house coal mine drillers. Basically, the same set-up (and methodology) applies from the Illawarra to the northern Bowen Basin. Similarly, South Africa, China, Japan and the US use the same system. Drilling rigs are purpose built, with the most popular Australian systems currently in use manufactured by Boart Longyear (see http://www.boartlongyear.com.au), Universal Drill Rigs and Valley Longwall Drilling (http://www.valleylongwall.com.au).

The capital required to assemble a drilling rig suitable for degasification drilling is high. A suitable drill rig, rod string, survey tool and downhole motor would cost in excess of AU$1.2M. This high capital cost impacts on the cost of the service from contractors. A key factor in this high cost is the need for equipment to be certified intrinsically safe (IS) for underground use. This also keeps competitors out of the business.

The following minimal standards apply to inseam drilling rig configurations typical of Australian operations:-

- 75kW hydraulic power unit (operating at 1000V).
- 250 l/min water supply and a 10 MPa high pressure pump.
- 135 kN thrust and pull.
- 1500 to 2000 Nm torque.

An NQ or CHD rod string is usually utilised, and an electronic survey tool and a 2 7/8" downhole motor (Figure 3 and Figure 4). Electronic survey tools have effectively replaced the use of single shot cameras due to the speed at which survey information can be processed and acted upon by the drill operator. Electronic survey tools are an integral component in the process of steering the drill. The increased reliability of the survey result has also had a favourable impact upon the geological interpretation process, which may be (sporadically) associated with coal mine directional drilling.
Figure 4: Downhole motor assembly (see Baker Hughes web site, http://www.bakerhughesdirect.com).
The capital cost of the downhole component – rods, survey tool and downhole motor is often at risk in gas drainage boreholes. The implications of a stuck drill string are extremely serious and the result is that drilling operators tend to err on the side of caution. At the first sign of downhole drilling problems, the rods will usually be withdrawn and the hole abandoned. Nobody wants the responsibility for $500,000 of lost equipment in a borehole.

In addition, there are unfavourable implications of a lost drilling string for mine planning and safety reasons. Taking a longwall operation through a lost string increases the risk of creating sparks that may prove to be an ignition hazard. Drill rod strings can also be caught up in the shearer drum, and may be difficult to remove. A lost drill string could result in a reassessment of the mine plan, with serious implications for mine scheduling and production.

Permanently lost drill strings are a relatively uncommon event, but do occur. The authors are aware of around half a dozen currently bogged drill strings in the Australian coalfields, with variable probabilities of ultimate retrieval. This is a not too daunting a figure given the maturity of the guided drilling business in Australia (approximately 600,000m per year). However, the rate of tool loss is decreasing as operators tend to be more risk adverse. At the first sign of downhole trouble rods are withdrawn and onus on further progress passed to the mining companies (and usually respectfully declined).

Advanced Mining Technologies Pty Limited (AMT) manufactures the survey technology commonly used in underground gas drainage in Australia. AMT has been at the forefront of the development of electronic survey tools, starting with the Directional Drill Monitor (DDM) in the early 1990’s, and subsequently developing the DDM Mecca (an electronic hard wired connecting rod system) and the Drill Guidance System (DGS). The latter is now the system of choice for underground inseam drilling in Australia and overseas.

The DGS measures pitch to 0.2° and azimuth to 0.5°. The system is reliable and robust and comes with an optional gamma sensor that may be used to measure proximity to roof and floor during drilling. For further information on AMT and its products, the reader should visit the company web site (http://www.advminingtech.com.au).

2.2.2 Methodology

With directional drilling there is no core, and cuttings from the borehole are not normally collected. The only formal record of the borehole is contained in the data from the electronic survey instrument and the written records of the driller.

Current practice is for the driller to record changes in drill machine performance as the string advances. This is carried out in a subjective manner and recorded by the driller on separate hand written log sheets (Figure 5). In addition, downhole survey data is recorded in real time during the drilling process and used to guide the borehole to reach a targeted dip and azimuth. This data is also stored digitally in the survey tool itself, and may be downloaded to a separate PC at any time.
Figure 5: Example of a hand written underground driller's log sheet.

XYZ survey data is measured at the end of each rod advance, usually every 6m.

If the borehole deviates from its targeted path, or it intersects unexpected geological features, then it may be necessary to create a branch from the main borehole.

Branching practice involves withdrawing the drill rods to the desired branch point, and turning the angle of the downhole motor in such a manner that it cuts into the side of the existing borehole and makes a new path (Figure 6). This is usually done to the right and down (to seek the advantage of gravity and rod rotation). Once the new hole is created the driller then has the flexibility to steer the drill string to any desired target (given an appropriate bend radius).

2.3 Inseam drilling and reservoir modeling (simulation)

Inseam drilling patterns have been developed on the basis of practical experience, and are not normally the subject of computer modeling (simulation) and history matching (comparing actual data with the model) as is common in the Coal Seam Methane (CSM) industry. Inseam drilling practice has been largely developed by practitioners in the gassy mines of the Illawarra, and by the service drilling operators themselves in conjunction with their mining clients. Success is judged on mining safety, not on the amount of gas captured per se.

Normal practice is to determine borehole spacing for drainage on the basis of experience. If the spacing is too far apart, subsequent compliance cores will reveal inadequate drainage and the spacing will be tightened up. If gas levels have been reduced to safe levels, mining will continue and drilling patterns that have been proved successful will be repeated. The process is reactive and intuitive.
Figure 6: Typical inseam borehole paths drilled from the same stub. The first borehole (top) has navigated through a near full seam fault. The other boreholes rely on roof scrapes and floor touches to maintain position inseam. Note the multiple branch points. The hills and hollows of the borehole profile will impede gas flow from the borehole. In addition, these down dip boreholes may struggle to release gas as water is sporadically ejected from the borehole after building gas pressure.
In some cases, modeling of single boreholes may be carried out using SIMED (a reservoir modeling package developed by the CSIRO and the University of NSW) by independent gas consultants. Application is however, sporadic, and modeling is not a routine part of Australian mine gas drainage planning. Even if this approach has been adopted early in the mine-planning phase, by the time mining is established the old patterns of trial and error are likely to be entrenched. At best, single borehole SIMED modeling may be considered helpful as a ‘guide’ to spacing that will be subsequently tested by practical application.

Some full-field modeling has been carried out associated with MRD SIS drilling for a developing longwall operation in the Hunter Valley (see Hennings et al, 2008).

Consequently, inseam drilling in Australia is an intuitive, reactive process and decision-making remains in the hands of a few experienced individuals at any one site, and consultants. The process is therefore not ‘scientific’ but is empirical, and experience based. The natural tendency is for practitioners to ensure drilling units remain fully utilised and it is highly likely that this leads to “over drilling” and redundancy. The incentive is to drill to planned (metre based) targets, and to ensure that gas levels are low enough for safe mining. If this results in some unnecessary drilling, so be it.

This approach cannot be too heavily criticised, because it has achieved the desired results – namely, reducing the risk of outbursts to virtually negligible and vastly improving mine safety.

For a more complete review of the potential role of simulation in Australian underground inseam drilling and drainage refer to Section 4.

3 State of the art of inseam drilling in Australia

3.1 Factors limiting inseam drilling: the lockup condition

The equipment limits the distance the hole can be drilled. The major limiting factor is the behavior of the drill pipe in the hole. Borehole geometry, wall roughness, cuttings accumulation and annular pressure all contribute to the overall drag force required to move the string in the hole. There is a limit to which a drill pipe can be pushed into a borehole. This limiting point is known as “lockup” and occurs when the axial force applied by the rig causes the pipe to buckle in the hole. Once this level of force is reached, pushing harder just increases the buckling.

For NQ in a horizontal straight hole, the force sustained before lockup is around 12 tonnes. The specific maximum feed force for a typical inseam drilling rig such as an LM75 is 12.5 tonnes. How much hole you drill before you accumulate 12 tonnes of drag will depend on the management of the contributing factors mentioned above. It is rare to reach lockup in cross block inseam drilling. It usually requires longer holes to experience drill pipe lockup.

A typical scenario is for feed force to be steadily increased, and the thrust force transmitted to the bit. As the force increases the pipe begins to buckle, first in a sinusoidal fashion, then
A friction force between the helix and the wall is produced and this force will increase as the rig feed force increases. The transmitted force from the rig to the bit reaches a maximum as increasing rig feed force is entirely absorbed by the helix-wall friction – lockup point has been reached.

Once lockup is reached, the string cannot be further advanced into the hole unless rotated. From here, unless borehole conditioning can reduce drag, the hole has reached its conclusion. In some circumstances, the annular pressure may further limit the depth capacity of the directional-drilling project. The onset of lockup point can happen quite rapidly. The transition from “drilling well” to “can’t drill anymore”, “boggy ground” can be sudden. It can be due to the bit intersecting boggy ground but it can also be due to a change in borehole condition 100’s of metres away from the bit. ‘Boggy ground’ is a frequent cause of abandonment of a drilling exercise.

Inseam directional drilling currently involves the use of a downhole motor with a bent sub. The continual process of correcting the path of the borehole by modification of the orientation of the bend angle results in a borehole path that is not straight, more a series of subtle bends (the ‘flip flop’ effect), with a typical bend radii of 120-220m. Without rotating the drill pipe, cuttings fall to the low side of the hole and form a bed. This increases the surface area across which drag is transmitted to the drill string during movement across the borehole wall. This increases the thrust required to move the string forward, accelerating the onset of lockup.

Outside of the inseam drilling scene, this is ‘slide’ drilling. Australian underground directional drilling practice is almost exclusively ‘slide’ drilling. Elsewhere, the standard directional drilling method using downhole motors is ‘slide and rotate’. Here, the rods are turning whilst using a downhole motor and slide drilling is only carried out to get a deviated borehole to the desired attitude. The technique of ‘slide and rotate’ is most widely used because it delivers a smoother well bore and assists the borehole conditioning process.

Applying the ‘flip flop’ method (solely) contributes to the accumulation of cuttings beds, tortuosity and the premature termination of inseam boreholes. A comparison of drilling long inseam directional boreholes using slide / rotate and ‘flip flop’ methods has been carried out and is presented in Figure 7 (from Thomson, 2001). Here the standard ‘flip flop’ technique has resulted in termination of the borehole at 864m. Drilling a parallel borehole in the same seam with the same equipment, but using slide / rotate (only from 450m onward), resulted in a borehole that reached a TD of 1302m.

The ‘rotate/ slide’ method effectively reduces the dogleg severity of the borehole. For the example mentioned above, dogleg severity plotted versus borehole depth reveals a compelling case for ‘rotate / slide’ over ‘flip flop’. Dogleg severity is identical for the first borehole and the first 450m of the second borehole. After the ‘rotate / slide’ technique is introduced (beyond 450m in Hole 2), dogleg severity is markedly reduced (Figure 8), leading to the success of the second borehole. This example provides a good comparison as to the effect of borehole geometry. The shorter hole has an average dogleg severity of 10deg/30m, the longer hole 6.5deg/30m. Both were drilled to lockup point. It is important to note the borehole has been terminated due to physical limitations (borehole conditioning issues) rather than because of geological problems.
Figure 7: Comparison of two parallel boreholes, one drilled entirely with the ‘flip flop’ method (Hole 1) and the other with mainly ‘slide / rotate’ (Hole 2), (Thomson, 2001).

Figure 8: Dogleg severity in two parallel boreholes, one drilled entirely with the ‘flip flop’ method (Hole 1) and the other with mainly ‘slide / rotate’ (Hole 2).

3.2 A question of balance

Underground directional drilling is ‘underbalanced’ (Figure 9); in other words, the formation pressures generally exceed the annular or circulating pressures. This because the borehole is drilled from near atmospheric pressure at the collar (~120kPa) and the formation is subject to its virgin in situ pressure state, which may be of the order of 1500-3000+kPa (and higher, 5 Mpa is not uncommon). This pressure differential will naturally allow for the gas and water in
the formation to flow into the borehole, and out through the gas drainage network. This phenomenon underpins the success of inseam gas drainage in coal mining.

**Figure 9:** The underbalanced drilling condition, common in underground inseam drilling. Formation pressures exceed annular pressures and in extreme cases, "outbursts" may be experienced down hole (from Thomson and MacDonald, 2004).

The process of increasing underbalance with drilling advance is illustrated in Figure 10. Here, the drill will pass through the Critical Desorption Pressure (CDP) point and become increasingly underbalanced until the maximum underbalance point is reached in the virgin reservoir.

The success of inseam drilling depends also upon the ability of the annular wall to remain stable. In underbalanced drilling the risk is always that the borehole walls will collapse around the drill string, disrupt circulation, lead to pressure differentials, differential sticking, mechanical jamming and a failed borehole. This is why current Australian directional practice struggles in coals which are 'soft' (usually tectonically disturbed) such as some of the coals of China and New Zealand (note: an exception is Chinese anthracite, which is of such a high rank that cleats are annealed – these coals can be drilled but struggle with drainage due to low permeability).

In Australia the coal tends to be relatively strong, and underbalanced drilling is generally successful. One major contributor to this success is that the mined seams are shallow. This means the differential between annulus and formation pore pressure is generally low (1500 – 120 = 1380kPa (200psi)) underbalance. For coal of bulk strength above 5mPa this is likely to be no problem. In deeper seams with higher underbalance (for example, in parts of China, and noted in parts of the Sydney and Bowen Basins) the stability problem becomes a major issue, particularly when the coal is weakened by tectonic history.
Figure 10: A borehole will pass through the Critical Desorption Pressure (CPD) point resulting in increasing underbalance with advance. A point of maximum underbalance is met in virgin reservoir conditions. The point at which this state is reached will depend upon local conditions, including proximity to mining activities, time, and the relevant adsorption isotherm for the coal.

The overbalanced drilling case occurs when the pressure of the annulus exceeds that of the fluid contained in the pore space of the formation (Figure 11). As a result, drilling fluids will tend to migrate into the surrounding geology and circulation may be lost. This also has the negative effect of damaging the borehole wall, leading to ‘skin’ effects – which may affect gas drainage performance. ‘Skin’ is a concept that has emerged from the oilfield industry to describe lower than expected permeability of the borehole wall, caused by damage to the formation during drilling. A positive skin implies well damage, a negative skin implies flow from the well bore to the formation (such as might occur after stimulation of the well).

Although unusual in underground directional drilling, the overbalanced condition may occur when a borehole becomes locally blocked (disrupting circulation) or close to the collar where coal de-stressing occurs associated with the gas / water desorption process from the rib. It may also occur in areas of local high permeability associated with geological structures.

The place where overbalanced drilling is of the most concern is in surface to seam drilling in high permeability coals. Here, it is desirable to maintain borehole pressure above the gas desorption point (CDP), and below the local pore pressure average (Figure 12). In this example, taken from an MRD surface to seam project in Queensland, off and on-bottom pressures are maintained in the desired window in order to minimise differential sticking and
skin effects caused by drilling ‘overbalanced’ and avoid premature desorption by drilling too far ‘underbalanced’.

It is therefore theoretically desirable to maintain perfect balance in drilling boreholes, underground or otherwise. In underground drilling it is currently impossible to maintain this balance, however the subject has received some attention in the past. Gray (1998) noted the importance of maintaining borehole pressure to minimise the pressure differential between borehole wall and annulus, and developed a prototype borehole pressurisation device. The system was never trialed in an underground mine.

Why was the Gray technology never adopted for use in Australian coal mining? The premise was sound, and the prototype equipment worthy of further interest. Anecdotal comments from operators who considered the application suggest that concerns re safety (high pressure differentials needing to be controlled in a hazardous zone, rod handling under pressure) and a lack of commitment to underground test work were the main reasons for the development being shelved.

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P_1 - P_2 = \Delta P
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**Figure 11:** The overbalanced drilling condition, common in surface to inseam drilling. Annular pressures exceed formation pressures and may result in fines being forced into cleats thereby impinging on gas flow (from Thomson and MacDonald, 2004).
3.3 Potential Solutions – directions for further research

The major weaknesses of current inseam drilling practice can be summarised thus:

1. **Balance cannot be controlled during drilling** – this leads to borehole collapse, failed boreholes and lost drill strings. The problem increases as coal strength decreases (e.g. through tectonic processes), and reservoir pressure increases (coals get deeper).

2. **Well completion techniques and methodologies are largely ignored** – inseam drilling does not complete wells (boreholes) in the CSM sense, and as a consequence uncontrolled desorption takes place down hole (see point 1, and Figure 10), and often during the drilling process itself. Well completion techniques includes a range of methods derived from the CSM industry for ‘bringing a well on line’, controlling the desorption process, interference patterns and including stimulation techniques. This lack of attention to ‘completion’ will inevitably lead to patchy and inefficient drainage, and borehole redundancy. The performance of individual wells is not measured, thus “good wells” are indistinguishable from poorly performing wells.
3. **Culturally, the emphasis is on drilling rather than drainage** – inseam drilling success is predicated on length of holes drilled rather than effective drainage (see point 2).

4. **Inadequate downhole sensing** – boreholes drill a significant percentage of redundant metres trying to stay inseam (branching into roof and floor etc.). Each branch also increases the risk of a failed borehole. Hills and hollows in the drill path – due to inadequate sensing capability - also impinge upon effective drainage (see points 1, 2 and 3). Improved downhole sensing would result in a less reactive (and more consistent) borehole path. In addition, geosensing technologies could (and should) be used to feed important geological data into mine planning models.

5. **Expensive downhole equipment which may be ‘parked’** – the brains of the inseam drilling system is located at the point of maximum risk, i.e. at the pointy end of the borehole. This is unnecessary and inefficient. Solutions, which locate the most expensive steering components and controls at the rig and not down hole, are clearly advantageous.

6. **Cost and deployment issues** – inseam drilling is costly, and involves bulky equipment which is often in the way of production or development related functions.

7. **Safety** - inseam drilling is operator driven and involves complex interactions between man and machines, with potential for injury. Inseam drilling has the potential to be more automated.

8. **Geologic and drainage functions are not integrated** – this relates to point 4, namely that inseam directional drilling for gas drainage provides potentially valuable exploration data which is rarely used as input to the mine geological model. This is a severely underutilised opportunity to improve understanding of coal seam structure and increase production certainty. This is an important step towards eventual longwall automation.

How can these issues be addressed? One possible approach is to take the entire process entirely out of the mine, and this is in effect what has happened in many longwall operations over the past 5-6 years, utilising the benefits of Medium Radius Drilling (Surface to Inseam). MRD enables predrainage to take place independent of mine development, a significant advantage over the currently real time proactive (and reactive) nature of inseam drilling. Other advantages of MRD include:

- Balance can be controlled (addresses point 1 and potentially, point 5 – lower risk).
- Desorption process can be controlled (addresses point 2, and potentially, point 3) via controlled ‘bringing the well on line’ through the vertical borehole.
- Boreholes can be lined using PVC pipe, thereby minimising the risk of a lost borehole (relates to issue of redundandcy – mentioned in point 2).
- MRD techniques can potentially call on a range of oilfield geosensing tools (addresses point 4 and potentially, point 8).
• May be cost effective if lead time is adequately factored in during planning stage, and may also be linked to Coal Mine Methane (CMM) capture and utilisation efforts (addresses point 6).
• MRD is surface based, and the equipment is more likely to be automated (rod handling etc.) and therefore will be a safer operation (addresses point 7).

On the basis of the notes above it would appear that a MRD approach provides a clear beneficial answer to longwall predrainage needs, so why even consider improving underground inseam drilling practice? The reasons include:

• MRD applications require surface access and this may not always be possible, particularly in urban or other intensive land use settings (e.g. the Illawarra).
• MRD requires a long-term commitment to predrainage, and once established the mine plan that accompanies the drainage pattern needs (ideally) to be fixed.
• MRD means (significant) capital up front, not just as an additional, incremental “operating cost”.
• With increasing depth of cover, MRD cost benefits will decline relative to underground methods.
• It will still be necessary to drill ahead of development from underground for outburst compliance testing.
• It will also likely still be necessary to drill ahead to degas some areas that may not have drained adequately from primary (MRD) drilling and drainage.

CRC Mining has long recognised the need for an improved underground inseam logging system and this is reflected in the development of the Coiled Tubing Project. The rationale for development of Coiled Tubing is based on recognition of the following flaws inherent in the underground inseam directional drilling process:

• “The drilling process is labour intensive - manual handling injuries associated with drill rod handling are a major contributor to total LTI’s. This high manual labour intensity also tends to limit drilling productivity, and contributes to the relatively high cost per metre drilled.
• A monopoly supply situation exists for the downhole survey and electronic components. Replacement cost for these components is in excess of $300,000, representing significant capital at high risk of being lost (stuck) down hole (an all too frequent event for some mines).
• Current equipment is not suitable for real-time monitoring of drill rig operating parameters, or the integration of down-hole geological sensing probes. Therefore, important geological information suitable for input into the mine geological database is not collected as part of the drilling process”

(from ACARP Proposal, P. Lugg, 2007).

Coiled Tubing Drilling (CTD) can address these issues through the reduction of manual handling and automation, the introduction of a CRC Mining survey system that has already been developed for Tight Radius Drilling (TRD), and the utilisation of a hard-wired electronic connection inherent in Coiled Tubing rods. In addition, Coiled Tubing is much more suited to
borehole pressure control through the elimination of manual rod handling and a continuous
feed mechanism.

CTD consists of metal piping that is housed on a spool and is usually around 1” to 3.25” in
diameter. The method of drilling was developed in the oilfield industry primarily as a workover
tool, to improve gas flow from sub-par production wells (it has a well developed milling and
open hole drilling capability). The main benefits of CTD is the ability to “push” the string into the
hole not reliant on gravity and the lack of rod connections.

CTD offers significant advantages over conventional drilling technology. The continuous coil
provides for a faster, non-cyclical drilling process and eliminates the need for manual handling
of the drill string. Conservative estimates predict a 15% reduction in cost per metre for inseam
holes. Its design is also suited to the measurement and capture (through a wire connection in
the coiled tubing) of drill parameters such as rate of penetration (ROP), thrust force and torque,
all useful in identifying important geological features.

CTD rigs drill thousands of kilometres of directional boreholes in North America primarily in the
oil and gas industry. The technology is robust and mature; it does however remain to be
adapted to the unique requirements of underground directional drilling.

A conceptual design for CTD has already been developed (Figures 13 and 14), and support for
the program has been initially provided by BHPB Illawarra Coal (P. Lugg, pers. Comm.). The
CTD system for underground use, as envisaged, uses a coiled tube mounted on a spool, and a
unique feed and steering mechanism mounted on a skid.

![Coil Tube Drilling Rig With Coil Tubing Drum Axis Horizontal](image)

*Figure 13: Coil Tube Drilling Rig With Coil Tubing Drum Axis Horizontal*
Figure 14: Coil Tube Drilling Rig With Coil Tubing Drum Axis Rotated 45°.

The proposed steering system for the in-seam CTD concept utilises the combination of a bent drill sub and rotation of the drill string to provide directional control. This combination has proven very reliable for the in-seam environment and obviates the need for an expensive steering sub down the hole. The steering of the hole effectively is carried out at the rig, by rotating the drum. The “push” effect on the downhole bent sub results in a deviation of the borehole towards a desired azimuth and pitch, which can be incrementally corrected as the drill advances through periodic survey check shots.

Continual rotation of the string also aids in the clearance of cuttings and reduces friction on the string. The in-seam CTD concept will include a downhole navigation sub transmitting continuous tool orientation information necessary to automate the steering process.

In addition, there will likely be advance rate advantages of CTD over conventional systems. CRC Mining figures, arrived at in consultation with BHPB mining engineers suggest that instead of advancing only 21 minutes every drilling hour, as is the case for the conventional rig, the continuous drilling and surveying features of the CTD unit will operate from 30-45 minutes every hour. The basis of this assumption includes:

- The continuous drill string eliminates time lost for rod changes, and associated issues regarding circulation of the drilling fluid and cuttings returns.
- Data from the downhole orientation sensor will be continuously transmitted back to the Rig Control System, providing a real-time display of borehole trajectory – this eliminates non-productive survey time.
The CTD Specification includes an automated drill steering system which will reduce the drill operators steering decision time.

Figure 15 provides a range analysis of the effect of increased penetration time per hour drilling on metres drilled per shift and ultimately, the reduction in the number of shifts required to complete the mines annual target metres. Effectively, a more productive CTD unit will reduce the required number of manned shifts.

![Annual Benefit From Introducing Single More Productive CTD Unit](image)

*Figure 15: Comparison of CTD drilling rates with conventional inseam drilling (from Lugg, 2007).*

It is the authors' considered opinion that Coiled Tubing Drilling offers the best opportunity to address most of the outstanding weaknesses inherent in current inseam drilling practice, and provide a more cost effective solution to underground mine degasification needs moving forward. Little else presents as a 'catch all' to address key issues such as borehole pressure control and steering. Other possible alternatives include post drilling surveying of pseudo directionally drilled rotary holes (perhaps using an extended length stabiliser), and high speed cross panel drilling using a derivative of the Tight Radius Drilling (TRD) technology. A 'road map' that illustrates the basis for this judgement is presented in Figure 16.
Figure 16: ‘Road map’ for inseam drilling indicating that Coiled Tubing Systems offer the best solution to the entrenched problems associated with current practice.
4 Gas flow simulation from an inseam borehole using FLUENT

4.1 Introductory remarks

Gas drainage from coal seams is critical to coal mine safety in “gassy” mines and relevant for energy use efficiency and environmental concerns. Coal seam gases continue to be a significant safety problem in coal mining. The major current strategy to handle this gas problem is to drain the gas before mining, usually through horizontal in-seam boreholes drilled either from the surface or from existing workings (Meaney et al. 1995, Thomson 1999). Whereas mine safety was initially the primary purpose for coal seam gas drainage, the commercial benefits from the sale of coal bed (or seam) methane (CBM or CSM) has increased in the last decade (Diamond et al 2001, Hennings et al, 2007). In addition, the reduction of coal gas emissions to the atmosphere by the collection of drained gas is likely to be important for protecting the environment (Saghafi et al, 2008).

An early assessment of the potential for methane emission problems provides the greatest amount of lead time to incorporate longer term gas drainage techniques into the mine development plan (Diamond, 1994). Numerical simulation of the expected gas release and borehole flow rates are a potentially valuable economic tool which can provide insight into the characteristics of gas flow at any given mine site. Reliable simulation methods will enable the mining engineer to optimise the design of a drainage program and to forecast and assess the performance of the gas drainage scheme. Accurate simulation may also potentially contribute to reducing gas drainage costs.

Numerical simulation of gas production has attracted a great deal of interest in the past decade. Researchers have developed various numerical models to simulate the process of gas release from coal seams (King et al 1986, Shi and Durucan 2005, Meaney et al 1995, Linzer 1995). Currently a significant number of simulation codes exist in the world. Most of these simulators have been designed for the Coal Bed / Seam Methane (CBM or CSM) industry where drainage usually takes place from vertical holes drilled from the surface (Meaney et al. 1995) or simply converted from conventional petroleum applications. Examples of these simulators includes: GEM, (CMG Ltd., Canada); ECLIPSE, (Schlumberger GeoQuest,UK); COMET 2, (ARI, USA); SIMED II, (CSIRO, Australia); MORE (ROXAR, UK / Norway) and GCOMP, (BP, USA). These simulators have been developed largely independently and all have their own unique features and their own strengths and limitations. In terms of handling gas release, most of the simulators assume flow is governed by Fick’s Laws relating to diffusion. To reduce the numerical complexity and save computational time, unsteady-flow is replaced by pseudo-steady-state flow (Meaney et al. 1995). Improvements are still being continuously made to all simulators.

A commercial CFD code, FLUENT, is being used widely to simulate a wide range of engineering fluid problems. However, the current version (6.2.16) of FLUENT has no specific module for simulating coal seam gas. Although it has very strong pre-processing, post
processing and calculating functions applicable to a wide range of flows (including porous
media, multiphase, multi-component flows, heat transport and species transport models), it
cannot model gas emission within a coal seam due to the lack of a specific model for handling
the release rate of the gas.

It can be said that FLUENT adequately addresses most of the features that currently exist in
carbon seam gas simulators, except for the adsorption/desorption characteristics of gas which is
the key feature for coal seam gas simulation. It was a major objective of this work contained
herein to describe a model capable of implementation in the FLUENT code to simulate this
process.

It is noted that in existing numerical models which simulate gas desorption, gas flow in a coal
seam is divided into two discrete components. In the cleats, the gas flow is driven purely by the
pressure gradient. In the coal matrix, the gas flux is driven by diffusion. As the diffusion
mechanism is determined by concentration, it follows that diffusion is governed at all by the
isotherm. It is our contention that this represents a fundamental flaw in the way that most
modern simulators treat coal seam gas flow.

In our model developed herein, the mechanism of gas release and flow is explained as follows.
As pressure is decreased within a finite volume of the coal seam, according to the isotherm, a
certain amount of gas will be liberated from the micro pore surface into the cleats. The amount
of the released gas is dependent upon the diffusion properties of the coal. This rate is a
function of the difference of pressure within the micro pore system at incremental moments and
the accompanying reduction of pressure (it is therefore a dynamic process). Once released into
the cleats the gas will obey the ideal gas law flow through the cleat system driven by the
pressure gradient.

4.2 Description of the gas release mechanism in coals

4.2.1 The main equation governing multiphase flow

Assuming multiphase flow in the coal seam (that is, the flow of gas and water), the continuity
equation for the mixture is:

\[
\frac{\partial}{\partial t} (\rho_m) + \nabla \cdot (\rho_m \bar{v}_m) = \dot{m} \bar{v}
\]  

(1)

where \( \bar{v}_m \) is the mass-average velocity.

\[
\bar{v}_m = \frac{\sum_{k=1}^{n} \alpha_k \rho_k \bar{v}_k}{\rho_m}
\]  

(2)

And \( \rho_m \) is the mixture density:
\[ \rho_m = \sum_{k=1}^{n} \alpha_k \rho_k \]  

(3)

\[ \alpha_k \] is the volume fraction of phase k.

\[ m' \] represents mass transfer due to user-defined mass sources.

The momentum equation for the mixture is:

\[ \frac{\partial}{\partial t} (\rho_m \vec{v}_m) + \nabla \cdot (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \nabla \cdot [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}_m^T)] + \]

\[ \rho_m \ddot{\vec{v}} + \vec{F} + \nabla \cdot (\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k}) \]  

(4)

where \( n \) is the number of phases, \( \vec{F} \) is a body force, and \( \mu_m \) is the viscosity of the mixture:

\[ \mu_m = \sum_{k=1}^{n} \alpha_k \mu_k \]  

(5)

\( \vec{v}_{dr,k} \) is the drift velocity for secondary phase k:

\[ \vec{v}_{dr,k} = \vec{v}_k - \vec{v}_m \]  

(6)

The output energy equation for the mixture takes the following form:

\[ \frac{\partial}{\partial t} \sum_{k=1}^{n} (\alpha_k \vec{v}_k E_k) + \nabla \cdot \sum_{k=1}^{n} (\alpha_k \vec{v}_k (\rho_k E_k + p)) = \nabla \cdot (k_{eff} \nabla T) + S_E \]  

(7)

where \( k_{eff} \) is the effective conductivity. The first term on the right-hand side of equation represents output energy transfer due to conduction. \( S_E \) includes any other volumetric heat sources.

In the above equation,

\[ E_k = h_k - \frac{p}{\rho_k} + \frac{v_k^2}{2} \]  

(8)

for a compressible phase, and \( E_k = h_k \) for an incompressible phase, where \( h_k \) is the sensible enthalpy for phase k. The volume fraction equation for secondary phase p is:

\[ \frac{\partial}{\partial t} (\alpha_p \rho_p) + \nabla \cdot (\alpha_p \rho_p \vec{v}_m) = -\nabla \cdot (\alpha_p \rho_p \vec{v}_{dr,p}) \]  

(9)
4.2.2 The desorption rate of gas release

Coal seam gas is mostly held in the large surface of micro pores of coal under pressure. A typical surface area for high rank coal can reach up to 200 m²/g (Killingley, 1990). The cumulative increase in adsorbed gas with pressure is represented by adsorption isotherms. An adsorption isotherm reflects the premise that adsorbed gas content (C) is a function of pressure:

\[ C = f(p) \]  

What we are most interested in is the desorption rate, which is (in principle) the inverse of the adsorption rate. The rate of gas content release over time (t) with declining pressure (p) can be defined as the desorption rate. From (1) we have

\[ \frac{dC}{dt} = \frac{\hat{c}(p) \, dp}{\hat{c}p \, dt} \]  

(11)

For a finite volume of gas within a coal seam, \( \frac{dC}{dt} \) can be considered the gas release rate (or desorption rate). Here the mass transfer due to the gas desorption or adsorption is treated as a mass source, similar to the phenomena of evaporation and condensation.

It can be seen that the gas release rate depends upon two parameters. One is the derivative of the Langmuir curve, \( \frac{\hat{c}(p)}{\hat{c}p} \), which is also a function of pressure \( p \), and another is the change rate of pressure \( \frac{dp}{dt} \). In other words, gas release is a function of pressure \( p \) and the rate of pressure change.

In an unsteady gas flow in the coal seam domain, pressure \( p \) is different at different points and at different times. However, it can be computed by CFD using the unsteady model. Also the rate of pressure change can be computed. Thus, equation (11) is used as the formula to describe the gas release rate. Applying equation (11) over the entire finite volume of the coal domain, the complete expression for gas generation is obtained.

The most favoured isotherm describing the relation of adsorption and pressure is the Langmuir isotherm, which assumes only monolayer adsorption, and the Langmuir equation relates the amount of gas adsorbed to the partial vapour pressure of the gas.

Assume gas sorption obeys the Langmuir isotherm, i.e.,

\[ V(p) = \frac{V_l p}{p_l + p} \]  

(12)
where $p$ is gas pressure, $V(p)$ is the amount of gas adsorbed at $p$. $V_L$ represents the Langmuir volume parameter: the maximum volume of gas adsorbed as pressure approaches infinity. $P_L$ represents the Langmuir pressure parameter: the pressure at which the volume of adsorbed gas achieves 50% of the maximum value.

If reservoir pressure is known (or estimated) then the gas capacity at that pressure can be readily calculated. However, knowing the pressure only is not enough to determine the amount of gas release. Another necessary condition is to know the rate of pressure change. From (3), we have:

$$\frac{dV(p)}{dt} = \frac{V_L p_L dp}{(p_L + p)^2 \frac{dp}{dt}}$$

In an unsteady flow domain, $p$ and $\frac{dp}{dt}$ can be calculated for a finite volume at a certain time point. Thus, $\frac{dV(p)}{dt}$, the rate of change of the amount of gas adsorbed at that pressure $p$ may be obtained.

4.2.3 Incorporation into FLUENT code

Consistent with equation (13), a program has been written in C and integrated with the commercial CFD code FLUENT as a user defined function (UDF) and thereby applied to the coal seam domain.

4.2.3.1 Simulating gas release from a core sample

Before the numerical model could be applied to a borehole gas drainage simulation, it was necessary to first apply the simulation to experimental data obtained from gas emissions from a core sample of coal.

Langenberg and Ronaghan (2004) conducted a series of gas content measurements from cores drilled in the Coal Valley Area, in the Alberta Foothills of Canada. The core samples were obtained from a depth of 282 to 295 metres underground. They measured gas emission history for 16 core samples and conducted adsorption experiments to determine Langmuir parameters for one of the samples. According to their tests, the Langmuir parameters are:

$$V_L = 22.43 \text{ cc/g}$$
$$P_L = 12.97 \text{ (MPa)}.$$
The Langmuir equation for this coal can be written according to the parameters from the experiment as:

\[ V(p) = \frac{22.43p}{12.97 + p} \]

where the unit of pressure \( p \) is MPa, and the unit of \( V(p) \) is cc/g.

The formula for gas release rate for a finite volume is:

\[ \frac{dV(p)}{dt} = \frac{22.43 \times 12.97 \, dp}{(12.97 + p)^2 \, dt} \]

A sample with a diameter of 50 mm and a length of 310 mm was modelled using the FLUENT code (Figure 17). The two-phase flow (water and gas) model was applied. The gas is treated as a source term as explained previously. The initial condition is that the whole domain of the core is subjected to an initial pressure of 2.83 MPa (an approximation of reservoir pressure). The sample is gradually lifted up to the surface in 5 minutes during the core extraction process. Thus the boundary pressure around the sample is linearly decreased from 2.83 MPa to 0.101325 MPa. The core sample is treated as axisymmetric and the domain is divided into 3875 meshes. To test the mesh dependence of the result, another mesh scheme using a total mesh number of 7750 was employed. It was found that the difference of gas release rate between the two mesh schemes is less than 3 %. Thus, the simulation results are considered mesh-independent. Figures 16 to 21 show some of the simulation results.

It can be seen from Figure 17 that within the core sample, pressure stays high (near the initial pressure of 2.83 MPa) at 19.4 hours (\( t = 70000 \) s). This is because the gas release mechanism will prevent the local pressure from sharply decreasing. Only those areas near the boundary of the sample show evidence of pressure reduction. As a result, gas release occurs only in those areas near the boundary. The vectors of the flow velocity are shown in Figure 18. The maximum velocity of about \( 4 \times 10^{-8} \) m/s occurs on the boundary.

As time approaches 35 hours (127000 s), the pressures within most of the core sample have reduced significantly (Figure 19), and gas emission is maximised (Figure 20).

As time approaches 14 days (1200000 s), pressures in the whole sample are reduced and gas dominates the domain (most of water has already been driven out) (Figures 21 and 22). In parallel, the gas velocity flowing out the boundary has also been significantly reduced (4.79x10^{-9} m/s) as the rate of pressure change is diminished (see Figure 23).

The simulated history of gas emission is presented in Figure 24 in comparison with experimental data conducted by Langenberg and Ronaghan (2004). The experimental data indicates quite a range of variation although the samples were drilled from the same borehole with a depth difference of less than 13 m (282 to 295 m). The simulated results are within the range of the variation of the samples, indicating that the developed model is able to reasonably simulate gas emission.
Figure 17: Profiles of pressure at early stage (t = 7000 s).

Figure 18: Velocity vectors at t = 7000 s.
Figure 19: Pressure contours at $t = 35$ hours.

Figure 20: Gas phase fraction profiles at $t = 35$ hours.
Figure 21: Pressure contours at $t = 14$ days.

Figure 22: Gas phase fraction profiles at $t = 14$ days.
4.2.3.2 Simulating a borehole flow

To illustrate the application of this method to the practical simulation of horizontal boreholes, the above model is used to simulate a two phase flow in an inseam borehole of 30 metres length. The computational domain includes the borehole of diameter 96 mm, a coal seam with...
thickness of 4 metres and the layers of rock (assume shale) of thickness of 2 metres confining the coal seam. For convenience, the domain is assumed as axisymmetric, as shown in Figure 25. It is assumed that the boundary pressure on the shale is 2.83 MPa, and the outlet pressure at the exit of the borehole is decreased linearly from 2.83 MPa to 0.101325 MPa in 20 minutes. The permeability for the shale is assumed constant as 10-19 m², and for the coal seam is variable which increases from 10-19 m² when pressure is 2.83 MPa to 10-16 m² at the final stage when pressure decreases to 0.101325 MPa. Some of the results are shown in Figures 26 to 29.

Pressure reduction starts from near the borehole wall and extends into and within the coal seam accompanying gas release. When it comes to the final stage of 2880 days (2.49x10⁸ s), the pressure in the coal seam has reduced to atmospheric pressure (see Figure 26), and the fraction of the gas phase is shown in Figure 27.

The predicted rate of gas production and accumulation of gas are shown in Figures 28 and 29. As the simulated coal seam is confined in a cylindrical column of radius 2 metres, the predicted gas production rate and gas accumulation volume is relatively small. To simulate a coal seam with a large lateral width, a 3-D model will be needed, which is possible but requires larger computational time.

**Figure 25:** Meshed computational domain of borehole and coal seam and confined rock layer.
Figure 26: Contours of pressure at $t = 2880$ days (pressure on Y axis). The coal seam has been reduced to atmospheric pressure.

Figure 27: Gas fraction at 2880 days.
4.2.4 Discussion

A model for simulating inseam borehole gas flow has been presented. This method treats the gas emission as a source term. The generation rate of the source is derived from the Langmuir isotherm equation, which depends on pressure and the rate of pressure change. By incorporating this equation with the widely used CFD code FLUENT, the model is able to simulate gas flow within a coal seam and borehole. The simulation results for the gas emission
of a core sample of coal agree well with experimental data, indicating the applicability of the
developed method. Application of the simulation to borehole flow provides an accurate
predictive tool for gas release, accounting for variability of flow parameters including pressure,
phase fraction and temperature. This technique can be used to improve the understanding of
gas release and flow mechanisms operating within a coal seam and borehole. As this model is
complementary with FLUENT code, it is easy to use. With FLUENT’s strong pre-processing,
post-processing and computation functions including multiphase, porous medium and
compressible flows, this model has the potential to be used to simulate various geometries and
flows related to gas adsorption and desorption described by the adsorption isotherm, including
horizontal drilling applications and potentially, experimental programs related to
geosequestration.

5 Conclusions and recommendations

This project has addressed two separate issues relating to inseam directional drilling, namely
the development of a coal seam gas simulation tool using an off-the-shelf engineering package
(FLUENT), and the identification of key issues in current inseam drilling practice including
recommendations for future development.

The simulation package is now in a form that it could be further developed and used as a tool
to investigate gas drainage issues in coal seam boreholes. It is recommended that further work
be initiated to improve the user friendliness of the software, and distribute it to gas drainage
practitioners.

Inseam drilling as it currently exists has limitations that are only likely to be more problematic
as mining continues into areas of higher reservoir pressure and increased seam depth. Some
of these problems can be at least partially overcome by moving the predrainage function to the
surface, and the utilisation of MRD or other surface based techniques is likely to increase in the
future relative to underground inseam drainage.

However, a step change in inseam drilling practice is needed that in particular, addresses the
issue of balanced control during drilling, geosensing issues, and borehole (“well”) completion
practice. Current empirical, experience based, reactive inseam drilling systems are not
efficient, and need to be improved.

The work that has been carried out to date by CRC Mining on Coiled Tubing Systems for
underground applications is well advanced and addresses most of the key underground drilling
issues. It is the authors’ opinion that Coiled Tubing offers the best opportunity to significantly
improve underground inseam drilling and drainage practice and that this project should be
supported by industry and receives focused, output driven research funding.
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7 References


