Investigations Into the Effectiveness of Water Infusion Using the Radio Imaging Method (RIM)

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Three different methods of water infusion were studied to ascertain the most appropriate for the prevailing conditions at BHP Steel's Appin Colliery. This project demonstrates an innovative application of RIM which has been used to better understand the migration of water during the infusion process.

1. Introduction
At Appin Colliery an extensive pattern of methane drainage holes is utilised to reduce the content of in-seam methane. This drainage also reduces the moisture content of the coal. Because the coal is then dryer, it is also dustier during the extraction process. In an effort to lower dust concentration, water infusion has been initiated at the colliery with some success. The electromagnetic geophysical technique known as RIM (Radio Imaging Method) has been used in an attempt to: quantify the extent of water infusion; determine the effectiveness of the different infusion methods and to improve the overall understanding of water infusion technology. A description of the RIM technique is given in Thomson et al. (1990).

The RIM technique is highly sensitive to changes in the bulk conductivity of coal seams, normally caused by seam disruptions such as faults and dykes. In this case, the water introduced into the seam increases bulk seam conductivity significantly and this can be detected by the RIM signal. Bulk seam conductivity is proportional to the amount of water in the seam. Sophisticated tomographic modelling procedures enabled the RIM field data to be used to create an image of the spread of water within the block. This 'snapshot' may be used to provide a qualitative view of the relative effectiveness of various water infusion techniques.

During a routine RIM survey of Longwall 22, results were observed to be highly erratic across a zone of water infused coal (Doyle, 1991). As a result of this observation a survey was commissioned to cover an area of water infusion to determine the extent and the rate of water migration. An area of Longwall 22 was set aside to be water infused using three different techniques.

A follow-up survey program was undertaken across Longwall 23. During this second set of surveys only two of the techniques were compared.
2. Water Infusion Techniques
The first RIM survey covered an area of three borehole fans. Each fan covered different segments of the longwall block ranging in length from 120 to 170 metres along the roadway. When this distance is multiplied by the longwall width (200 metres) and the seam thickness, a coal volume is determined. The layout of the test areas can be seen in Figure 1. The three different techniques used were described as the “non-bagged”, “semi-bagged” and “fully-bagged” methods (see Figure 2).

The “non-bagged” method basically consists of pumping water into a bore and sealing the extremities of the holes. It appears to be an inferior technique because water loss occurs through the ribs into the roadways.

The “fully-bagged” method of water infusion involves the sealing of boreholes at spacings of approximately 16 to 20m down the borehole. This grouting procedure effectively installs obstacles in the path of the water. It was hypothesised that the water is forced out into the coal around these bags.

Figure 1. Mine and Survey Layout.
bour and materials, the fully-bagged method needed to be proved to be a better technique than the others.

3. Geological Conditions
Within the Test Areas
The two areas tested (Longwall 22 and Longwall 23) contain some minor geological features such as jointing and minor strike slip faults. In Longwall 22, these features appeared to affect the areas covered by the semi- and non-bagged methods more than the fully-bagged area which was relatively free from geological structure. In Longwall 23, geological structure appears to affect the area covered by the fully-bagged technique, more than the semi-bagged area. Despite these minor variations, the geology of the test area can be considered as relatively similar throughout the zone of interest.

4. Rim Surveys - Longwall 22
Program
Two tomographic RIM surveys were undertaken over a period of ten days. The results from a previous direct-ray survey conducted in July 1991 were used as a base line. As each survey was conducted the direct-ray results were extracted from the tomographic results and used to check the progress of water infusion for the three different techniques.
Table 1: Longwall 22, Flow Rates For Water Infusion and Associated Ratios.

<table>
<thead>
<tr>
<th>TECHNIQUES</th>
<th>TOTAL WATER INPUT (m³)</th>
<th>TOTAL BORE LENGTH (m)</th>
<th>COAL VOLUME (m³)</th>
<th>RATIO WATER INPUT / BORE LENGTH</th>
<th>RATIO WATER INPUT / COAL VOL.</th>
<th>RATIO COAL VOL / BORE LENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully-bagged</td>
<td>1250</td>
<td>1450</td>
<td>85000</td>
<td>0.86</td>
<td>0.015</td>
<td>58</td>
</tr>
<tr>
<td>Semi-bagged</td>
<td>1500</td>
<td>1000</td>
<td>60000</td>
<td>1.50</td>
<td>0.025</td>
<td>60</td>
</tr>
<tr>
<td>Non-bagged</td>
<td>1200</td>
<td>1250</td>
<td>75000</td>
<td>0.96</td>
<td>0.016</td>
<td>60</td>
</tr>
</tbody>
</table>

4.1 Direct-ray Results

Figure 3 shows the results of the direct-ray readings over the program. The initial results in July show a relatively even attenuation rate of between 15 and 20 dB/100m. After the first tomographic survey the results indicated a dramatic increase in attenuation response in the area of the fully-bagged method. A small increase in attenuation was observed for both of the other techniques. The first survey of the water infused area was undertaken on the 17/11/91, 3 days following the commencement of infusion.

On the 24/11/91 a further RIM survey was conducted. The direct-ray results generally showed a dramatic across-the-board increase in attenuation rate. The semi-bagged and non-bagged methods show a steep gradient on the 'dry' coal sides, reflecting a sharp cut-off in the effective migration of the water-infused zone. The fully-bagged area shows a broad high attenuation result indicating a high level of water saturation.

4.2 Water Volume

From the start of this project, water meters were used to measure the exact amount of water placed into each fan system so that a fair comparison could be made (see Table 1). The table shows water input, the total borehole length, and the volume of coal covered by the boreholes in each fan site.

To compare the three techniques used in Longwall 22, three ratios were used to take into account variations in borehole length and coal volume. The ratio of water to bore length is basically telling us how much water went into a unit length of borehole and therefore the higher the result the better the infusion. The semi-bagged holes performed much better in this case. The ratio of the water input to coal volume indicates the level of saturation. In this test the semi-bagged method stored 1m³ of water in 40m³ of coal whereas the other methods stored less water in the same coal volume. The final ratio of coal volume to bore length simply allows us to determine if the areas we are examining are comparable. In this case, because of the closeness of the result, it demonstrates that although we have quite different areas the borehole coverage in each was relatively equal.

4.3 Tomographic Results

Figure 4 shows the tomographic image after 3 days of water infusion. It shows the initial response (darker shades) of the area covered by the fully-bagged method, while the rest of the test area was relatively unaffected. Figure 5, after 10 days of infusion, shows a water saturated area dominated by geological control. The linearity appears to be related to structural grain, such as cleats.

![Tomographic Image 17/11/91](image)

Figure 4. Longwall 22, Tomographic Image 17/11/91.
Table 2: Longwall 23, Flow Rates for Water Infusion and Associated Ratios

<table>
<thead>
<tr>
<th>TECHNIQUES</th>
<th>TOTAL WATER INPUT (m³)</th>
<th>TOTAL BORE LENGTH (m)</th>
<th>COAL VOLUME (m³)</th>
<th>RATIO WATER INPUT / BORE LENGTH</th>
<th>RATIO WATER INPUT / COAL VOL.</th>
<th>RATIO COAL VOL. / BORE LENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully-bagged</td>
<td>300</td>
<td>1000</td>
<td>64000</td>
<td>0.38</td>
<td>0.005</td>
<td>64</td>
</tr>
<tr>
<td>Semi-bagged</td>
<td>650</td>
<td>800</td>
<td>70500</td>
<td>0.65</td>
<td>0.009</td>
<td>88</td>
</tr>
</tbody>
</table>

Following the completion of this stage of testing it appeared that the fully-bagged method was a more effective technique for raising the moisture content of the coal quickly. With time, however, the semi-bagged method appeared to allow greater volume and further migration of water through the longwall block. This is highlighted by the ratio of water input divided by borehole length (Table 1).

The non-bagged method was discarded due to its tendency to flood the roadways around it. Loss of water through the ribs produced a higher than expected ratio of water volume to bore length.

The results did not give sufficient information to ascertain individual borehole performance. It was decided that the snapshots taken by RIM had been spaced too far apart in time. To this end another program of water infusion was planned, with more survey runs conducted over a shorter period of time.

5. Rim Surveys
   - Longwall 23 Program

5.1 Direct-ray Results
The second series of tests focused on comparing the fully-bagged and the semi-bagged methods by infusing water into a single borehole within a fan. A set of seven tomographic runs were conducted from 15/12/91 to 29/12/91, covering an area of Longwall 23 (see Figure 1).

Figure 6 shows a comparison of the direct-ray survey results. Despite logistical problems and the loss of some data over the semi-bagged area, the results indicate a more intense infusion and a broader spread in the semi-bagged area.

5.2 Water Volume
In Longwall 23 the ratio of coal volume to borehole length for the fully-bagged method is 3/4 the value for the semi-bagged method (see Table 2). This suggests that the borehole fan used for the fully-bagged method provides a denser pattern of coverage of the longwall block, putting it at a slight disadvantage. However, even when this factor is taken into consideration, the semi-bagged method is clearly more efficient as the ratio of water volume to bore length as well as the ratio of water volume to coal volume for the semi-bagged method are almost twice that of the fully-bagged method.

5.3 Tomography Results
Seven tomographical images were produced over a period of 14 days. This set of images shows the progressive and gradual change in moisture content of the longwall. They also clearly demonstrate the inherent difference in the two infusion techniques used. Four images are included to show the changing nature of water in the coal (Figures 7-10). Infusion started on 18/12/1991.
Figure 7 shows the background attenuation rate of the area tested. The minor variation in response is believed typical of an area drained of methane, devoid of geological structure. Figure 8 highlights the two techniques, the fully-bagged on the left and the semi-bagged on the right after four days of water infusion (21/12/1991). A far greater response to water infusion is associated with the semi-bagged technique. Figure 9 illustrates the relationship after seven days (24/12/1991), and Figure 10 after 12 days (29/12/1991). The semi-bagged method clearly out-performed the fully-bagged method throughout the duration of the survey period.

6. Conclusions
The purpose of this project was to attempt to identify the most effective water infusion technique. Although the fully-bagged technique fulfilled statutory requirements with regard to dust counts, Appin Colliery decided that it wasn’t satisfactory to just pump the water in and hope for the best. The process needed to be proved and improved. This project has enabled the performance of the different water infusion techniques to be objectively evaluated. The sensitivity of the RIM technique to changes in conductivity due to water saturation has enabled snapshots of water infusion to be taken and compared.

By performing this study a modified technique, the semi-bagged method, has proven to be the most successful. This conclusion is expected to result in a saving of time, labour, resources and money to the colliery. The project illustrated the applicability of RIM as an analytical tool for the evaluation of fluid migration in coal seams.

7. Acknowledgments
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at all times, particularly Paul Thompson. Downunder Engineering designed and manufactured the bags used for grouting of the boreholes. The image processing capability developed by Glynn Rogers of CSIRO Division of Radiophysics played an important role in the success of the project. Darryl Grosse drafted Figures 1 and 2 and Jenny Ribeyro kindly typed the manuscript.

8. References
