Coal Mine Outburst
Mechanisms, Thresholds and Prediction Techniques

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Westcliff Colliery
Outburst Illustration 1
(Marshall et al)
Westcliff Colliery
Outburst Illustration 2
(Marshall et al)
Westcliff Colliery
Outburst Illustration 3
(Marshall et al)
Westcliff Colliery
Outburst Illustration 4
(Marshall et al)
Westcliff Colliery
Outburst Illustration 5
(Marshall et al)
Westcliff Colliery
Outburst Illustration 6
(Marshall et al)
Leichhardt Colliery Outburst Illustration, (Moore and Hanes, 1980)
Leichhardt Colliery
Outburst Cavity – Induced Cleavage Planes
Leichhardt Colliery
Outburst – Cleat Line
Pressures
Leichhardt Colliery – Cleat Pressure Stabilisation
Leichhardt Colliery
December 1978 Outburst Cavity
Bowen No. 2 Mine, Collinsville Faults, Outburst and Floor Heave Sites
Collinsville No. 2 Mine
Sketch of 53 ½ Level outburst in the six metre throw thrust fault.
View of southern ribside.
Gas Flow In Coal

Darcy Flow

\[ V = -\frac{k}{\mu} \cdot \frac{dp}{dx} \]

Diffusion

\[ F = -D \frac{dC}{dx} \]
Strain energy per unit volume of a biaxially stressed coal face is as shown in equation (1). This is simply the integral of stress and strain.

\[
W_d = \frac{1}{2} \varepsilon_r \sigma_r = \frac{1}{2} \sigma_r^2 \left( \frac{1 - \nu}{E} \right)
\]  \hspace{1cm} (1)

Where:
\( W_d \) = energy elastically stored per unit volume under biaxial states conditions
\( \sigma_r \) = uniform radial stress field
\( \nu \) = Poisson’s ratio
\( E \) = Young’s modulus
The coal surrounding the failing cylinder may also impart energy to the core by elastic release. This energy is given in equation (2).

\[ \frac{W_r}{Vol} = 2\sigma_r^2 \left( \frac{1 - \nu^2}{E} \right) \]  

(2)

Where:
- \( W_r \) = Energy due to elastic wall contraction on unloading
- \( Vol \) = Volume of cylindrical hole
- \( \sigma_r \) = radial stress
- \( \nu \) = Poisson’s ratio
- \( E \) = Young’s modulus
Potential Energy from Adiabatic Expansion of Gas

Equation (3) describes the potential energy available from adiabatic expansion of gas.

\[ W = \frac{P_1 V_1^\gamma}{(\gamma - 1)} V_1^{(1-\gamma)} \left( 1 - \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \right) \]  

(3)

Where:
- \( W \) = work performed
- \( P_1 \) = initial pressure
- \( P_2 \) = final pressure
- \( V_1 \) = initial volume
- \( V_2 \) = final volume
- \( \gamma \) = ratio of specific heats \( \frac{C_p}{C_v} \)
Energy available from 50 litres of gas expanding adiabatically to atmospheric pressure. Note 50 litres per cubic metre corresponds to a porosity of 0.05% in one cubic metre.
The energy available from expanding gas is by definition the integral of pressure with volume change. Mathematically this concept may be expressed in equation (4).

\[ W = \int_{V_1}^{V_2} P \, \delta V \]  

(4)

The energy available from gas being diffused out of a coal particle assumes that the gas comes out at a pressure and then expands to do work. The particle must be able to deliver this gas at a pressure and the gas must be able to expand. As the volume diffused is time dependent then the power of the expanding gas is dependent on time.
The equation (5) describes desorption from a cylinder with a uniform initial concentration.

\[
\frac{M_t}{M_\infty} = 1 - \sum_{n=1}^{\infty} \frac{4}{JOR_i^2} e^{-D \left( \frac{JOR_i}{a} \right)^2 t}
\]

(5)

where \( \frac{M_t}{M_\infty} \) is the ratio of desorbed gas over the total gas that may be released

\( JOR_i \) are the roots of a Bessel function of the first kind for the equation \( J_0(a\alpha_n) = 0 \)

\( D \) is the diffusion coefficient

\( t \) is time

\( a \) is the radius of the cylinder
Desorption from a Cylinder

For small values of \( Dt/a^2 \) equation (5) may be approximated to equation (6):

\[
\frac{M_t}{M_\infty} = \frac{4}{\sqrt\pi} \left( \frac{Dt}{a^2} \right)^{\frac{1}{2}} - \frac{Dt}{a^2} - \frac{1}{3\sqrt\pi} \left( \frac{Dt}{a^2} \right)^{\frac{3}{2}} + \ldots \tag{6}
\]
Solution to Diffusion from a Cylinder

Ratio of gas desorbed to total gas content vs. \(\frac{Dt}{(a^2\Delta)}\)

1st term approximation
2nd term approximation
3rd term approximation
True Solution
Square-Root Solution to Diffusion from a Cylinder

1st term approximation

2nd term approximation

3rd term approximation

True Solution

Ratio of gas desorbed to total gas content

sqrt(Dt)/a
Evaluation of $Dt/a^2$ using Equation (6)

Evaluation of $Dt/a^2$ for 5% and 10% errors using the 1st, 2nd and 3rd term solutions of equation (6).

<table>
<thead>
<tr>
<th></th>
<th>1st term</th>
<th>2nd term</th>
<th>3rd term</th>
<th>% error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Dt/a^2$</td>
<td>0.0125</td>
<td>0.265</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>$Dt/a^2$</td>
<td>0.050</td>
<td>0.40</td>
<td>0.625</td>
<td>10</td>
</tr>
</tbody>
</table>
Field Testing and Theoretical Diffusion Curves from a Cylinder
Diffusion Coefficients

Unfractured HQ Core (61 mm diameter)
- Desorbs 10% of gas content in 20 minutes.
- \[ D = 5 \times 10^{-9} \text{ m}^2/\text{s} \]

If the effective diameter = 20 mm (due to fractures)
- \[ D = 6.5 \times 10^{-10} \text{ m}^2/\text{s} \]
Work Done by Adiabatically Expanding Gas on Hypothetical Piston

Shear Zone

Failing Coal (Piston)

Development Roadway
The diffusion of gas from spherical particles is described by Crank (1975) in equation (7) which may be reduced to equation (8) for small values of $Dt/a^2$.

\[
\frac{M_t}{M_\infty} = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} e^{-\frac{-Dn^2\pi^2t}{a^2}} \quad \text{(7)}
\]

\[
\frac{M_t}{M_\infty} = 6\left(\frac{Dt}{a^2}\right)^{\frac{1}{2}} \left\{ \pi^{-\frac{1}{2}} + 2\sum_{n=1}^{\infty} ierfc \frac{na}{\sqrt{Dt}} \right\} - 3\frac{Dt}{a^2} \quad \text{(8)}
\]

$ierfc$ is the complimentary error function.
Volume of Coal Corresponding to Atmospheric Pressure

V1

V2

P2

P1

Gas Sorption Pressure
Diffusion from coal particles initially at concentration to P1; to edge corresponding to P2.

Adiabatic expansion from P2 to atmospheric pressure.

Adiabatic expansion = Potential to do work.
## Coal Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus, $E$</td>
<td>2.0 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio, $\nu$</td>
<td>0.3</td>
</tr>
<tr>
<td>Uniaxial Compressive Strength, UCS</td>
<td>12 MPa</td>
</tr>
<tr>
<td>Seam Stress</td>
<td>12 MPa</td>
</tr>
<tr>
<td>Seam Gas Pressure</td>
<td>4.0 MPa</td>
</tr>
<tr>
<td></td>
<td>$= 18.5 \text{ m}^3/\text{m}^3 = 14.8 \text{ m}^3/\text{tonne}$</td>
</tr>
<tr>
<td>Seam Void Ratio (Porosity)</td>
<td>2%</td>
</tr>
</tbody>
</table>
Sorption Isotherm for Gemini Seam, Leichhardt Colliery

\[ a = 28.295 \times \frac{0.5828 \times P_{\text{abs}}}{1 + 0.5828 \times P_{\text{abs}}} \]
Gas Energy Release, $D = 1\times10^{-8} \text{ m}^2/\text{s}$

![Graph showing the relationship between gas pressure and energy release for different coal particle sizes.](image-url)
Gas Make, $D = 1 \times 10^{-8} \text{ m}^2/\text{s}$

- $d = 0.1 \text{ m}$
- $d = 0.3 \text{ mm}$
- $d = 1 \text{ mm}$
- $d = 3.2 \text{ mm}$
- $d = 10 \text{ mm}$
- $d = 31.6 \text{ mm}$

$d$ => Coal Particle Size in mm

Gas Pressure, MPa

Gas Make, $\text{m}^3/\text{m}^3$
Gas Velocity In Roadway of 12.5 m²

$D = 1 \times 10^{-8} \text{ m}^2/\text{s}$
# Important Energies

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Strain Energy Release per m$^3$</td>
<td>0.16 MJ/m$^3$</td>
</tr>
<tr>
<td>Maximum Free Gas Strain Energy Release on Adiabatic Expansion</td>
<td>0.13 MJ/m$^3$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy From Diffusion, MJ/m$^3$</th>
<th>D=1x10$^{-8}$ m$^2$/s</th>
<th>D=1x10$^{-10}$ m$^2$/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 mm particles</td>
<td>0.94</td>
<td>0.47</td>
</tr>
<tr>
<td>1 mm particles</td>
<td>0.47</td>
<td>0.009</td>
</tr>
<tr>
<td>10 mm particles</td>
<td>0.009</td>
<td>0.001</td>
</tr>
</tbody>
</table>
TEST TECHNIQUES

• Finding Structure

• Finding Properties

• Solid Coal Outburst
Finding Structure

• Coring
  – Core Loss => Concern

• Monitoring
  – Gas Release
  – Cuttings Volume
  – Cuttings Size

• Torque and Thrust Sub

• Structure Size Important
Finding Properties

• Coring
  – Gas Content
  – Diffusion Coefficient (Conservative)

• Open Hole
  – Particle Size (Conservative)
  – Diffusion Coefficient (Particles may have degassed too much)
  – Use of Borehole Pressurisation Tool to get Undegassed Chips

• Pressure Sensing
Solid Coal Outbursts

• Will the Coal Fragment?
• Gas Pressure
• Stress
• Toughness
  – Measure of Energy to Propagate Fracture
• Core Test?
Solid Coal Outbursts Test

- **Axial Load**
- **Gas Pressure, P**

**Fully Gassed Core**

**Does the Core Fragment?**

- **Axial Load**
- **Gas Pressure Released**
Hargraves Emission Meter
Thank You

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