13 February 2014

APPLYING PREVIOUS RESEARCH ON SPONTANEOUS COMBUSTION TO DEVELOP RISK MAPS FOR UNDERGROUND MINES AT EXXARO

DISCARD BACKFILLING IMPLEMENTATION AT GROOTEGELUK MINE

Exxaro Mining Processes
Dr Stefan Adamski
Introduction
Exxaro Coal

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<th>REGIONAL LOCATION</th>
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<td>Limpopo</td>
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<td>2 Leuvupan mine</td>
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Exxaro Coal
Spontaneous Combustion Case

1. Grootegeluk - big problem within outside dumps
11. NBC - isolated problems within backfill dump
8. Arnot - risk of spontaneous combustion within UG old workings
9. Matla - risk of spontaneous combustion within UG old working
10. NCC - Expected risk of spontaneous combustion while stooping in future
11. NBC - isolated problems within backfill dump
What is spontaneous combustion?

Spontaneous combustion is an oxidation reaction leading to fire without an external heat source.

The process changes the internal heat profile of the material leading to a rise in temperature, when the rate of heat generation is higher than the rate of heat dissipation.
Main contributing factors to spontaneous combustion

Heat generation contributing factors:
- Total reactive (mostly Vitrinite)
- Volatile matter
- Raw Caloric Value
- Sulphur content
- Temperature, every 10 C degree increase of coal temperature doubles the rate of oxidation

Heat dissipation contributing factors:
- Thermal conductivity
- Heat radiation
- Migration processes of gases

Factors contributing to the movement of gases:
- Molecular diffusion and the density
- Barometric breathing
- Thermal breathing
- Wind pressure
- Natural convection
Other contributing factors to spontaneous combustion of coal

Intrinsic

- Coal composition, rank and petrographic constituents
- Coal friability, particle size and surface area
- Moisture content
- Presence of iron pyrites and sulphur

Extrinsic

- Climatic conditions
- Stockpile compaction
- Height and stockpiling segregation
- Slope angle
- Presence of timber or other organic waste material in abandoned areas or dumps
- Excavation-highwall stability and maintenance
- Ventilation
- Stoomping
Primary cause of spontaneous combustion in coal mining

Underground mines (UG)
- Crushed coal (goaf, highly stressed pillars)
- Sluggish airflow

Surface mine (SU)
- Coal stockpiles
- Coal waste dumps
- Highwalls - undressed
- Blasted mining blocks
- Wind
Impact of Spontaneous Combustion on working environment

Reaction linked to spontaneous combustion at short supply of oxygen

\[5C + O_2 + 3H_2O \text{(moisture)} = 3CO + H_2 + CO_2 + CH_4\]

Reaction associated to a big UG fire at discontinued oxygen access

\[4C + 3H_2O \text{(moisture)} = 3CO + H_2 + CH_4\]

Other reactions depend on mineralogical composition of coal deposit but the most probable products associated to spontaneous combustion are:

**Flammable gases:**

- Hydrogen \((H_2)\)
- Methane \((CH_4)\)
- Carbon Monoxide \((CO)\)

**Lethal gases:**

- Carbon Monoxide \((CO)\)
- Hydrogen Sulphide \((H_2S)\)
- Sulphur Dioxide \((SO_2)\)
- Nitric Oxides \((N_xO_y)\)
- Ammonia \((NH_3)\)

**Neutral (inert) gases:**

- Carbon Dioxide \((CO_2)\)
Risk
Risk related to spontaneous combustion

• Explosion of flammable gases and coaldust
• Inhalation of toxic gases
• Water and air pollution
Risk related to spontaneous combustion

- Inhalation of toxic gases
- Dump or coal pile explosions
- Instability of dumps/coal piles and uncontrolled subsidence or slope failure
- Water and air pollution
- Carbon dioxide pockets at lower areas of the pit
Learning
From
Incidents
The most probable development of the disaster was related to:

- *UG fire in the sealed area resulted by spontaneous combustion*
- *Explosion of the flammable gases in the sealed area carried over into the workings through the destroyed by explosion stopping system*
- *Transport of the associated to the spontaneous combustion toxic gases into the workings, by the explosion and after explosion due to diffusion and convection of the UG gases*

We learned:

Always isolate the abandoned areas with the well designed fire-stopping system
Five bricklayers were overcome by CO at Matla 2, one died.

**Comments**

*The goaf gases of three seams (5, 4 and 2) were contaminated by spontaneous combustion fire, developed most probably within seam 5.*

*Decrease of the barometric pressure in conjunction with the main fan depression pulled the goaf gases into the working area through the broken stopping, where the workers were present.*

We learned:

*Never approach the stopping at the goaf area without the gasses monitor. Ensure that no lethal gas is present within the working area.*
Two road-sweepers were poisoned by CO working in RAW of Boomlager 2

Investigation has found that:

- A carbonated waste dump on surface was undermined by a development section
- After the area was stooped the dumped subsided and cracked, developing spontaneous combustion
- Through the goaf area and the crack, the toxic gases produced by the spon com, within the dump, were sucked into the RAW

We learned:

Never stoop under coal waste dumps, especially in the shallow coal mines.
A general worker was poisoned by CO within the waste dump of carbonated waste

Investigation has found that:

- The worker during a winter’s night sat down within the dump to warm-up
- He was found dead the next morning

We learned:

“No Entry” notice-board at every coal waste dump for unauthorised person.
Never enter the coal waste dumps without gas monitor.
Ensure that no lethal gas is present within the working area.
Sharing Experience
from
Grootegeluk Mine
Iscor / Kumba Resources / Exxaro research at Grootegeluk

- Successful storage of middlings for more than 11 years before being reclaimed
- Stacking of discards in 1980, about 12m high without compaction
- Crushed waste test heaps in 1985
- A large-scale test performed in 1988 in a prepared excavation within the pit of GG

- The Radial Stacking Method
Problem of the current Radial Discard Dump

Conclusions

- The radial geometry of the dump causes a low stacking advance within the central part of the dump, which allows the development of spontaneous combustion.
- The height of the dump allows advanced segregation of the stacked material and a "chimney effect" due to very high permeability of the material at the bottom of the dump.
- The natural angle of the slope and the dump’s height increase the impact of wind pressure and allows for easy transportation of air into the dumps.
The objective for Grootegeluk Mine is to backfill all waste material at:

- Minimal Risk of Spontaneous Combustion
- Minimal Cost associated with the Backfilling Method
- Maximum Safety
- Uncomplicated Technology and Simple Code of Practice
Conclusions from the Grootegeluk Mine experience

• Use sealing to reduce oxygen inflow.

• Speed up stacking rates to ensure stack faces are exposed for the minimum period, (this will need careful planning and will be used in conjunction with other techniques).

• Compact the top layer of stacked material.

• Avoid the uncontrolled segregation during stacking – modification of size distribution and stacking methods.

• Adopt strategies that will minimise the probability of deep-seated combustion.
Tests Concluded during the Research 1998-2004

Chemical and physical properties of coal and coal waste per bench per waste

Petrographic analysis of drill core material per bench

Reactivity tests of coal and waste
  - WITS EHAC test
  - Glasser test
  - Straus test

Column sealing test
  - one column tests
  - two column tests
  - four column test
Sealing Model for Surface Sealing at Grootegeluk Mine

- Oxygen Depletion [%] vs Overburden Sealing Thickness [m] for Different Waste Materials:
  - 10% Ash Product
  - 15% Ash Product
  - Plant Discards
  - Inter-burden Bench 7A
  - Inter-burden Bench 8

- Reactivity after Glasser [ml of oxygen/kg/day] vs Temperature [degree C] for Inter-burden bench 7A & 8, Inter-burden bench 7A, 7B & 8, Plant Discards (All Plants Run):

Impact of the 3m thick sealing layer on temperature of sealed material, when reactivity of the sealed material will rise to 1000ml of oxygen/kg/day.
Combustion Risk at Grootegeluk Mine

Spontaneous Combustion Risk within Stacking Area at average Environmental Conditions

Exposure before Sealing [weeks]

- All plants running
- Only GG1 running
- GG3 & GG4/5 running
References


SIMRAC Project COL713, available on the following website: 
http://researchspace.csir.co.za/dspace/handle/10204/1285

Presentation of South African Institute of Mining and Metallurgy in association with Mining Alumni Society of the University of Pretoria, available on the following website: 
Backfilling into sealed compartments with fixed width that allows a constant stacking rate, has been found to be the optimum backfilling method for the Grootegeluk pit.

The most important suppositions of the theory are:

- Filling material into compartments at the appropriate stacking rate
- Building compartments with a fixed width
- Sealing of the compartments
- Isolate reactive waste from the pit high-walls
Main Standards of the Backfilling Method

According to the mathematical risk model the main standards are:

- **Slopes** within the stacking (dumping) area cannot be exposed to air (oxygen access) for longer than **8 weeks**

- **Surface** of any stacking level cannot be exposed to air (oxygen access) for longer than **3 months**

- Stacking dimensions and stacking rate must adhere to the above assumptions.
Construction sequence

- Parting i.e. inter-burden at the bottom of the pit
- Plant discards on top of the parting level, forming the following level/levels
- Hard OVB on top of the last discard level
- Soft OVB i.e. subsoil on top of the hard OVB
- Topsoil on top of the subsoil level, forming the rehabilitation process
North-South Section

- 10m thick overburden rehabilitation layer
- 32m U-System
- 35m L-System with 3m sealing layer
- 37m Level of Inter-burden constructed in 6m layers
- 40m Level of Inter-burden with 3m of sealing

Sealing Overburden

> 120m

B1, B2, B3, B4, B5
Stacking at 10m thick passes the tempo disallows spontaneous combustion within the slope. The slope is exposed for oxidation maximum 2 months. Therefore the slope does not require sealing.
May 2000 - Implementation of Inter-burden Backfilling

Trial - Step 1

Sub-level 1C

Place for Large-scale Discard Test
Trial – Step 2

Discards test

Demarcating the Sealing wall for the next year compartment

30-03-2001
Trial – Step 3

Area for the second test inter-burden benches 7-8

Discards compartment has been sealed
Monitoring system has been installed

Test 2
Bench 7A, B & 8

Test 1
Plant
Discards
The very stable conditions within all three compartments, the high quality of the backfilling process and involving all employees to understand the standards of the backfill process, allowed the management of Grootegeluk Mine to include the backfilling method into EMPR of Grootegeluk Mine.
Backfilling Continuation - 2003

- The first sublevel completed and sealed along slopes
- The second sublevel - under construction
- The new sump
Backfilling Progress - 2010
Conclusions from the Backfilling Test

The inter-burden material has a lower reactivity if compared to the plant discard, but the risk of spontaneous combustion of the inter-burden and mixed material is higher:

- Plant discard has a fixed material size distribution (equal permeability) and relatively small fluctuations of reactivity; therefore protection by a fixed sealing layer is safer due to equal internal conditions (i.e. lower impact of convection due to the equality of condition)

- Inter-burden material consists of bench 10 sandstone containing a small amount of highly reactive coal from bench 11 (combustion trigger), very low reactive bench 8 material and medium reactive bench 7a material; all material has variable permeability which depends on blasting results

In Conclusion, the inter-burden backfilling level requires more sealing attention
Discard Backfill Model for 2013-2014 Implementation

- Lower System
- Upper System
- Pedestal
- Inter-burden Level
Discard Backfill System

The plant discards backfill system consists of the following:
• Buffer capacity between the plant and backfill area
• Earthwork pedestals in the mining void for the initial position of the conveyor system
• Dual conveyor belt system, one on the lower level and another on the upper level. The conveyor system consist of overland conveyors, regenerative conveyor (decline conveyor), extendable conveyors and parallel shifting conveyors
• Two spreaders, one on each level of the backfill in the mining void
• Sealing layers of non-combustible material stacked by the use of mining equipment
Spreader and Stacking Philosophy
Discard Backfill System at Present (Implementation Phase)

Picture 1
Discard Backfill System at Present (Implementation Phase)

Picture 2
Discard Backfill System at Present (Implementation Phase)

Picture 3
Discard Backfill System at Present (Implementation Phase)

Picture 4
Discard Backfill System at Present (Implementation Phase)

Picture 5
Spontaneous Combustion Risk Mapping For Underground Mines
Examination of chemical constituents

- Caloric Value
- Petrological classification
- Ash content
- Volatiles
- Sulphur content

Thermal studies

- Initial temperature
- Crossing point temperature
  - Olpinski index
  - WITS-EHAC liability index

Oxygen avidity

- Glasser test
- Straus test
- Rate studies
- Russian U index
- Wet oxidation method
- $H_2O_2$ methods
- Other oxidation methods ($KMnO_4$ method)
Introduction to the Exxaro material risk model

Testing coal petrography is the best way to find the risk

Exxaro geological modeling does not include total reactives and Vitrinite content. Mining Processes risk modeling is based on the three most important material, contributing factor to the spontaneous combustion namely:

- **Volatile Matter**
- **Caloric Value**
- **Total Sulphur Content**

<table>
<thead>
<tr>
<th>Role</th>
<th>Spon Com</th>
<th>Risk</th>
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<tbody>
<tr>
<td>Weight</td>
<td>Contribution</td>
<td>Hazard</td>
</tr>
<tr>
<td>0.625</td>
<td>1</td>
<td>Volatile [%]</td>
</tr>
<tr>
<td>0.250</td>
<td>2</td>
<td>R CV [MJ/kg]</td>
</tr>
<tr>
<td>0.125</td>
<td>3</td>
<td>Tot R_S [%]</td>
</tr>
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</table>

Example of calculating the total risk indicator

Total Risk Indicator \(0.625 \times 5 + 0.250 \times 4 + 0.125 \times 2 = 4.38\)
Critical time and aggravating factors

Critical time is the time it takes to initiate the risk of combustion. The critical time was determined empirically at Grootegeluk Mine. The correlation between the risk indicator and the critical time is assumed, based on the practical experience and observations done at Grootegeluk Mine.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Total Risk</th>
<th>Critical time</th>
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</thead>
<tbody>
<tr>
<td>&lt;1.0-1.5</td>
<td>VL</td>
<td>&gt; 18</td>
</tr>
<tr>
<td>&lt;1.5-2.5</td>
<td>L</td>
<td>&gt; 12</td>
</tr>
<tr>
<td>&lt;2.5-3.5</td>
<td>M</td>
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<tr>
<td>&lt;3.5-4.5</td>
<td>H</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>&lt;4.5-5.0</td>
<td>VH</td>
<td>&gt; 1</td>
</tr>
</tbody>
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Aggravating factors: moisture and size of material

<table>
<thead>
<tr>
<th>Contribution of:</th>
<th>Moisture</th>
<th>Size of Material</th>
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<tbody>
<tr>
<td>Decreasing risk when going down</td>
<td>High for blasted or naturally crushed</td>
<td>Low for segregated coarse</td>
</tr>
<tr>
<td>Neutral when constant</td>
<td>Medium for segregated fine</td>
<td></td>
</tr>
<tr>
<td>Increasing risk when rising</td>
<td></td>
<td>High for blasted or naturally crushed</td>
</tr>
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</table>
Risk Mapping
Arnot
Spontaneous combustion material risk model for Seam 2 lower
Risk Mapping
Diepspruit
Spontaneous combustion material risk model for Seam 2t
Spontaneous combustion material risk model for Seam 2p
Spontaneous combustion material risk model for Seam 2s
Risk Mapping
Matla
Spontaneous combustion material risk model for Seam 5
Spontaneous combustion material risk model for Seam 4 lower
Spontaneous combustion material risk model for Seam 2
Exxaro Way Forward
“I know my coal” and what next?

- Mine design (layout, mining method and LOM plan) according to the material risk
- Best mining practices preventing, minimizing and monitoring the risk
- “Early Warning” system
- Spontaneous Combustion Community of Practice (CoP)
- Regular audits
Thank You