IMPACT of COAL QUALITY on COMBUSTION
and POWER GENERATION

Southern African Scenarios and challenges in
Clean Coal Technologies

Rosemary Falcon, Roland Zepeck, Mike Andrews

Powergen, Johannesburg November 2012
Outline

1. **Introduction** - low carbon economy, dependence, prod users, qualities

2. **Current experiences in combustion performance**

3. **Advanced Methods of Investigation**
   - Coal Quality Assessments
   - Temperature Assessments using Thermography
   - Observations

4. **Conclusions**
1. Introduction

- **Relevance of coal in SA** -
  
  Highest dependence on coal in the world
  
  - 92% of energy/electricity is coal-based,
  - 14 major coal-fired power stations
  - 6,000 industrial boiler users
  
  40% of liquid fuels derived from CTL
  
  Major foreign exchange earnings

- **Commitment to a Low Carbon Economy** -
  
  South Africa is committed to GHG and CO₂ reduction

- **Methods to reduce GHG emissions**
  
  CCS; Increased combustion and boiler efficiency
Future Technologies for a Low Carbon Economy
i.e. Reduction in both GHG and non-GHG (NO$_x$, SO$_2$, PM) emissions.

Technologies for cleaner coal generation

(1) Reducing coal consumption
(increase boiler efficiency)

(2) Reducing of non-GHG emissions

(3) Carbon Capture and Storage

Pollutants to be reduced
• SO$_2$, NO$_x$, Mercury
• Particulate matter

CO$_2$ Capture
N$_2$, H$_2$O

CO$_2$ Storage

Technologies shown:
- Mill to Boiler for coal combustion
- Condenser for water cooling
- Steam flow
- Turbine for power generation
- Generator
- De-NO$_x$ and De-SO$_x$ for pollution control
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Challenges in the Coal Industry - 1

- **Run-of-mine coal qualities** are generally poor (high ash)
- **Beneficiation** of coal is a “must” (difficult)
- **Bulk of the best quality coals** have been mined out in conventional areas
- **Remaining coal resources** lie in relatively remote coalfields
- **Infrastructure** in those areas is as yet lacking (also many are difficult to mine conventionally)
Challenges in the Coal Industry - 2

- **Increasing export tonnages to the India and the Far East** leaves poorer grades for local markets
- **Increased costs** to obtain higher grades and qualities of coal
- **Variable combustion efficiencies** occur due to poor and variable feedstocks
- **Environmental constraints** increasingly stringent post 2012 (SO$_x$, NO$_x$, CO$_2$, particulates); C tax pending
Power Station L –
- Extreme difficulty in ignition
- Required 7 burner designs (Mark 7)
- 10m added to height of boiler
- 1m extra between rows of burners
- Tube mills selected to ensure extra fine pf sizes
- Burner mouths melted
- Pop-corn fly ash blocked air heaters
- Unusually high % of fly ash

Power Station M –
- Ignition and combustion difficulties when using coal from different zones in the coal sequence (non-design coals)

Unscheduled outages sometimes occur at a rate of one a week per boiler in some power stations
RISE IN CO$_2$ IN ESKOM OVER 10 YEARS

Eskom grid emission factor

<table>
<thead>
<tr>
<th>Year</th>
<th>t CO$_2$e / MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0.90</td>
</tr>
<tr>
<td>2003</td>
<td>0.90</td>
</tr>
<tr>
<td>2005</td>
<td>0.91</td>
</tr>
<tr>
<td>2007</td>
<td>0.92</td>
</tr>
<tr>
<td>2009</td>
<td>0.93</td>
</tr>
<tr>
<td>2011</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>0.98</td>
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<td>0.99</td>
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</tbody>
</table>
Spreader stoker Boilers:

- Poor ignition when air-born
- Delayed combustion
- High level freeboard fire-ball
- Extreme slagging and fouling
- High percentage fines carryover
- Excessively high back end temperatures
- Excessively high temperatures on the grate, melting and fusing of chains and refractory linings
FLUIDISED BED BOILERS

- Corrosion of the sparge pipes below the rims
- Agglomeration of particles within the moving bed
- Ash deposits dropping down to the base
- Difficulties in ash removal
- Difficult temperature control

During the commissioning of one bubbling bed boiler, the entire bed slagged.
CEMENT KILNS

Flame configuration, heat transfer and burnout change with coal type - Grade, CV and proximate analyses are the same

Desired effect – short hot flame

Problem effect – long flame
## SPECIFICATIONS OF TWO COALS

NB: THE SAME PROXIMATE ANALYSES
BUT DIFFERENT COMBUSTION PROPERTIES

<table>
<thead>
<tr>
<th></th>
<th>Coal A</th>
<th>Coal B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross Calorific Value</strong> (MJ/kg ad)</td>
<td>28,70</td>
<td>28,93</td>
</tr>
<tr>
<td><strong>Proximate Analyses</strong> (% ad)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inherent Moisture</td>
<td>3,7</td>
<td>2,4</td>
</tr>
<tr>
<td>Volatile Matter %ad</td>
<td>30,5</td>
<td>28,9</td>
</tr>
<tr>
<td>Ash Content %ad</td>
<td>11,1</td>
<td>12,2</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>54,7</td>
<td>56,5</td>
</tr>
<tr>
<td><strong>Combustion efficiency</strong></td>
<td>83,0</td>
<td>66,0</td>
</tr>
<tr>
<td>C in ash%</td>
<td>4,4</td>
<td>15,5</td>
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**Slagging** can occur even when ash fusion temperatures are **high**

**Unburnt C in ash** can be as high as **73%** in some industrial boilers; often **25-35%+**
It has therefore become vital to find ways to:

- increase combustion efficiency
- Increase power generating capacity
- Reduce outages (due to slagging, fouling, water tube/wall damage etc)
- Minimise GHG and especially CO₂ emissions
Outline

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     Temperature Assessments using Thermography
     Observations
4. Conclusions
COAL QUALITY ASSESSMENTS FOR COMBUSTION

EMPIRICAL PROPERTIES

### Chemical and Physical Analyses

<table>
<thead>
<tr>
<th>OTHER</th>
<th>ASH</th>
<th>ULTM</th>
<th>PROXIM.</th>
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<tbody>
<tr>
<td>CV</td>
<td>SiO₂</td>
<td>C</td>
<td>H₂O</td>
</tr>
<tr>
<td>AFT</td>
<td>Al₂O₃</td>
<td>H</td>
<td>VM</td>
</tr>
<tr>
<td>Si</td>
<td>Fe₂O₃</td>
<td>O</td>
<td>ASH</td>
</tr>
<tr>
<td>HGI</td>
<td>CaO</td>
<td>N</td>
<td>FC</td>
</tr>
<tr>
<td></td>
<td>MgO</td>
<td>P</td>
<td></td>
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Conventional analyses
MACERAL BURNOUT TIMES AT 1,000°C AND A VELOCITY OF 11 m/sec

- INERTINITE
- 15 m
- VITRINITE
- 10 m
- 5 m difference
BEHAVIOUR OF COAL LUMPS ON HEATING
- BITUMINOUS COAL -
DOMINANT FORMS OF CHAR DERIVED FROM BITUMINOUS COAL

HIGHLY POROUS AND REACTIVE

MIXED SEMI-POROUS AND DENSE INERT

DENSE INERT NON-REACTIVE
Power station L

Coal particle (feed) and Unburnt char particle (in fly ash)

NB: inert carbon form in char is unchanged

\[T^\circ C \text{ in Boiler estimated to be } 1800^\circ C\]
### Specifications of Two Coals

**NB: The same proximate analyses but different combustion properties**

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</tr>
<tr>
<td><strong>Petrographic Composition</strong> %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maceral comp (vitrinite%)</td>
<td>62,0</td>
<td>30,0</td>
</tr>
<tr>
<td>Rank (RoV random%)</td>
<td>0,73</td>
<td>0,75</td>
</tr>
</tbody>
</table>
ORGANIC MATTER VARIES ACCORDING TO

Age, Continents and Regions (Gondwana to Laurasia)

Nature of the coal seam

Mine plan and extraction procedures

Levels of Beneficiation
Age, Continents and Regions

Qualitative Organic Matter differences between Carboniferous Laurasian and Permian Gondwana Coals

<table>
<thead>
<tr>
<th>Organic Petrographic components</th>
<th>Key Technological Property on heating</th>
<th>GERMAN COAL RUN-OF-MINE</th>
<th>SOUTHERN AFRICAN RUN-OF-MINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive vitrinite</td>
<td>80</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Highly reactive Liptinite/exinite</td>
<td>10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Inert to semi-inert Inertinite</td>
<td>10</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Ash %</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

* Petrographic observations indicate that reactive macerals ignite and burn out fast whereas inert maceral forms undergo delayed ignition and combustion.
Nature of the coal seam
Mine plan and extraction procedures

COAL QUALITY CHANGES SUBJECT TO MINE PLAN
- WHOLE SEAM OR SELECTED PARTS OF THE SEAM -

- Hanging wall
- Upper dull coal
- Mid-seam parting
- Lower bright t coal
- Foot wall

Whole seam mining
Selective mining

Dull coal is **inertinite** rich and poorly reactive
Bright coal is **vitrinite** rich and highly reactive
ASH, VOLATILE MATTER AND MACERAL CONTENT CHANGES WITH BENEFICIATION

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>ASH %</th>
<th>VOLATILE%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low ash</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>Middlings 1</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td>Middlings 2</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>Discard</td>
<td>75</td>
<td>10</td>
</tr>
</tbody>
</table>
## Facts and Fantasies

<table>
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<th>FACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV, proximate, ultimate and ash analyses are sufficient to market and select a coal</td>
<td>NO – coals from different geographic regions, collieries, seams, washed products will require <strong>in-depth analysis and technical assessment</strong> to ensure efficient combustion performance</td>
</tr>
<tr>
<td>All volatiles are combustible</td>
<td>NO – some are <strong>incombustible and inert</strong>; this is evident especially in coals with ash contents &gt;20%; e.g. CO₂ from carbonate minerals and H₂O from clays</td>
</tr>
<tr>
<td>Low volatile coal is not likely to ignite and combust</td>
<td>NO – there are certain coals with low volatiles which <strong>will ignite and combust if the combustion conditions are suitable</strong> – BUT IT IS NECESSARY TO COMPENSATE FOR THE MORE EXTREME CONDITIONS NECESSARY TO BURN THEM</td>
</tr>
</tbody>
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Lateral view of thermal camera into grate-fired boiler – computer determines temperature based upon colour
Grate fired – delayed combustion 2

COAL X- Sequence 2
Grate fired – delayed combustion 3
COAL X- Sequence 3
Grate fired – delayed combustion 4

COAL Z
PF-Boiler - Power station A

NB: Top of an off-centre fireball – temperatures 1700°C ++
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- Proximate (volatiles and ash analyses) and calorific value **alone do not indicate how coals will burn**, at what temperatures and for how long.

- There is clear evidence that **certain coals burn at higher temperatures** than was previously thought.

- There is also clear evidence of **delayed combustion** – longer than previously believed.

- These facts are likely to have **significant impact on boiler operation** and combustion efficiencies *e.g.* *Thermal damage to water tubes and superheaters, clinkering and excessive NOx formation*.

- These facts are likely to have **significant impact on future boiler design**, *e.g.* *Requiring high temperature steels in boiler manufacture*.

- Further work needs to be done to study combustion performance linked to more specific properties of coal and using thermography to control and achieve higher combustion efficiencies.
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Conclusions

- **Anomalous combustion behaviour can be explained**
  - By in-depth analysis of coals (petrographic composition)
  - By observation and monitoring *in situ* using on-line thermography

- **Combustion and thermal efficiency can be improved and controlled**
  - By monitoring combustion behaviour via thermography
  - By adjusting operating conditions in real time

- **Significant reductions in CO$_2$ and NOx emissions can be achieved**
  - by ensuring optimum combustion and burn-out
  - by maintaining maximum steam output
  - By reducing slagging, fouling and water tube failures and minimum outages
Energy – source of Industrialisation! Africa needs this....

Coal provides over 45% of the world’s energy requirements