Gasification of Australian and North Dakota Lignites in a Pressurised Fluidized Bed Gasification Process Development Unit

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Dried Coal

- Feed Rate: 250 Kg/hr
- Max. Pressure: 10 bar
- Max. Bed Temperature: 1000°C
- Modifications by the PDU team
- Sampling points

Fuel Gas

Gas Cooler

Clean Fuel Gas

Flue Gas

Steam (4 levels)
Air/O2 (5 levels)

N₂
PLANT SERVICES

- COOLING TOWER
- GAS ANALYSIS
- AIR
- COAL
- PDU GASIFIER
- FLARE
- SCRUBBER
- BOILER
- N2

Cooperative Research Centre for
CLEAN POWER FROM LIGNITE
BROAD OBJECTIVES

• Data on gasification of Victorian and SA lignites - scant

• Generate engineering data for design of gasification based power systems

• Generate data for development / validation of gasifier mathematical models

• Generate data to compare with those generated using laboratory rigs & instruments

• Provide other data as appropriate to the needs of advanced power generation process
  • bed level control
  • particle size/ moisture restriction - flow through the lock hoppers
  • assess agglomeration
TEST PROGRAM

• Victorian lignites
  • Loy Yang
  • Morwell
  • Yallourn
  • Mixed - 80% Loy Yang, 20% Yallourn, commercially procured
  • Char - from Yallourn lignite, commercially procured
  • Mixed “briquetted coal - Gruss” 80% Loy Yang, 20% Yallourn, commercially procured

• South Australian lignite
  • Lochiel - with and without dolomite/limestone

• North American lignite - as part of the CAP program
  • Falkirk
  • Freedom
  • with and without dolomite

• Steam-air gasification
• Steam-oxygen (enriched air) gasification
  • first time attempted
<table>
<thead>
<tr>
<th></th>
<th>Lochiel</th>
<th>LoyYang</th>
<th>Morwell</th>
<th>Yallourn</th>
<th>Char</th>
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</thead>
<tbody>
<tr>
<td>Moisture, %</td>
<td>60.3</td>
<td>59</td>
<td>59</td>
<td>62.0</td>
<td>7.1</td>
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</tbody>
</table>

**Ultimate, dry basis, %wt**

<table>
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<tbody>
<tr>
<td>Carbon</td>
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<td>67.8</td>
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<td>65.4</td>
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<td>Hydrogen</td>
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<td>4.7</td>
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<tr>
<td>Nitrogen</td>
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<td>0.66</td>
<td>0.63</td>
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<td>Oxygen</td>
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<td>25.4</td>
<td>24.1</td>
<td>26.7</td>
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<td>Sulfur</td>
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<td>Ash</td>
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<td>1.10</td>
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<tr>
<td>Sodium</td>
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<td>0.065</td>
<td>0.079</td>
<td>0.067</td>
<td>0.12</td>
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<td>Chlorine</td>
<td>0.50</td>
<td>0.06</td>
<td>0.04</td>
<td>0.05</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Particle Size**

- Lignites: 900 μm mean size, 30-42% below 350 μm; coarser sieved feed
- Char: 2 mm mean size
VIC: 6400 of 7800 MW
66 mt coal

SA: 760 of 3100 MW
3.3 mt coal

source: ESAA 2002
• Gas yield/composition and C-conversion
  • as a function of p, t and other variables
  • target C-conversion >85%
  • target LHV: no less than 4 Mj/kg (~95 Btu/SCF)
  • optimise temperature & reactant concentration at fixed pressures - for each coal

• Elutiation and loss of fines
  • assess elutiation levels
  • control
    • fine fraction in feed coal
    • hydrodynamics in riser/recirc loop - freeboard gas, purge, pulse frequency and quantity
    • control of bed C (bed material)
ENGINEERING DATA - 2

• Product gas
  • CO, H₂, CH₄, C₂H₆, >C₂H₆, CO₂, N₂
  • NH₃ (in gas and condensate), HCN
  • COS, H₂S, CS₂
• Alkali level in gas and Control
• Control of NH₃ and H₂S
• Tar
• Condensate - Na, Ca, Mg, Cl, S=, TOC, phenols (2/3 methyl, dimethyl/ethyl)

• Assess agglomeration propensity
  • long-term tests
  • control
    • additive (simultaneous control of NH₃ and H₂S)
    • bed drainage
  • solid samples - TMA, XRD and Quantitative X-ray Mapping
TEST PROGRAM

• 11 commissioning/recommissioning tests - with YL char and various coals
  • test the full P/T/feed rate capabilities
  • bed level maintenance

• Actual tests - 77 successful attempts in total
  • total gasification hours ~400

• 51 air-blown tests
  • 3 - 8 bar, A/F ~1.8-2.5, steam/ F ~0.2-0.4
  • 750-900C average bed temperature
  • up to 950C freeboard temperature

• 26 O2-blown tests (concentration of O$_2$ up to 35% w of total inlet gas - steam, air, purge nitrogen)
  • 8 bar, ~760-900C average bed temperature

• duration of test: 3 - 32 hrs
RESULTS : C-conversion

- C-conversion: 75-87% for VIC lignites, 75-83% for Lochiel
  - Higher C-conversion with coarser feed and/or “Gruss”
  - Up to 3% point increase during O₂-runs

- Factors affecting C-conversion
  - Coal type (reactivity, attrition resistance)
  - Concentration of fines (<100 micron) in feed coal
  - Elutriation of fines, originally present in coal and fines generated due to attrition/reaction
  - Coal feed rate and reactant (steam, oxygen) concentration, P, T
  - Bed drainage - bed level control - a must for FB gasifiers
  - Recirculation of fines - cyclone efficiency, pulsing and purge in recirc leg
  - Low ash coals - C-conversion limited by elutriation
  - High ash coals - C-conversion limited by elutriation and bed drainage

- Higher C-conversion expected with
  - Coarser coal feed and
  - Double/more efficient cyclone
  - Increased residence time/taller gasifier - work in progress with CSIRO
RESULTS: Fuel gas

- No tar observed during steady state measurement period
- Gas composition (VIC and SA lignites) - as measured
  - air-blown
    - 11-15% H₂, 10-20% CO, 0.7-2.5% CH₄, ~1% C₂H₃, 10-16% H₂O
    - 2.7-4.1 MJ/kg (65-97 BTU/scf) LHV
    - up to 1600 ppm NH₃, 100 ppm HCN, 100 ppm COS
    - ~3000 ppm H₂S (Lochiel coal) without dolomite, <50 ppm with dolomite (Ca/S molar ratio = 2)
    - no detectable sulphides during Victorian lignite based tests
  - use of dolomite also reduced NH₃ levels by ~50%

- O₂-blown (O₂- enriched air)
  - 15-24% H₂, 15-24% CO, 1-4% CH₄, >1% C₂H₃, 10-18% H₂O
  - 3.5- 5.6 MJ/kg (71-133 BTU/scf) LHV
  - higher levels, up to 1800 ppm NH₃, than air-blown tests

- all alkali in char or filter fines
RESULTS: Fuel gas

- Fuel gas LHV, as measured, is combustible
- Gas composition during short and long duration tests similar
- Tests with freeboard $O_2$ and steam, and steam distribution
  - Total combustibles ($CO, CH_4, C_2H_y, H_2$) increased
  - Fines elutriation decreased slightly
  - C-conversion improved
  - No effect of steam distribution in bed

- PDU units
  - Large surface/volume ratio - large heat loss, large air/fuel ratio
  - Cooling effect from large quantities of air/N2 purge
  - Low bed height

- Fuel gas LHV from larger/taller units will be higher, as these will
  - Allow higher freeboard temperature (less wall effects)
  - Longer residence time with deeper bed, and expanded freeboard
  - Higher $O_2$ concentration in the feed reactants
  - Use of recirculated fuel/flue gas instead of N$_2$
OTHER OBSERVATIONS

• Fines from Attrition/reaction: 6-8% of the coal feed

• Combustion tests on filter fines in a pf environment
  • 3-4 secs, 1100C and 1250 C, 20% excess air
  • burnout >99% at 1250C
  • only 5-20% of the original water-soluble form of the alkaline metals (Na, Ca, Mg) present in fines

• Char morphology
  • Porous inside, but fused on the surface
STRATEGIES: for stable operation, reduce fouling/agglomeration

- **Lochiel lignite**
  - require Dolomite (rather than the limestone tested) for control of $\text{H}_2\text{S}$ and bed fouling
  - bed temperature $< 800\text{C}$, while freeboard temperature $\sim 850\text{C}$ by $\text{O}_2$-injection improve C-conversion and gas composition
  - continuous bed drainage (up to 6% of solid feed) necessary to maintain bed level and bed renewal, as this lignite has high ash content relative to VIC lignites

- **Victorian lignites**
  - bed temperature $\sim 900\text{C}$, while freeboard temperature $\sim 950\text{C}$ by $\text{O}_2$-injection to improve C-conversion and gas composition
  - small continuous bed drainage (1-2% of solid feed) necessary to maintain bed level and bed stability during long-duration tests

- **Ensure steady coal feed to have stable bed level**
  - moisture content up to 18% for steady feeding
  - exclude the “woody” and “fines” fraction during coal preparation
STRATEGIES: Woody/lump in coal feed
OPERATING ISSUES

Fouling - sintered deposits in bed, light and brittle

Range of rates
0.05-0.9 kg/run
for coal feed 130-200 kg/hr

XRD: mainly sulfates, silicates, but trace Sodalite and Halites
TMA: low temperature compounds 800-850°C
COLLABORATIVE PROJECT WITH USDOE/ UNDEERC

tests in HTW PDU

- Freedom and Falkirk - after dried to ~15% moisture
- Air-blown and \( \text{O}_2 \) -enriched air blown gasification
- 8 bar pressure, total of 8 tests
- 4 hours at steady state

- Severe bed agglomeration and freeboard fouling during preliminary tests when tested at a bed temperature of around 900°C

- Average bed temperature 800-830°C to prevent bed agglomeration, and freeboard temperature below 900°C to prevent freeboard fouling

- C-conversion - 75-83%, limited by the need to continuously drain the bed material to maintain bed level and bed stability

- Gas composition - as measured
  - 10-12% \( \text{CO} \), 10-14% \( \text{H}_2 \), ~1% \( \text{CH}_4 \), ~15% \( \text{H}_2\text{O} \)
  - up to 4000 ppm \( \text{NH}_3 \) (much higher than VIC lignites) and 1000 ppm \( \text{H}_2\text{S} \) without dolomite
  - with dolomite at \( \text{Ca/S} = 2 \) (molar), \( \text{H}_2\text{S} \) was below detection limit, and \( \text{NH}_3 \) was around 1000 ppm
Objective: preliminary tests to assess the performance of two Australian lignites in a Transport gasifier

Raw coal sent, dried locally at the EERC

8 bar, ~ 200 kg/hr, air and O₂ blown

Lochiel (with dolomite) - 740-760°C
Loy Yang coal - 800 - 880°C
not necessarily under optimized conditions

Tests in progress
COLLABORATIVE PROJECT WITH USDOE/ UNDEERC
tests in Transport Gasifier at UNDEERC - preliminary data

• C -conversion
  • 77-83% for Loy Yang coal
  • 72 - 74% for Lochiel coal
  • low values due to too much fines in the feed and cyclone problems
  • Pilot plant at PSDF - Wilsonville produces higher C-conversion over that attained at the EERC (smaller) gasifier
  • tests resume with coarser feed

• Dry gas composition
  • Loy Yang
    • 18% H2, 12% CO, 4% CH4, 18% CO2, 47% N2 - air blown
    • 26% H2, 17% CO, 8.6% CH4, 40% CO2, 8% N2 - O2 blown
  • Lochiel
    • 13% H2, 10% CO, 3% CH4, 19.5% CO2, 55% N2 - air blown
    • 33% H2, 12% CO, 8.4% CH4, 39% CO2, 7.4% N2 - O2 blown