Coal Bed Methane and Coal Mine Methane Power Generation

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Coal Seam Gas Extraction
CMM – Coal Mine Methane

**Coal Seam Methane (CSM)**
High purity gas (with methane concentration typically above 95%) trapped in the coal seam produced via coalification.

**Coal Bed Methane (CBM)**
Extracted from the coal seam during premining drainage with typical methane concentration above 90%.

**Coal Mine Gas (CMG)**
Various types of lower concentration gases related to coal mining activities with methane concentrations typically below 80%.

**Abandoned Mine Methane (ABM)**
Extracted from sealed and pressurized abandoned mines with typical methane concentration between 60 to 80%.

**Coal Mine Methane (CMM)**
Extracted from active mines during drainage with typical methane concentration between 25 to 60%.

**Ventilation Air Methane (VAM)**
Methane and air mixture carried out with shaft or mine ventilation air with typical methane concentration below 1.5%.
## CMM Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Symbol</th>
<th>Units</th>
<th>Pipeline Natural Gas</th>
<th>CBM</th>
<th>CMM*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH$_4$</td>
<td>vol %</td>
<td>92.3</td>
<td>85.9</td>
<td>40.0</td>
</tr>
<tr>
<td>Ethane</td>
<td>C$_2$H$_6$</td>
<td>vol %</td>
<td>2.5</td>
<td>3.8</td>
<td>---</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>H$_2$S</td>
<td>vol %</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O$_2$</td>
<td>vol %</td>
<td>---</td>
<td>2.1</td>
<td>12.6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N$_2$</td>
<td>vol %</td>
<td>3.5</td>
<td>8.2</td>
<td>46.8</td>
</tr>
<tr>
<td>Others</td>
<td>---</td>
<td>vol %</td>
<td>1.8</td>
<td>0.0</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>LHV</th>
<th>MJ/Nm$^3$</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Heating Value</td>
<td>33.2</td>
<td>32.5</td>
<td><strong>13.4</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MN</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caterpillar Methane Number</td>
<td>---</td>
<td>80</td>
<td>86</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

* Represents one particular site at one particular time
China’s Coal Basins and Coalbed Methane Resources

Estimated methane resources, cu m
- 1 trillion
- 100 billion-1 trillion
- 10 billion-100 billion
- < 10 billion

Key:
- 0 161 Km
- 0 100 Miles

CMM Volume
CMM Mitigation

➤ Existing
  ➤ Gas reciprocating engines – Power production and CHP/COGEN
  ➤ Gas turbines – Power production and CHP/COGEN
  ➤ Conventional industrial boilers, furnaces and burners – Power production, dryers, CHP, heating systems and others
  ➤ Gas purification or enrichment systems – Feedstock for pipeline or chemical production and others
  ➤ Co-firing and flaring – Fuel augmentation

➤ Under Development
  ➤ Fuel cell, catalytic, oxidizer, and reverse flow systems
  ➤ High efficiency concentrators
Combustion Characteristics of Coal Mine Methane

- CMM vs. Pipeline Natural Gas
  - Similar flame speed
  - Similar autoignition delay time
  - Similar flame temperature
  - Similar NO$_X$ emissions

Impacts: detonation, mistfire, backfire
CMM – Key Challenges

➢ Fuel Quality
  ➢ Concentration fluctuation
    ▶ Changes in the amount of \( \text{CH}_4 \) vs. air
    ▶ Rate of change
  ➢ Flow fluctuation
    ▶ Pressure and flow control
    ▶ Supply
  ➢ Contamination
    ▶ Other volatiles/cOMBustibles
    ▶ Particulates
    ▶ Humidity
CMM – Key Impact

- Poor Fuel Management
  - Combustion instability
    - Overall genset instability (kW instability)
      - Reliability
    - Reduced system component life
      - Availability
      - Robustness
  - Higher emissions
    - Possible penalties
Key Fuel Management and Handling Concerns

➢ Fuel Quality Considerations
  ➢ Predetermined fuel composition information
    ▶ Ensures engine safety, reliability, performance and life

➢ Contaminant Control
  ➢ Minimized contaminants
    ▶ Ensures longevity
    ▶ Reduces downtime
    ▶ Lowers O&M and repair costs
Caterpillar Gas Engines

Key Technology Strength

- Robust diesel based core components
- Reliable and prove design
- Stable performance (±1% deviation in kW)
- High efficiency (40 %)
- Low emission (250/500 mg/Nm³)
- Tolerant to ambient changes
- Tolerant to fuel changes

G3520C – CMM
Gas Conditioning Requirements

- **G3520C – CMM Fuel Specification**
  - Concentration: 25 to 100% CH₄
  - Rate of change: < 24% CH₄ per minute
  - Supply pressure: 3.5 to 35 kPag (at engine entry)
  - Supply pressure: 40 to 60 kPag (at fuel train entry)
  - Rate of change: < 1.7 kPag per second
  - Particulates: < 5 microns Beta 100
  - Relative humidity: < 80%
**Efficiency and Emissions**

Caterpillar G3520C - CMM Gas Engine Performance  
(500 mg/Nm³ case)

<table>
<thead>
<tr>
<th>Load</th>
<th></th>
<th>100</th>
<th>75</th>
<th>50</th>
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</thead>
<tbody>
<tr>
<td>Engine Power</td>
<td>kW</td>
<td>w/out fan</td>
<td>2035</td>
<td>1526</td>
</tr>
<tr>
<td>Generator Power</td>
<td>e kW</td>
<td>w/out fan</td>
<td>1966</td>
<td>1474</td>
</tr>
<tr>
<td>Engine Efficiency</td>
<td>%</td>
<td>ISO 3046/1</td>
<td>41.4</td>
<td>40.1</td>
</tr>
<tr>
<td>Engine Efficiency</td>
<td>%</td>
<td>nominal</td>
<td>40.4</td>
<td>39.1</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>%</td>
<td>nominal</td>
<td>45.5</td>
<td>46.0</td>
</tr>
<tr>
<td>Total Efficiency</td>
<td>%</td>
<td>nominal</td>
<td>85.8</td>
<td>85.0</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>MJ/bkW-hr</td>
<td>ISO 3046/1</td>
<td>8.71</td>
<td>8.99</td>
</tr>
<tr>
<td>Exhaust Mass Flow</td>
<td>kg/bkW-hr</td>
<td>nominal</td>
<td>5.66</td>
<td>5.73</td>
</tr>
<tr>
<td>Exhaust Temperature</td>
<td>°C</td>
<td>nominal</td>
<td>472</td>
<td>495</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>corr. 5% O₂</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>CO</td>
<td>mg/Nm³</td>
<td>corr. 5% O₂</td>
<td>1076</td>
<td>1019</td>
</tr>
<tr>
<td>THC</td>
<td>mg/Nm³</td>
<td>corr. 5% O₂</td>
<td>2331</td>
<td>2584</td>
</tr>
<tr>
<td>O₂</td>
<td>%</td>
<td>dry</td>
<td>9.4</td>
<td>9.3</td>
</tr>
</tbody>
</table>
Fuel Flexibility

- VAM
  - Can use VAM as combustion air
  - VAM with methane concentration up to 3% can be used

Combustion Air
Up to 3% CH\textsubscript{4} (e.g., VAM)

CMM Fuel
25 – 100% CH\textsubscript{4}
CMM Power Plant Requirement

- **Gas Supply**
  - Sufficient amount of gas supply meeting minimum fuel quality requirements

- **Gas Treatment and Conditioning**
  - Sufficient filtration and flow control

- **Engine Installation**
  - Follow all OEM recommended installation guides/instructions

- **Power Control, Monitoring and Protection**
  - Use and tuning of certified switchgear control panel
**Typical Plant Layout**

- **Gas Tank**
- **Fuel Train**
- **Pretreatment**
- **Switchgear**
- **Prime Mover**
- **kW Output**

Diagram showing the components of a typical plant layout with arrows indicating the flow of processes.
CMM Power Plant Project Management

➤ Team Members
➤ Use experienced and certified project team including OEM suppliers, design institute, inspectors and carbon credit experts

➤ Project Scheduling
➤ Use realistic time tables
➤ Allow at least six months for product delivery
➤ Allow at least six weeks for completion of installation and commissioning
Capital and Life Cycle Cost

- **Capital Investment**
  - Genset system: US$500 to 700/kW
  - BOP: 30 to 70% of genset system cost

- **Yearly Operating Cost**
  - Genset system: US$35k to 55k per year
  - Does **not** include CMM fuel cost

- **Life Cycle Cost – 10 Year Parts Only**
  - US$40 to 65/yr-kW (depending on quality of application, installation and maintenance)
Typical Payback and ROI

- Payback
  - Capital Investment
    - Two to three years
    - Government electricity price incentive
    - CDM credit
    - Good A&I and PM
CMM Power Plant in China

2006-2009: > 250MW installations

- Yangquan Huweigou: 3xG3520C
- Jincheng Sihe: 60xG3520C
- Jincheng Meiganshi: 21xG3520C
- Jincheng Chengzhuang: 10xG3520C
- Huainan Pansan: 2xG3520C
- Xiyang: 3xG3520C
- Shaqu: 14xG3520C
- Malan: 2xG3520C

CMM Power Installations

SRET: 24xG3520C
Project Samples

- China
  - Yangquan-5.4MW: CMM
  - Jincheng: CMM
    - Sihe-120MW
Yangquan CMM Projects

- **Prime Mover**
  - 3x G3520C-CMM gas engines
  - 1800 ekW each at 41% elec. efficiency
  - 220 ppm NO\textsubscript{X} (corr. 5% O\textsubscript{2})

- **Operation**
  - 24/7 grid parallel

City of Yangquan
Shanxi Province
Jincheng Sihe Site

- World Largest Power Plant - CMM
- Jincheng Anthracite Mining Group 120MW Electricity Capacity
- Power Generated and Sold to Utility
  - 840,000 MW-hr/yr
Conclusions and Recommendations

- Understanding of the CMM Market
  - Economic benefits and returns
  - Criticality of life cycle cost

- Project Team Readiness
  - People, coverage, support and skills
  - Weathered and experienced
  - Positive attitude with relentless execution

- Technology Readiness
  - Caterpillar gas engine
  - Integrated and proven systems solution