Improved drainage boosts CMM to Power economics

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GE Energy Jenbacher gas engines

EPA/GMI Technical Seminar on State-of-the-Art Coal Mine Methane Capture and Use Technologies

Donetsk, Ukraine, September 21-22
Worldwide CMG potential in MWel

- Captured CMM/AMM ~4,850 MWel
- Utilized ~2,500 MWel for PG ~1.665 MWel
- Current dynamics CMM/AMM

Annual worldwide coal mining related CMG emissions account for 25,000 MMm³

- Poland (110/65)
- Czech Rep. 50
- Germany 235/220
- Ukraine
- Mexico 7/0
- Colombia 0/0
- Mongolia
- South Africa 3/0
- Nigeria 0/0
- Indonesia 0/1
- South Africa 3/0
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- Mongolia
- South Africa 3/0
- Nigeria 0/0
- Indonesia 0/1
CMG to Energy Business Drivers

Mine Safety: Gas explosions in coal mines still cause severe accidents.

Carbon offset: Trading with carbon credits creates additional revenues besides feed-in tariff.

Coal mine sector restructuring: For many mines CMG to Power helps to establish green image, energy autarchy and business diversity.
Safety/ productivity aspect of CMM drainage

- Explosive zone 5-15% CH4/air + buffer in case of fluctuations
- > CH4 lower utilization limits 20-30% in most countries
- Surface: Piping, engine, other devices protected by flame arrestors, shut down valve
- Still there is ignitable CMM underground
- Effective gas drainage saves money in the layout of the ventilation system
- Safety aspect is predominant, but coaling productivity will be improved as well

> Independent from CMM utilization, there is a strong business case for installing and operating high efficiency gas drainage systems
Utilization of low CH4 CMM in gas engines

Extended gas conditioning
Special gas train lay-out
Special gas mixer
Special turbocharger
Special pre-chamber geometry/ valves
Special spark plugs

NG Operation

Air

NG

19.8% O₂
74.6% N₂/ 0% CO₂
5.6% CH₄

0% O₂
0% N₂
0% CO₂
100% CH₄

1m³ fuel: 0.056m³
Air/CMM 17/1 m³ N

CMM Operation

Air

CMM

19.4% O₂
74.3% N₂/ 0.7% CO₂
5.6% CH₄

14% O₂
58% N₂
3% CO₂
25% CH₄

1m³ fuel: 0.222m³
Air/CMM 3.5/1 m³ N

> For further decrease of lower utilization limit additional adjustments need to be taken, that will increase gas engine CAPEX and OPEX considerably

GE imagination at work

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GE Jenbacher Coal Mine Gas to Energy
September 2011
Low CH4 CMM Gas Conditioning

Conditioning skid needs to handle multiple times higher gas flows with even higher humidity due to water injection for safety reasons (CHN)

The quality of the gas conditioning has a big influence on the availability of the gas engine

Coal Mine Gas

Volume
Pressure
Temperature
Humidity
Dust
Impurities

Engine fuel

TA 1000-0301

GE Jenbacher Coal Mine Gas to Energy
September 2011

GE proprietary information
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### Relative gas train costs/ LHV

<table>
<thead>
<tr>
<th>Gas type</th>
<th>Gas flow Nm³/h</th>
<th>Pressure</th>
<th>Flame arrestor</th>
<th>Engine adaption</th>
<th>Price</th>
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<tr>
<td>Sewage Gas</td>
<td>1150</td>
<td>80-450</td>
<td>-</td>
<td>2 x 150/16</td>
<td>305%</td>
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<td>Sewage Gas</td>
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<td>80-450</td>
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<tr>
<td>Biogas</td>
<td>1660</td>
<td>120-450</td>
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<td>2 x 150/16</td>
<td>304%</td>
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<tr>
<td>Biogas</td>
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<td>80-450</td>
<td>-</td>
<td>2 x 150/16</td>
<td>449%</td>
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<tr>
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<td>80-450</td>
<td>x</td>
<td>2 x 150/16</td>
<td>541%</td>
</tr>
<tr>
<td>LFG</td>
<td>1980</td>
<td>80-450</td>
<td>-</td>
<td>2 x 150/16</td>
<td>547%</td>
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<tr>
<td>LFG</td>
<td>1980</td>
<td>80-450</td>
<td>x</td>
<td>2 x 150/16</td>
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<td>1980</td>
<td>120-450</td>
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<td>541%</td>
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<tr>
<td>CMG</td>
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<td>x</td>
<td>2 x 150/16</td>
<td>839%</td>
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<tr>
<td>CMG (F)</td>
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<td>200-450</td>
<td>x</td>
<td>2 x 100/16</td>
<td>469%</td>
</tr>
<tr>
<td>NG</td>
<td>800</td>
<td>80-450</td>
<td>-</td>
<td>100/16</td>
<td>114%</td>
</tr>
<tr>
<td>NG</td>
<td>800</td>
<td>120-450</td>
<td>-</td>
<td>100/16</td>
<td>103%</td>
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<tr>
<td>NG</td>
<td>800</td>
<td>2 - 4 bar</td>
<td>-</td>
<td>100/16</td>
<td>100%</td>
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<tr>
<td>NG (F)</td>
<td>850</td>
<td>80-450</td>
<td>-</td>
<td>100/16</td>
<td>186%</td>
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<td>100/16</td>
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<td>NG (F)</td>
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<td>100/16</td>
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<td>NG (F)</td>
<td>853</td>
<td>380-1000</td>
<td>-</td>
<td>100/16</td>
<td>137%</td>
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<tr>
<td>NG (F)</td>
<td>850</td>
<td>2 - 4 bar</td>
<td>-</td>
<td>100/16</td>
<td>95%</td>
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<td>NG (F)</td>
<td>850</td>
<td>3 - 8 bar</td>
<td>-</td>
<td>100/16</td>
<td>97%</td>
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</tbody>
</table>

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**Investment in gas train for very low LHV fuel can become extremely high because of exponentially growing material demand and small batch sizes**
Fast Changing CH₄ Content

Facts
- CH₄ Concentration is changing faster than 11.5Vol%/30s
- Only small Load Fluctuation – Engine operation is still stable
- LEANOX control system
- Fast Reaction of Gas Mixer
- Longtime experience with turbo charger bypass system

Optimal compensation of CH₄ fluctuation to increase gas engine availability and save gas supply investment becomes harder the lower the average CH₄ level. Relative LHV decrease is much higher from lower outset level. From 64 to 52.5% CH₄ = -18%, from e.g. 28 to 16.5% CH₄ = -41%!!
BMEP/Efficiency development – type 6

- Proven specific output increase of >100% over 2 decades
- Proven efficiency increase of ~30% over 2 decades

CMG achievements

> Electrical efficiency only slightly below NG operation and considerable higher than in open chamber concept
> Spare parts costs at the same level or even lower than with NG
Bring your Coal Mine Gas to a good quality!

Only Coal Mine Gas with a CH4 concentration of at least 30% ...

- improves mine safety through better gas drainage
- saves investment into ventilation system and improves coaling productivity
- complies to official utilization guidelines from local authorities
- will still provide an usable fuel for PG even if CH4 content decreases with time
- safes money in the piping, gas conditioning, gas train and specific engine investment
- eases the cooperation with western technology partners
- ensures an optimal and schedulable carbon credit generation

> Thus your ROI will be finally clearly higher, than developing the project with low CH4 gas concentration
Thank you for your attention!
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