PRODUCER GAS ENGINE

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Background

- Scenario in 1995 - 96
  - Spiraling crude oil resulted in dual-fuel operation to be expensive
  - Forced technologists to adapt 100% gas engines
  - No gas engines commercially available for producer gas
  - No engine manufacturer was favorable for producer gas
    - Market potential not clearly defined
    - Issue of gas contaminants a major one
  - Research & development was initiated at this laboratory
Major Milestone

- **Phase I (1996 – 1998)** – Basic research on a three cylinder, high compression ratio gas engine (20 kW) converted from a diesel engine; satisfactory 100 hours test.

- **Phase II (1999 – 2001)** – Adapted Greaves bio-gas engine (250 kW); Gas carburetor developed; Cumulative experience of 100 hours in the lab.

- **Phase III (2002 onwards)** – Adapted Cummins NG engines; Lab testing of two engine models along with Cummins; long duration trials - 75 hrs test; 3.0 MW installed in field, joint monitoring in progress; 25 kW engine for village project being tested.
Power generation using producer gas

Using R/C engines

Dual – Fuel Engine
80% gas & 20% diesel

Gas Engine
100% gas
Merits
• Easy for retrofitting with existing diesel engine without any modifications
• Plant availability higher – utility will not suffer due to non-availability of gasifier
• Economical compared to fossil fuel – diesel

De-Merits
• Expensive can’t compete with State grid electricity
Gas Engine option

**Merits**
- Economical and can compete with State grid electricity
- Plant availability reasonably high – provided correct operation practice are adhered to!
- Environmental friendly – emission meets pollution norms

**De-Merits**
- Start-up power required where grid is not available
- Not suitable if gas quality is poor (energy content – low & contaminants – high)
The Approach

- Basic Research – Experimental & Modeling
- Development of gas carburetion system
- Reliability tests - Long duration trails
- Collaborative work with Cummins India
  - Adaptation of Natural gas engines
  - Laboratory trails & Field monitoring
- Open for collaborative work with other engine manufacturers
How is PG different from NG engine?

- The air-to-fuel ratio of PG is 1.3:1, whereas for NG it is 17:1 – this calls for a different carburetor.
- PG has higher octane rating, therefore can be used in engines with higher Compression ratio.
- The flame speed of PG is higher ~ 20%; calls for a different ignition timing setting.
- The energy density of PG is lower ~ 20%, this causes de-rating of the engine power.
- The flame temperature is lower by about 300 K, implies different operating condition in the engine cylinder and turbocharger.
## Analysis of Producer Gas Engine

### Reasons for de-rating with PG

1. **Energy density**
   - PG < NG by 20 - 23%
2. **Sub-optimal – Turbocharger**
3. **Reactant:Product < 12%**

### Properties of Gaseous Fuel

<table>
<thead>
<tr>
<th>Fuel + Air</th>
<th>Fuel LCV, MJ/kg</th>
<th>Air/Fuel @ (Φ =1)</th>
<th>Mixture, MJ/kg</th>
<th>Φ, Limit</th>
<th>S_l (Limit), cm/s</th>
<th>S_l, Φ =1, cm/s</th>
<th>Peak Flame Temp, K</th>
<th>Product/Reactant Mole Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>121</td>
<td>34.4</td>
<td>3.41</td>
<td>0.01</td>
<td>7.17</td>
<td>65</td>
<td>75</td>
<td>270</td>
</tr>
<tr>
<td>CO</td>
<td>10.2</td>
<td>2.46</td>
<td>2.92</td>
<td>0.34</td>
<td>6.80</td>
<td>12</td>
<td>23</td>
<td>45</td>
</tr>
<tr>
<td>CH₄</td>
<td>50.2</td>
<td>17.2</td>
<td>2.76</td>
<td>0.54</td>
<td>1.69</td>
<td>2.5</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>46.5</td>
<td>15.6</td>
<td>2.80</td>
<td>0.52</td>
<td>2.26</td>
<td>-</td>
<td>-</td>
<td>44</td>
</tr>
<tr>
<td>C₄H₁₀</td>
<td>45.5</td>
<td>15.4</td>
<td>2.77</td>
<td>0.59</td>
<td>2.83</td>
<td>-</td>
<td>-</td>
<td>44</td>
</tr>
<tr>
<td>PG</td>
<td>5.00</td>
<td>1.35</td>
<td>2.12</td>
<td>0.47a</td>
<td>1.60b</td>
<td>10.3</td>
<td>12</td>
<td>50c</td>
</tr>
</tbody>
</table>
Results of Basic Research

- Operation of gas engine with PG is possible without any limitation due to knock, this implies:
  - Higher compression ratio (CR) can be adapted
  - Efficiency > 30%
  - Higher power for a given engine volume size
- Maximum de-rating of 16% at 17 CR, 26% at 11 CR
- Optimum ignition timing for NG different from NG
- The peak cylinder pressure is found to be lower compared to a diesel engine at comparable power level; this implies less wear and tear
- Emission friendly; low NOx & CO level
Why need for a different Gas Carburetor?

1. The air-to-fuel of NG is about 17:1 (mass basis), whereas for PG it is about 1.3:1.
2. NG carburetor requires gas under pressure ~ 1 bar, whereas PG is available at low pressure.

Designed to meet variable load operation.
Collaborative work with Cummins

- It was hard to convince Cummins to offer their NG engine for PG

- Cummins laid a condition that engine needs to qualified on PG

- Two models of engines were tested at the laboratory

- Tested for 75 hours at the laboratory; two 24 hour run – active participation from Cummins

- Systematic trail conducted – energy input, power output and emissions were measured

- Condition of engine components were checked prior to and after the trail
Trails at the Lab ...
## Engine Components

<table>
<thead>
<tr>
<th>Time T=0 Hours</th>
<th>T = 24 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>

*24 hour run*

All engine components – throttle, manifold and valve were clean
Outcome of the collaborative work

- The laboratory trails very encouraging for Cummins; impressed with the gas quality & overall performance
- Initially 2 Engines were offered for commercial operations with close monitoring jointly by Cummins & IISc
- One engine has satisfactorily undergone this monitoring
- Today there are more than 12 installations with an installed capacity of over 3.0 MWe.
- Currently qualifying a 25 kWe engine for rural electrification package
# Typical Applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Electrification</td>
<td>- Short duration ~ 4 – 6 hour/day, low PLF</td>
</tr>
<tr>
<td></td>
<td>- High plant availability &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>- Load reasonably constant</td>
</tr>
<tr>
<td>Industrial - Captive</td>
<td>- Continuous operation – 24 hr x 6/7 day a week</td>
</tr>
<tr>
<td></td>
<td>- High plant availability &gt; 90%</td>
</tr>
<tr>
<td></td>
<td>- Large load fluctuations</td>
</tr>
<tr>
<td>Independent Power Producer – grid lined</td>
<td>- Continuous operation – 24 hr x 7 day a week</td>
</tr>
<tr>
<td></td>
<td>- High plant availability &gt; 90%</td>
</tr>
<tr>
<td></td>
<td>- Large load fluctuations</td>
</tr>
</tbody>
</table>

Producer gas engine can meet each of the above applications
The Company
• Group Company of United Bleachers Limited, Mettupalayam, TN, one of the largest textile processing facilities in Tamil Nadu.
• UBL Imports over 270 kWe of power from TNEB grid @ Rs. 4.50 (US c 10)/kWh

The Power Plant
• 120 kWe power plant supported by 150 kg/hr Gasifier). Commissioned in August 2003.
• 100 % gas based system with Cummins gas engine GTA 855 G
• Feedstock is coconut shell & Julifora Prosopis
• 300 kg/hr waste heat drier installed to dry biomass with free energy from engine exhaust
Plant Configuration

GASIFIER

Producer gas

120 kWe PG ENGINE

EMISSION ~ Qualifies for CDM Benefits

Flue gas

Overall efficiency ~ 22 -24%

FEED STOCK

DRIER

EFFLUENT TREATMENT

440 V

INDUSTRY

Recycled water

PROCESSOR

CAPTIVE
Snap Shots

The Power Plant

Gasifier Unit

PG Engine

Biomass Drier

Effluent Treatment
The Arrangement
Performance

• Max output of 134 kWe at an optimum ignition timing of 22° CA; nominal output is 120 kWe
• 30 - 40% fluctuation in load
• Duty cycle 24 hours x 6 days
• Specific biomass consumption 1.1 ± 0.1 kg/kWh
• Biomass-to-Electricity: 22 - 24%
• Operated for more than 7500 hours
H₂ & CO : 19 ± 1%; CH₄ : 1.5%; LCV 4.7 + 0.1 MJ/kg
Cold Gas Efficiency : 80 - 82%
Emission

Load ~ 80-90%

CO, NO, g/MJ

Time Cycle, Hour
## Emissions Norms

<table>
<thead>
<tr>
<th>Parameter/Country</th>
<th>USA</th>
<th>EU</th>
<th>Japan</th>
<th>India</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>3.06</td>
<td>1.4 - 1.8</td>
<td>1.67</td>
<td>1.25 (3.9)</td>
</tr>
<tr>
<td>NOx</td>
<td>2.56</td>
<td>2.56</td>
<td>2.6 - 3.06</td>
<td>2.22 (5.0)</td>
</tr>
<tr>
<td>HC</td>
<td>0.36</td>
<td>0.36</td>
<td>0.4 - 0.56</td>
<td>0.3 (0.98)</td>
</tr>
<tr>
<td>PM</td>
<td>0.15</td>
<td>0.15 - 0.24</td>
<td>-</td>
<td>0.1 -0.2 (&lt;3.5 Bosch)</td>
</tr>
</tbody>
</table>

### KOEL Engine results between 6 to 20° CA for all CRs at \( \Phi = 1.0 – 1.2 \)

<table>
<thead>
<tr>
<th>Parameter/CR</th>
<th>17.0</th>
<th>14.5</th>
<th>13.5</th>
<th>11.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1.1 – 11.0</td>
<td>11.0 – 15.0</td>
<td>4.0 – 16.0</td>
<td>9.0 – 14.0</td>
</tr>
<tr>
<td>NOx</td>
<td>0.03 – 0.28</td>
<td>0.02 – 0.22</td>
<td>0.03 – 0.20</td>
<td>0.05</td>
</tr>
<tr>
<td>PM</td>
<td>&lt; 0.014</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Greaves Engine results between 12 to 24° CA for CR=12.0 at \( \Phi = 0.94 - 0.97 \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.58 – 1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>0.32 – 0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>&lt; 0.0005</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Cummins Engine results between 22 to 24° CA for CR=10.0 at \( \Phi = 1.01 - 1.03 \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.4 – 1.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>0.2 – 0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>&lt;&lt; 0.0005</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Joint field inspection by IISc & Cummins after 3000 hours

- Least amount of deposits on the engine components ~ particulate matter < 200 ppb
- Spark plug found clean
- No wear of cylinder liner
## Lube Oil Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fresh Oil</th>
<th>Used Oil (496 hrs)</th>
<th>Limit*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity @ 40° C, cSt</td>
<td>114</td>
<td>95</td>
<td>Low - 85 High - 155</td>
</tr>
<tr>
<td>TBN, mg KOH/g</td>
<td>5.7</td>
<td>2.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*as per Cummins

- Oil quality inspected after every 200 hours and well within the qualifying limits
- No water content in the oil
- Wear metals < 100 ppm
- Oil change recommended at 500 hours
**Techno-Economics**

**Investment Details**
- Capital Investment: 100,000 US$
- Federal Govt. Subsidy: 27,000 US$

<table>
<thead>
<tr>
<th>Electricity Generation Cost</th>
<th>US Cent/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed stock</td>
<td>3.4 (2.7 per kg)</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.35</td>
</tr>
<tr>
<td>Labour</td>
<td>1.0</td>
</tr>
<tr>
<td>Sub-Total (A)</td>
<td>4.75</td>
</tr>
<tr>
<td>Depreciation (B) at 6% per annum</td>
<td>0.45</td>
</tr>
<tr>
<td><strong>Sub-Total (A+B)</strong></td>
<td><strong>5.20</strong></td>
</tr>
<tr>
<td>Revenue from Charcoal (C)</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>Net Generation Cost (A+B-C)</strong></td>
<td><strong>4.70</strong></td>
</tr>
<tr>
<td>Grid Electricity</td>
<td>10.0</td>
</tr>
<tr>
<td>Sale of Electricity</td>
<td>7.70</td>
</tr>
<tr>
<td><strong>Income for 0.6 Million units/year</strong></td>
<td><strong>18,000 US$</strong></td>
</tr>
<tr>
<td>Return on Investment (with out subsidy)</td>
<td>18%</td>
</tr>
<tr>
<td>Return on Investment (with subsidy)</td>
<td>25%</td>
</tr>
</tbody>
</table>
Achievements

Scenario (end of 2005)

- Knowledge base on PG engine operation has been established
- Technology demonstrated with better reliability and uninterrupted operation
- Issues w.r.t. gas engine/s satisfactorily addressed
  - Technical issue w.r.t turbocharger on larger engine
  - Cummins considering extending warranties on engines with PG
  - Cummins willing to label gas engines as PG engines and market them
- Currently turbocharger basic studies are on to optimize the performance further
- More than 12 units totaling to 3.0 MWe equivalent plants working; Cumulative experience > 27,000 hours
- Cost of electricity generation ~ 5 US Cents against 10 US Cents (grid)
Thanking you