MEGTEC VAM processing

September 2012

Richard Mattus
### MEGTEC VAM Status Achieved by 2012

<table>
<thead>
<tr>
<th>Type of installations</th>
<th>Number of plants</th>
<th>Number of RTO units</th>
<th>Approx total processing capacity in Nm³/h</th>
<th>Year of installation (Locations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Completed</td>
<td>3</td>
<td>11</td>
<td>700,000</td>
<td>2007, 2008, 2011 (Australia, China)</td>
</tr>
<tr>
<td>- Under completion</td>
<td>1</td>
<td>2</td>
<td>200,000</td>
<td>2012 (China)</td>
</tr>
</tbody>
</table>

**Total of MEGTEC VAM plant operation experience** ~14 years

**Total of MEGTEC VAM RTO unit operation experience** > 30 years
In full operation by April 2007 – the world’s first VAM Power Plant: WestVAMP at the West Cliff mine of Illawarra Coal, BHP Billiton

Fuel = 0.9% methane (>99% air)
By 1st Q 2012 WestVAMP had generated:
>165,000 MWh of electricity
>1 million carbon credits (CO$_{2e}$ as NGAC’s).
MEGTEC VAM in China 2011
at the Da Tong mine, ChongQing Province, China

- Installed at the DaTong coal mine, ChongQing Province
- Supplied by MEGTEC
- Investor is a joint venture owned by:
  - Shenzhen Dongjiang Environmental Renewable Energy Co Ltd
  - SongZao Coal & Electricity Co Ltd
  - AES Corp (US-based global power generation company)
MEGTEC VAM in China 2011
at the Da Tong mine, ChonQing Province, China

World’s largest VAM abatement plant in operation in the ChongQing Province of China since mid 2011.
MEGTEC VAM in China 2011
at the Da Tong mine, ChonQing Province, China

- 6 Vocsidizer units mounted on two levels
- Processing capacity is 375,000 Nm3/h of ventilation air
- Includes hot water generation for local use
MEGTEC VAM in China 2008
ZhengZhou Coal Mining Group, Henan Province

System capacity: 62 500 Nm3/h

VAM concentration: 0.3% - 0.7%
Actual often <0.3%

The installation includes VAM abatement and energy recovery in the form of hot water for local use.
MEGTEC VAM in China 2008
ZhengZhou Coal Mining Group, Henan Province

System capacity: 62 500 Nm3/h
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The installation includes VAM abatement and energy recovery in the form of hot water for local use.

The globally first project to be awarded VAM-based CER’s
(Kyoto related Carbon Credits).
One Megtec 2-Can Regenerative Thermal Oxidizer (“RTO”) units with a capacity of 2,100 Nm3/min
One 1,200 Nm3/min capacity CH4MIN Regenerative Catalytic Oxidizer (“RCO”) built by Megtec.

- The first commercial deployment of the CH4MIN catalytic technology.
- The project is expected to generate 2 million CERs over its life.
- Completion planned for 2nd half 2012.
MEGTEC VAM demo installations
September 2012

- Demos

- British Coal Demo 1994
- CONSOL Energy Demo 2007 - 2008
- BHP, Appin Colliery Demo 2001 - 2002
- VAM Pilot Unit 2009 --
MEGTEC Commercial VAM installations
September 2012

- Demos
- Commercial

- British Coal Demo 1994
- ZHENGZHOU 2008
- AES-SONGZAO 6 units 2011
- BHP Billiton 4 units 2007
- BHP, Appin Colliery Demo 2001 - 2002
- VAM Pilot Unit 2009 --
MEGTEC Commercial VAM installations
September 2012

- Demos
- Commercial

British Coal
Demo 1994

DUERPING
2 units 2012,
RTO + CTO
(catalytic)

ZHENGZHOU
2008

AES-SONGZAO
6 units
2011

BHP Billiton
4 units
2007

BHP, Appin Colliery
Demo
2001 - 2002

VAM Pilot Unit
2009 --
Overall OPTIMIZATION of CH$_4$
- CMM and VAM emissions

- Low CH$_4$ (< 1%)
- High CH$_4$ >30%
Overall OPTIMIZATION of $\text{CH}_4$ - CMM and VAM emissions

- Gas Engines

- High $\text{CH}_4$
  - $>30\%$

- Low $\text{CH}_4$
  - $<1\%$

- 60-80% of emissions

- Main Coal Mine Vent Shaft

- Coal Excavation
Overall OPTIMIZATION of CH$_4$
- CMM and VAM emissions

Gas Engines

High CH$_4$
>30%

VAM processing

Low CH$_4$
<1%

60-80% of emissions

Main Coal Mine Vent Shaft

Coal Excavation
Overall OPTIMIZATION of CH$_4$
- CMM and VAM emissions

For optimization if motivated by VAM energy utilization.

Low CH$_4$
< 1%

60-80% of emissions

Gas Engines

VAM processing

Main Coal Mine Vent Shaft

Coal Excavation
MEGTEC – global leader in Industrial Emission Control

Locations Worldwide
- MEGTEC Worldwide Headquarters
- MEGTEC Regional Offices

MEGTEC – global leader in Industrial Emission Control
Industry Applications

**Advanced Materials Processing**
- Lithium-ion Batteries
- Solar Films
- Membranes
- Composites

**Environment, Climate & Energy**
- Air Abatement Systems
- Carbon Management
- Energy Recovery
- Biofuels & Renewable Energy

**Printing & Packaging Applications**
- Digital Printing
- Commercial Printing
- Newspaper Printing
- Packaging

**Battery Separators**
**Extrusion Laminates**
**Flexible Packaging**
**Foil Laminates**
**LCD Screens**
**Medical Products**
**Membrane Manufacturing**
**Metal Coil Coating**
**Photovoltaic Cells**
**PSA Label Stock**
**Rechargeable Battery Foils**
**Solar Films**

**Bakery & Food**
**Biofuels Production**
**Biogas Generation**
**Chemical Processes**
**Coal Mines**
**Electronics**
**Fiberglass Processes**
**Flexible Packaging**
**Gas & Diesel Engines**
**Landfills**
**Odour Market**
**Pharmaceutical**
**Wood Products**

**Commercial Printing**
**Semi-commercial Printing**
**Newspaper Printing**
**Digital Printing**
**Insert Printing**
**Direct Mail**
**Book Printing**
**Label Printing**
**Flexible Packaging**
**Carton Packaging**
Operational Excellence

Process Six Sigma (DMAIC)

Product Design For Six Sigma (DFSS)

Operations Strategy

200+ Green Belt, Black Belt and Master Black Belts

Continuous Improvement Six Sigma & Kaizen & Safety Projects
Innovation - 100+ Patents
Environment, Climate & Energy

- Regenerative Thermal Oxidizers (RTO)
- Recuperative Thermal Oxidizers
- Catalytic Oxidizers
- Solvent Recovery Systems
- Distillation Systems
- Heat Recovery Systems
- Bioscrubbers / Bioreactors
MEGTEC equipment – in total globally over 4,000 have been installed

.. whereof over 800 Vocsidizers
Regenerative Thermal Oxidizers

Sizes ranging from 300 to 160 000 Nm³/h capacity, single & multiple can designs
MEGTEC VAM processing concept is modular, based on VOCSIDIZERs, stacked in arrangements of VAM Cubes, each Cube processing 250,000 Nm3/h.
In the VOCSIDIZER, the methane in ventilation air can be completely oxidized.
PURE VAM ABATEMENT – OR CONVERTING
COAL MINE VENTILATION AIR METHANE
INTO USEFUL ENERGY

.. and converted to useful energy.
0.2 % methane needed to maintain oxidation.
Energy of concentrations above 0.2 % can be recovered.

Example:
800 000 m$^3$/h
1 % CH$_4$

$\rightarrow$ 72 MW(th) $\rightarrow$ 21 MW(el)
(at 30% efficiency)

Example:
800 000 m$^3$/h
0.6 % CH$_4$

$\rightarrow$ 36 MW(th) $\rightarrow$ 10 MW(el)
(at 30% efficiency)
Cogeneration of electricity and heating – plus cooling

Example:

\[
\begin{align*}
800,000 \text{ m}^3/\text{h} & \quad 1\% \text{ methane} \\
\rightarrow 72 \text{ MW}(\text{th}) & \quad 21 \text{ MW}(\text{el}) & \quad 19 \text{ MW}(\text{el}) + 38 \text{ MW}(\text{cool})
\end{align*}
\]
**Hot water from VAM** (thermal energy)

- Heat straight from bed:
  - Water at 70 - 150°C
  - 3 MW for 0.3%, 11 MW for 0.6%, 18 MW for 0.9%

- Secondary heat-exchanger:
  - Water at 70°C
  - 1 MW for 0.3%, 8 MW for 0.6%, 15 MW for 0.9%

- Secondary heat-exchanger:
  - Water at 150°C
  - 2 MW for 0.3%, 10 MW for 0.6%

---

*For each 250,000 Nm3/h of ventilation air*
**Electricity from VAM Power Plant**

For large size plants, conversion from thermal to electrical energy can be expected to be around 30%, and lower for smaller plants.

<table>
<thead>
<tr>
<th>Heat straight from bed. Water at 70 - 150°C</th>
<th>0.3%</th>
<th>0.6%</th>
<th>0.9%</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 MW&lt;sub&gt;th&lt;/sub&gt; = ½ -1 MW&lt;sub&gt;e&lt;/sub&gt;</td>
<td>11 MW&lt;sub&gt;th&lt;/sub&gt; = 3 -4 MW&lt;sub&gt;e&lt;/sub&gt;</td>
<td>18 MW&lt;sub&gt;th&lt;/sub&gt; = 5 - 6 MW&lt;sub&gt;e&lt;/sub&gt;</td>
<td></td>
</tr>
</tbody>
</table>

--- For each 250 000 Nm3/h of ventilation air ---
Generally applied for securing potentially dangerous installations in chemical process industries, in oil & gas industry, in paper & pulp industry, in power industry etc in Europe and elsewhere: **IEC 61511** *)

*) Since January 2010 recommended in the Machine Directive for all industrial systems

**IEC 61511** is based on assessment and confirmation of **SIL** (Safety Integrity Level) in design, implementation, operation and maintenance.

This is done by applying a number of established routines such as: Hazard and Operability Analysis (HAZOP), Layer Of Protection Analysis, Risk Matrix, Risk Graph, etc.
Example of SIL analysis acc to IEC 61511 of each potentially dangerous loop identified by HAZOP:

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Influence</th>
<th>Demand</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>C</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>D</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>E</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avoidance probability</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_B)</td>
<td>1</td>
</tr>
<tr>
<td>All avoidance conditions NOT fulfilled</td>
<td></td>
</tr>
<tr>
<td>(P_A)</td>
<td>0</td>
</tr>
<tr>
<td>All avoidance conditions ARE fulfilled</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exposure rate</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>(F_D) Permanent =1</td>
<td>2</td>
</tr>
<tr>
<td>(F_C) Frequent 0.1-1</td>
<td>2</td>
</tr>
<tr>
<td>(F_B) Occasionally 0.01-0.1</td>
<td>1</td>
</tr>
<tr>
<td>(F_A) Rare &lt;0.01</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand rate</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W_9) Often &gt;1/y</td>
<td>9</td>
</tr>
<tr>
<td>(W_8) Frequent 1/1-3 y</td>
<td>8</td>
</tr>
<tr>
<td>(W_7) Likely 1/3-10 y</td>
<td>7</td>
</tr>
<tr>
<td>(W_6) Probable 1/10-30 y</td>
<td>6</td>
</tr>
<tr>
<td>(W_5) Occasional 1/30-100 y</td>
<td>5</td>
</tr>
<tr>
<td>(W_4) Remote 1/100-300 y</td>
<td>4</td>
</tr>
<tr>
<td>(W_3) Improbable 1/1000-1000 y</td>
<td>3</td>
</tr>
<tr>
<td>(W_2) Incredible 1/10,000 y</td>
<td>2</td>
</tr>
<tr>
<td>(W_1) Inconceivable 1/10,000-1,000,000 y</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Likelihood sum (F+P+W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>a</td>
</tr>
</tbody>
</table>

Thereafter a LOPA *) is done to determine requirement for each component of the evaluated loop.

*) Layer Of Protection Analysis
1/ **Chemical industry example** of solution at an international **paint producer**, where process air comes from paint mixing with possible high solvent concentrations.

- Single measurement of incoming concentrations
- Bypass with separate fan when too high concentrations are detected
- Single block shut off valve for incoming process air when in bypass mode
- Rupture disc
- Flame arrester
- Etc
2/ **Methane example** of solution for processing slip from **biogas upgrading** system, where incoming methane concentration is likely to occasionally exceed accepted levels.

- Double measuring of incoming process air (to obtain min SIL 2)
- Dilution with fresh air when methane concentration >1%
- Bypass with separate fan when methane concentration is too high to dilute to safe level
- Double block-and-bleed shut of valve for incoming process air when in bypass mode
- Etc
**3/ VAM example** of solution at **coal mine** (DaTong, China), where VAM concentration at normal operating conditions does not exceed 0.7%.

- Double measuring of incoming methane (VAM) concentration
- Bypass when methane concentration is higher than Chinese legal level of 0.75%
- Double block-and-bleed shut of valve for incoming ventilation air when in bypass mode
- Etc
WHY ARE EMISSIONS OF VAM OF CLIMATE CHANGE INTEREST ??
The accumulated CO$_2$ can retain some additional heat in the atmosphere, causing Global Warming.
Methane can retain MUCH more heat!
Global Methane Emissions - by source

ANTHROPOGENIC

Global GHG contributions 2004
- excluding CO₂ addition from deforestation

- F-gases: 1%
- N₂O: 7%
- CO₂: 71%
- CH₄: 21%

CO₂
CH₄

Global Warming Power
1
25 (21 in the first Kyoto Period)

Life time in atmosphere (years)
20,000 – 50,000
12

 ✓ Second most important greenhouse gas
 ✓ Much more powerful greenhouse gas than CO₂
 ✓ Short life time in atmosphere, so emission reductions will have a quick, positive impact
 ✓ **Generates energy when abated (oxidized)**
Global Methane Emissions - by source (ANTHROPOGENIC)
Global Methane Emissions - by source

(ANTHROPOGENIC)

- Biofuel combustion: 4%
- Biomass burning: 5%
- Coal: 8%
- Waste water: 10%
- Rice: 11%
- Solid waste: 13%
- Natural gas: 15%
- Enteric fermentation: 28%
- Fuel stat & mobile: 1%
- Oil: 1%
- Manure: 4%

BIGGEST TOTAL SOURCE:
- Cows, sheep etc

PROBLEM:
- Each source is very small

50-100 kg CH4 per cow and year = 1-2 t CO2e
Global Methane Emissions - by source

(ANTHROPOGENIC)

BIGGEST TOTAL SOURCE: Cows, sheep etc

PROBLEM: Each source is very small

50-100 kg CH4 per cow and year = 1-2 t CO2e
Coal Mine VAM = singular large source of methane emission

1 million t CO$_2$e

1,000,000 m$^3$/h, 0.8%

= 50,000 tons methane/year
Coal Mine VAM = singular large source of methane emission

\[
\frac{1}{2} \text{ million cars} = 1 \text{ million t CO}_2e
\]

Coal mine VAM
1,000,000 m³/h, 0.8%
= 50,000 tons methane/year
Coal Mine VAM = singular large source of methane emission

½ million cars = 1 million cow

1,000,000 m³/h, 0.8% = 50,000 tons methane/year

1 million t CO₂e

Coal mine VAM
1,000,000 m³/h, 0.8%
= 50,000 tons methane/year
Calculations of CERs from VAM processing

Examples:
250 000 Nm³/h @ 0.9 % VAM comes to 240 000 tonnes of CO₂e
125 000 Nm³/h @ 0.9 % VAM comes to 120 000 t CO₂e
125 000 Nm³/h @ 0.3 % VAM comes to 40 000 t CO₂e

<table>
<thead>
<tr>
<th>VAM conc’n Nm³/h vent air</th>
<th>0.3 %</th>
<th>0.6 %</th>
<th>0.9 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 000</td>
<td>40</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>250 000</td>
<td>80</td>
<td>160</td>
<td>240</td>
</tr>
<tr>
<td>500 000</td>
<td>160</td>
<td>320</td>
<td>480</td>
</tr>
<tr>
<td>1 000 000</td>
<td>320</td>
<td>640</td>
<td>960</td>
</tr>
</tbody>
</table>

Annual emission reductions in thousand tons of CO₂e
The project economics of a VAM processing installation will largely depend on:

- Total costs for investment, operation and maintenance.
- Average VAM concentration of the ventilation air being processed.
- The value of reducing the emissions.
Indications of VAM project economics

CONCLUSIONS for reasonable/good pay back:
- VAM concentrations should be over ½ percent
- Carbon Credits should be worth min AUD ~20/t CO$_2$e
Indications of VAM project economics

CONCLUSIONS for reasonable/good pay back:
• VAM concentrations should be over ½ percent
• Carbon Credits should be worth min AUD ~20/t CO$_{2e}$
Field trip on Thursday will visit the VAM fuelled power plant of BHP Billiton;

WestVAMP
MEGTEC was awarded the prestigious US EPA Climate Protection Award for 2008

- for finding a technical solution to the VAM emission problem and for bringing it to the global market.
1. Most methane from coal mines is emitted as VAM.

2. MEGTEC has extensive experience of VAM Processing, in total over 30 years of VAM RTO unit operations.

3. VAM Processing can have a major positive impact on Global Warming and Climate Change.

4. With methane concentrations of at least half a %, Australian VAM projects can be financially attractive.
Pilot VAM VOCSIDIZER
- available in Australia for VAM processing demonstration

Thank you!
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