Emission Reduction Methods, Theory, Practice and Consequences

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Emission Control

What are exhaust gas emissions from two-stroke diesel engines?

- NO$_x$ (Nitrogen Oxides NO, NO$_2$)
- SO$_x$ (Sulphur Oxides)
- PM (Particulate matter)
- CO (Carbon MonoOxide)
- HC (Hydro Carbons)
- CO$_2$ (Carbon Dioxide)
All MAN B&W Diesel Engines Comply with IMO

Increased Requirements for Emission Control

- Customer requirements
- Operational costs
- Legislation
Emission Control

How can emissions be controlled?

- **Primary methods (Engine produces less NO\textsubscript{x})**
  1) Engine adjustments
  2) Engine process modifications
     - Water Injection; Water emulsified fuel
     - EGR (Exhaust Gas Recirculation)
     - HAM (Humid Air Motor, humidification of scavenge air)

- **Secondary methods (NO\textsubscript{x} is removed after the engine)**
  - SCR (Selective Catalytic Reduction NO\textsubscript{x})
  - EPS (Electrostatic Precipitator, PM)
  - OC (Oxidation Catalyst, CO and HC)

What is the cost for emission (NO\textsubscript{x}) control?

<table>
<thead>
<tr>
<th>Method</th>
<th>Reduction capability in %</th>
<th>First cost in % of engine price</th>
<th>Running cost index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary methods</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine adjustments</td>
<td>0-30%</td>
<td>0%/Small</td>
<td>100</td>
</tr>
<tr>
<td>Engine process modifications</td>
<td>0-70%</td>
<td>3-20%</td>
<td>30-50</td>
</tr>
<tr>
<td><strong>Secondary methods</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCR (Sel. Cat. Reduction)</td>
<td>0-98%</td>
<td>50-70%</td>
<td>200-300</td>
</tr>
</tbody>
</table>
SCR System

1. SCR reactor
2. Turbocharger bypass
3. Temperature sensor after SCR
4. Large motors for auxiliary blowers
5. Urea injector
6. SCR bypass
7. Temperature sensor before SCR
8. Additional flange in exhaust gas receiver

Conclusion on Emission Control

Emission control is a requirement – and will be even more so in the future

Primary methods are significantly more cost-effective than secondary methods
NO\textsubscript{x} Reduction Capability

**Primary Methods**

**Engine adjustments for ME-C and MC-C engines**

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**Flexibility of the ME Concept**

![Graph showing NO\textsubscript{x} and g/kWh changes across engine load in %]
Injection Profiles and Their Impact on SFOC and NO\textsubscript{x} Emissions

<table>
<thead>
<tr>
<th>Fuel flow</th>
<th>Ref.</th>
<th>Fast</th>
<th>Double</th>
<th>Slow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>-0.7</td>
<td>1.9</td>
<td>-0.9</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>121</td>
<td>87</td>
<td>105</td>
</tr>
</tbody>
</table>

\( \Delta \text{SFOC (\%)} \) and Rel. \( \text{NO}_x \) (\%)

Emission Control

Conditions for NO\textsubscript{x} formation in cylinder.

- Combustion temperatures must be higher than 2100-2200 K.
- \( O_2 \) (O) and \( N_2 \) (N) must be present
- \( \text{NO}_x \) concentration increases exponentially with temperature
NO\textsubscript{x} Reduction Capability

Primary Methods

Engine Process Modifications

HAM Humid Air Motor, scavenge air humidification

Principle Design of HAM system (Humid Air Motor)

HAM influence on NO\textsubscript{x} formation

- Humidification of scavenge air increases heat capacity and lower the O\textsubscript{2} content
- High heat capacity and low O\textsubscript{2} in scavenge air give low combustion temperatures
- Low combustion temperatures give low NO\textsubscript{x}
Schematic Design of EGR and HAM Systems Application on 4T50ME-X

Diesel engine

Line for simple EGR

Exhaust gas scrubber

Non return valve

Auxiliary blower

Cooler No. 1 + No. 2

EGR blower

EGR blower

Emission Parameters at 100% Load at zero, half and full HAM

Change in %

Absolute humidity (vol./vol.) of scavenge air in %
Engine Performance at 100% Load at zero, half and full HAM

Full HAM correspond to 40% reduction of NOx

Combustion Chamber Temperatures without HAM and with Full HAM

<table>
<thead>
<tr>
<th>Running conditions/components</th>
<th>Without HAM</th>
<th>With full HAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liner top °C</td>
<td>201</td>
<td>231</td>
</tr>
<tr>
<td>Piston top °C</td>
<td>435</td>
<td>453</td>
</tr>
<tr>
<td>Cylinder cover °C</td>
<td>295</td>
<td>312</td>
</tr>
<tr>
<td>Exhaust spindle seat °C</td>
<td>461</td>
<td>481</td>
</tr>
<tr>
<td>Exhaust spindle bottom °C</td>
<td>580</td>
<td>592</td>
</tr>
</tbody>
</table>
Primary Methods

Engine Process Modifications

EGR Exhaust Gas Recirculation

Schematic Design of EGR system

EGR influence on NO\textsubscript{x} formation

Re-circulation of exhaust gas lowers O\textsubscript{2} in scavenge air

Low O\textsubscript{2} in scavenge air gives low combustion temperatures

Low combustion temperatures give low NO\textsubscript{x}
"Bubble-bath" Scrubber (EcoSilencer) and Water Treatment Skid from DME

Schematic Design of EGR and HAM Systems Application on 4T50ME-X
Emission Parameters at 75% Load at Various EGR Ratios

Engine Performance at 75% Load at Various EGR Ratios
Combustion Chamber Temperatures without and with EGR

<table>
<thead>
<tr>
<th>Running conditions/components</th>
<th>Without EGR</th>
<th>With 15% EGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liner top °C</td>
<td>201</td>
<td>209</td>
</tr>
<tr>
<td>Piston top °C</td>
<td>401</td>
<td>412</td>
</tr>
<tr>
<td>Cylinder cover °C</td>
<td>253</td>
<td>257</td>
</tr>
<tr>
<td>Exhaust spindle seat °C</td>
<td>440</td>
<td>451</td>
</tr>
<tr>
<td>Exhaust spindle bottom °C</td>
<td>587</td>
<td>598</td>
</tr>
</tbody>
</table>

PM on Filters before and after Scrubber

Before scrubber

After scrubber
Optimising SFOC/NO\(_x\)

SFOC/NO\(_x\) relation can be optimised depending on requirements for future engine applications with EGR.

Heat Load on Combustion Chamber Components without/with 15% EGR

Heat transfer coefficients [W/m\(^2\) · K]

Exhaust valve and cover

Piston

Liner

Without EGR

With 15% EGR
Temperature Distribution

4T50ME-X combustion chamber
Temperature distribution in a horizontal incision in line with the atomizer holes

Without EGR

With 15% EGR
Temperature Distribution

4T50ME-X combustion chamber
Temperature distribution in a horizontal incision in line with the atomizer holes

Temperature distribution
- Without EGR
- With 15% EGR

Temperature absolute kelvin
- 2400
- 2380
- 2360
- 2340
- 2320
- 2300
- 2280
- 2260
- 2240
- 2220
- 2200
- 2180
- 2160
- 2140
- 2120
- 2100
- 2080
- 2060
- 2040
- 2020
- 2000

NO\textsubscript{x} Formation

4T50ME-X combustion chamber
NO\textsubscript{x} concentration in a horizontal incision in level with the atomizer holes

NO\textsubscript{x} concentration
- 0.150E-02
- 0.142E-02
- 0.135E-02
- 0.127E-02
- 0.129E-02
- 0.112E-02
- 0.105E-02
- 0.0975E-03
- 0.0900E-03
- 0.0825E-03
- 0.0750E-03
- 0.0675E-03
- 0.0600E-03
- 0.0525E-03
- 0.0450E-03
- 0.0375E-03
- 0.0300E-03
- 0.0225E-03
- 0.0150E-03
- 0.0750E-04
- 0.0000E-00
NO\textsubscript{x} Formation

4T50ME-X combustion chamber
NO\textsubscript{x} concentration in a horizontal incision in level with the atomizer holes

Soot/CO Formation

4T50ME-X combustion chamber
Soot concentration in a horizontal incision in line with the atomizer holes
**Soot/CO Formation**

- **4T50ME-X combustion chamber**
- Soot concentration in a horizontal incision in line with the atomizer holes

**CO\textsubscript{2} Emission**

- **Engine efficiency**: Limited scope for further CO\textsubscript{2} reduction
- **Plant efficiency**: Good potential for CO\textsubscript{2} reduction
Emission

CO₂ emission from large container vessel with 12K98MC/MC-C and service electrical consumption of 7530 kW

Relative CO₂ plant emission

- Standard plant
- TCS plant
- TCS+TG plant

Main engine load

86 88 90 92 94 96 98 100 102

Conclusion

Emission control is/will be a key issue for engine applications

MAN B&W Diesel is, as illustrated, prepared for future requirements for emission control

MAN B&W Diesel will make development results available to the licensees
Thank you for your attention

Schematic Design of EGR and HAM Systems Application on 4T50ME-X