Stainless steel cooler for EGR

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**MAN B&W two-stroke diesel engines**

<table>
<thead>
<tr>
<th>Engine type</th>
<th>5S30ME-B EGR</th>
<th>6S60ME-C EGR</th>
<th>12G95ME-C EGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (ton)</td>
<td>61</td>
<td>350</td>
<td>2.400</td>
</tr>
<tr>
<td>Length (m)</td>
<td>4.1</td>
<td>7.7</td>
<td>23.1</td>
</tr>
<tr>
<td>Height (m)</td>
<td>6.3</td>
<td>11.3</td>
<td>17.5</td>
</tr>
<tr>
<td>Output (MW)</td>
<td>3.2</td>
<td>14.3</td>
<td>82.4</td>
</tr>
<tr>
<td>SFOC (g/kWh)</td>
<td>176</td>
<td>168</td>
<td>165</td>
</tr>
<tr>
<td>SFOC (ton/d)</td>
<td>13</td>
<td>58</td>
<td>326</td>
</tr>
</tbody>
</table>
Typical exhaust gas composition

**Exhaust gas**
- 13.0% O₂
- 75.8% N₂
- 5.2% CO₂
- 5.35% H₂O

**Fuel**
- 175% g/kWh
- 97% HC
- 3% S
- 1500 vppm NOₓ
- 600 vppm SOₓ
- 60 ppm CO
- 180 ppm HC
- 120 mg/Nm³ part.

**Lube**
- 1 g/kWh
- 97% HC
- 2.5% CA
- 0.5% S

**Air**
- 8.5 kg/kWh
- 21% O₂
- 79% N₂

**Work**
Why worry about emissions?

**NO**<sub>x</sub>, CO, HC and **SO**<sub>x</sub>/PM cause respiratory health problems.

**NO**<sub>x</sub> and HC cause ground level ozone.

**NO**<sub>x</sub> and **SO**<sub>x</sub> contribute to acid rain.

**NO**<sub>x</sub> cause euthrophication (nutrient pollution).
Basic EGR principle

EGR = Exhaust Gas Recirculation

- O₂ in the scavenge air is replaced with CO₂.
- CO₂ has a higher heat capacity thus reducing the peak temperatures.
- Reduced O₂ content in the scavenge air reduce the combustion speed thus reducing the peak temperatures.
- Decreased peak temperatures reduces the formation of NOₓ
Section of EGR-unit

- Turbocharger
- TC cut-out valve
- Prescrubber
  
  - AISI 904L
- EGR-coolers
  
  - Stainless
- Scrubber inserts
  
  - AISI 316L
- Reversing Chamfer
  
  - AISI 316L
- EGR Drain pipes
  
  - AISI 316L
- EGR-Blower
- Shutdown valve

H₂O + NaOH

EGR-coolers
- Stainless
- Scrubber inserts
- AISI 316L
- Reversing Chamfer
- AISI 316L
- EGR Drain pipes
- AISI 316L
- EGR-Blower
- AISI 316L
- WMC
- AISI 316L
PRE-SCRUBBER
Cools the exhaust gas from approximately 450 to 90°C. Interface for particle and SO2 trapping from the combustion process.

EGR-COOLER
Cools EGR gas from approximately 90°C to 31°C. Interface for particle and SO2 trapping from the combustion process.
**Exhaust gas flow (No EGR)**

**EGR-COOLER**
Cools compressed air from approximately **250°C** to **31°C** (Operated as normal air cooler).

**SCRUBBER**
No water supplied. Acts as a water mist catcher.
Finned tube cooler

Standard air cooler materials:
- Tubes: CuNi
- Fins: Cu
- Tube sheet: CuZn
EGR cooler function

Exhaust gas:
$O_2, CO_2, CO, SO_x, NO_x, HC,$
PM (ash, soot unburned lube/fuel)

T/C cut-out:
Air

Scrubber water:
$OH^-, Na^+, H^+,$
$SO_3^{2-}, SO_4^{2-}, CO_3^{2-},$
Suspended solids from exhaust PM

Cooling water:
$Cl^-$
(For Sea water cooling application)
EGR cooler environment

Sulphuric acid: $\text{H}_2\text{SO}_4$ (e.g. 46 l/h at 61% load)
Other acids: $\text{HNO}_3 - \text{HCl} - (\text{CO}_2)$
Chlorides: $\text{Cl}^-$(e.g. 10-70 ppm)

\[ \text{Addition of NaOH to scrubber water:} \]

\[ \text{Presence of Na}_2\text{SO}_4 \text{ in scrubber water:} \]

\[ 2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} \] (neutralisation)

sulphate inhibition

R. Mellström and S. Bernhardsson
9th Scandinavian Corrosion Congress
Copenhagen, 1983.
## Stainless steel for EGR cooler

<table>
<thead>
<tr>
<th>Crystal structure</th>
<th>Composition (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Austenite</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>Ferrite</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>Martensite</td>
<td>&gt;0.10</td>
</tr>
<tr>
<td>Duplex</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Pitting Resistance Equivalent Number (PREN) = %Cr + 3.3 % Mo + 16 % N

High Cr, Ni and Mo provides best resistance in sulphuric acid

⇒ Austenitic stainless steel
Stainless steel for EGR cooler

Good formability for tubes in tube plates

⇒ Austenitic stainless steel
Stress corrosion cracking

Figur 17.30. Spændingskorrosionsbestandighed i iltholdige, neutrale kloridopløsninger. Prøvning udført ved materialernes flydespænding ved pågældende temperatur. Der indtræder spændingskorrosion over kurverne.

C.Vogel, C.Juhl & E.Maahn: Metallurgi for ingeniører
Salt deposits on EGR cooler

Salt deposits (Na$_2$SO$_4$) on cooler (the salt will be dissolved by the scrubber water when EGR is running)
Cooler corrosion

Malfunctioning NaOH feeding in scrubber water

⇒ pH = 1-3  + no inhibition
Cooler corrosion
EGR cooler with seawater

Figure 3: Pitting corrosion relationship as a function of chloride content, pH and molybdenum content of austenitic chromium alloys. Temperature range, 150-180° F (65-80° C), Pitting is not a problem below the line, but may be severe above the line.

Tverberg et al. 2005
Stainless Steel World
Acknowledgments

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