Design of Microwave Cavity for Non-Thermal Plasma Generation

Dr Nadarajah Manivannan (Mani)
Centre for Electronic System Engineering (CESR)
Department of Electronic and Computer Engineering,
Brunel University, UK
Email: emsrnnm@brunel.ac.uk
Contents

• Background
• Non-Thermal Plasma Reactor
• NTPR – Design and COMSOL FEM modelling
• Corona source – COMSOL FEM modelling
• Summary
Innovative After-Treatment System for Marine Diesel Engine Emission (DEECON)

<table>
<thead>
<tr>
<th>EU</th>
<th>Objectives</th>
<th>Brunel</th>
</tr>
</thead>
<tbody>
<tr>
<td>• FP7</td>
<td>• NO\textsubscript{X} &lt; 2%</td>
<td>• Project leader – Professor Balachandran</td>
</tr>
<tr>
<td>• 2.3m Euro</td>
<td>• SO\textsubscript{X} &lt; 2%</td>
<td>• NO\textsubscript{X} and SO\textsubscript{X} Reduction using Non-Thermal Plasma</td>
</tr>
<tr>
<td>• 3 years (2011 to 2014)</td>
<td>• PM &lt; 1% weight</td>
<td></td>
</tr>
<tr>
<td>• 8 partners (UK, Italy and Poland)</td>
<td>• HC &lt; 20%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CO &lt; 20%</td>
<td></td>
</tr>
</tbody>
</table>
Why $NO_x$ and $SO_x$?

- Toxic gases
- Health issues
- International and National Regulations
- Sulphur Content
- Coastal area
Non-Thermal Plasma Reactor (NTPR)

In-let: Marine Exhaust Gas

Electron Beam (EB)

NTPR (Microwave cavity)

Out-let: Treated Gas

NTPR schematic

©Centre for Electronic Systems Research, Brunel University
Microwave Cavity design

• Maximum MW energy is transferred from magnetrons to the cavity
• Well spread electric field distribution – electrons from electron beam energized homogenously
• COMSOL FEM model for calculating electrified distribution
Proposed MW Scheme of NTPR

MG : Magnetron (2.45GHz)
WL : Water Load
WG1 & WG2 : Wave guides (WR340 a= 109mm and b= 54.5mm )
S : Slots {2mm (width) x 109mm (height)}
λₔ : Wavelength of the waveguide (148mm)
COMSOL

Wave Guides
2×WR340:
(109mm×55mm)
2 × 3 Slots

Microwave generation
2×2 kW, 2.45 GHz (S Band)
Simplified representation

NTPR
Rectangular cavity
200mm(w)×200mm(h)×500mm(l)

Physics

$$\nabla \times \mu_r^{-1}(\nabla \times \mathbf{E}) - K_0^2 \left( \varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0} \right) \mathbf{E} = \mathbf{0}$$

$\mu_r$ - permeability; $\varepsilon_0$ - permittivity; $\mathbf{E}$ - electric field vector; $\sigma$ - density and $K_0$ – wave number.
FEM Modelling - Geometry

- Parameterized dimensions
- Simplified Model
- MW excited port
- User defined meshed
FEM Modelling – Position of slots

- Slot positions are at high intensity region (HIR)
- HIR can be adjusted by varying the length of the waveguide (Operation of plunger)

**Waveguide Equations TE10**

\[
\lambda_g = \frac{\lambda_o}{\sqrt{1 - \left(\frac{\lambda_o}{2a}\right)^2}}
\]

- \(\lambda_g\) = wavelength of waveguide
- \(\lambda_o\) = wavelength of microwave ( = 122mm)
- \(a\) = longest side of the rectangular cross section

<table>
<thead>
<tr>
<th>Type of wave guide</th>
<th>Dimension s (mm)</th>
<th>(\lambda_o) (mm)</th>
<th>(\lambda_g) (mm)</th>
<th>distance between slots</th>
</tr>
</thead>
<tbody>
<tr>
<td>WR 430</td>
<td>109 × 55</td>
<td>122</td>
<td>148</td>
<td>74</td>
</tr>
<tr>
<td>WR 340</td>
<td>86 × 43</td>
<td>122</td>
<td>173</td>
<td>86.5</td>
</tr>
</tbody>
</table>

©Centre for Electronic Systems Research, Brunel University
FEM Modelling – Line scans across the wave guide
Some FEM Modelling Results

- High electric field regions in the NTPR reflects the high energy electron plasma region
Some FEM Modelling Results

- Isosurface plots shows high intensity regions
Other MW arrangements

Non-Thermal Plasma Reactor

Movable plunger

A & B - Straight wave guide (WR340)
S1, S2, S3, S4, S5, S6 – slots

d1, d2, d3, d4 – distances integer multiples of half the wave length of the wave guide

Depth of the reactor = 250mm
### Corona source and COMSOL modelling

**Commercial DC Corona source**

- **High voltage needle dimensions**
  - Diameter of the cylindrical section – 3.15mm
  - Length of the cylindrical section – 5mm
  - Length of the conical section - 1mm

- **Grounded plate dimensions**
  - 5mm (length) x 5mm (width) x 1mm (thickness)

- **Distance between tip of the high voltage and the grounded plate**
  - 5mm

- **High voltage**
  - 48kV

**Simplified COMSOL geometry**
Some FEM Modelling Results
Dielectric Break Down of Air

- Dielectric breakdown will occur within 1cm region from the needle
- Plasma exists for more than 1cm region
- Microwave can then spread plasma to a wider region
NTPR in the Pilot Scale Test Site
Southampton
Conclusions

• Non-Thermal Plasma for emission control
• Microwave multimode cavity with slotted waveguide is designed with COMSOL
• Corona source was used generate plasma, also investigated using COMSOL
Thank You