Innovate UK
Technology Strategy Board

Brunel University London

Modelling of DPF Regeneration using Microwave Energy

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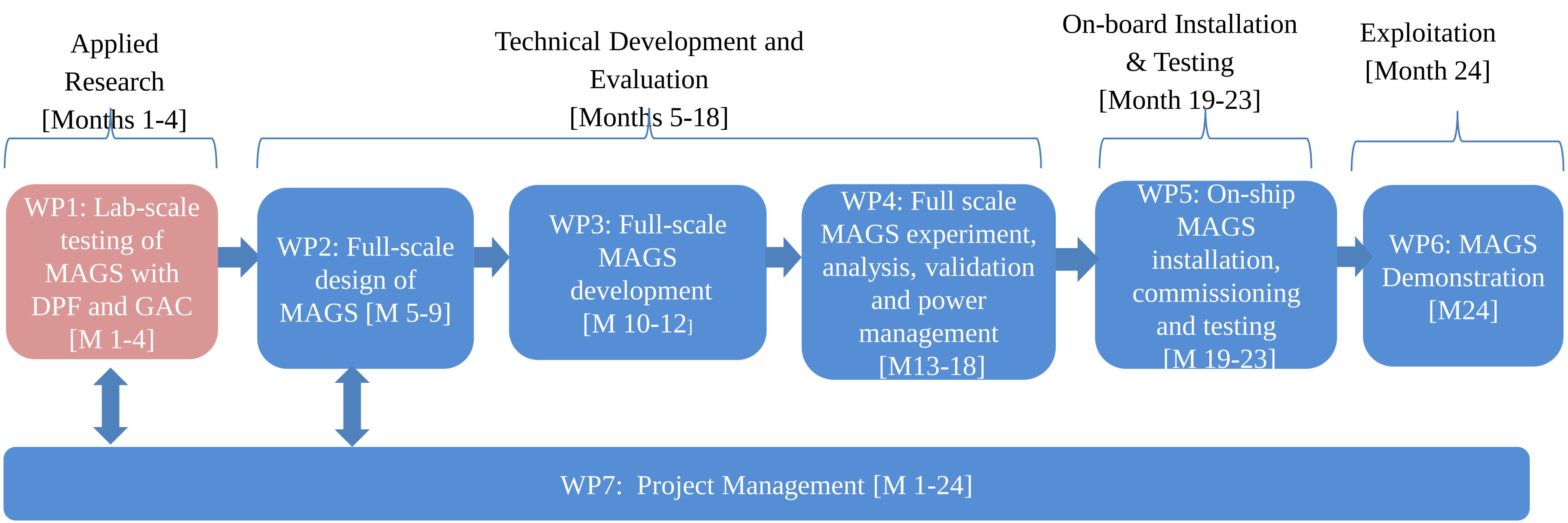
Contents

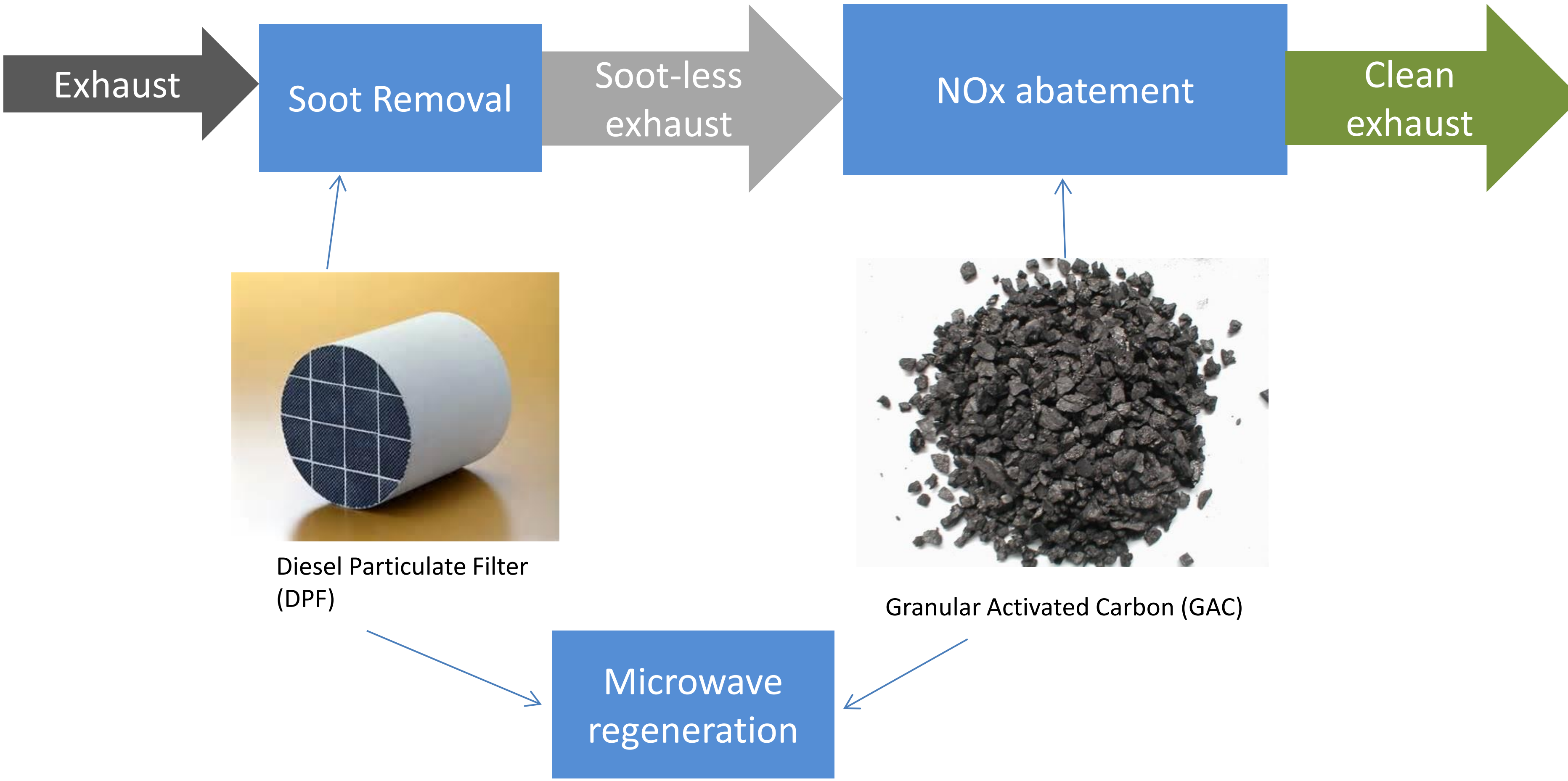
- MAGS- InnovateUK project
- Basic Concepts
- Existing Microwave Cavity and COMSOL Modelling

New Project: Marine Exhaust Gase Treatment System (MAGS)

Title: Marine Exhaust Gas treatment (MAGS)
Funding body and program: TSB Vessel efficiency II
Funding requested: £0.852million (total) and £0.362million (Brunel)
Partners: SMS (Wraysbury) - Lead , IMWSS (Milton Keynes), Codel (Bakewel) and Brunel University (Uxbridge)
Outcome: Successful and started in Feb 2014



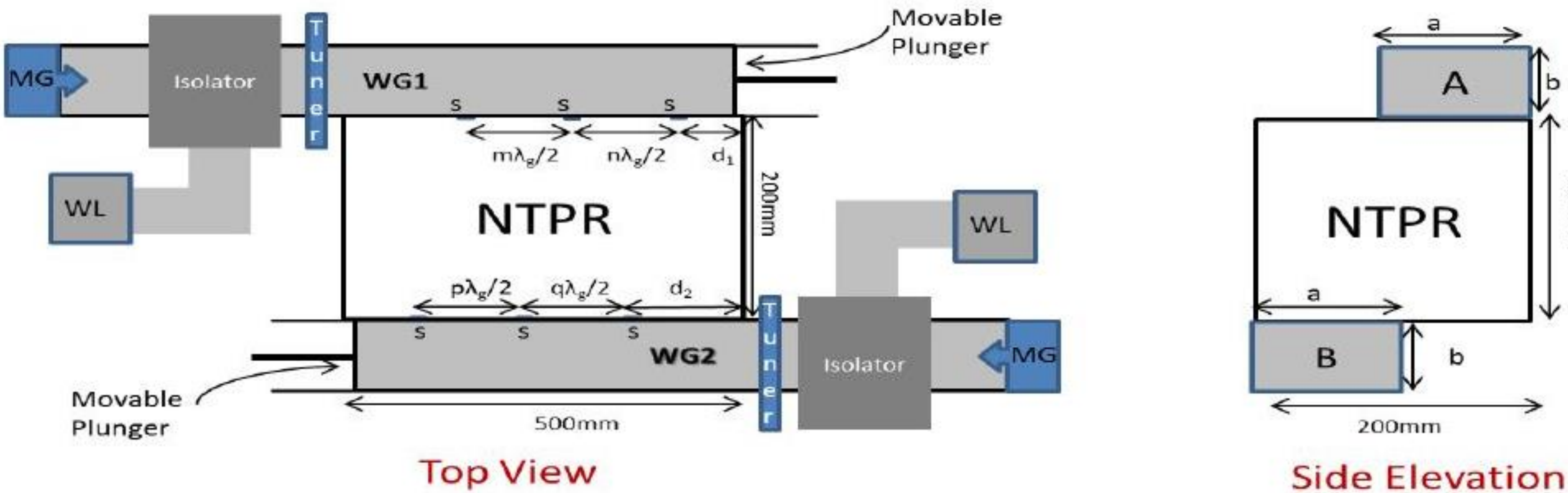
MAGS – Basic concepts



MW Cavity Design Considerations

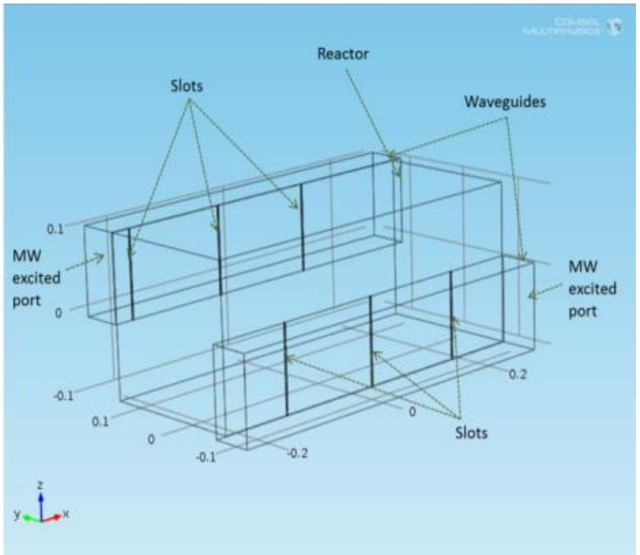
Measurable	• MW power generate • MW reflected
Controllable	• Variable MW power (0- Max) • MW to reactor tuneable
Safety	• No microwave leaks • No gas overheating • No damage to magnetrons
Efficient	• More useful power • Minimal heat loss • Minimal cooling energy
Small foot print	• No huge structure • Compact future magnetrons (solid state)

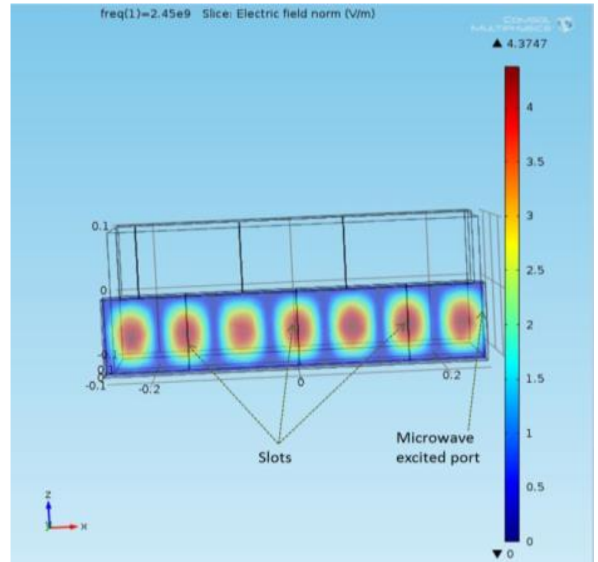
Pilot MW NTPR Scheme

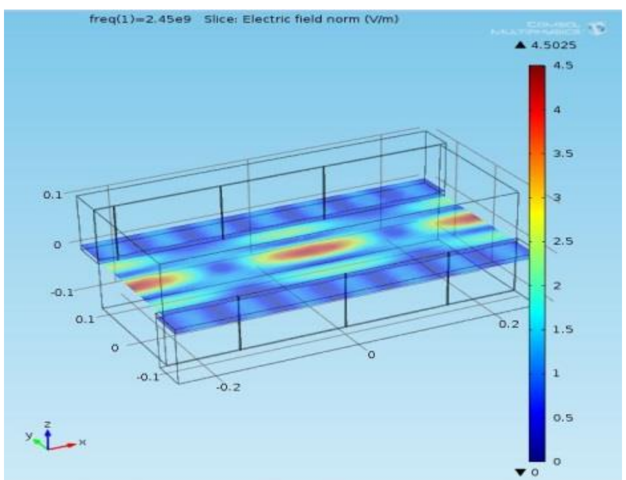


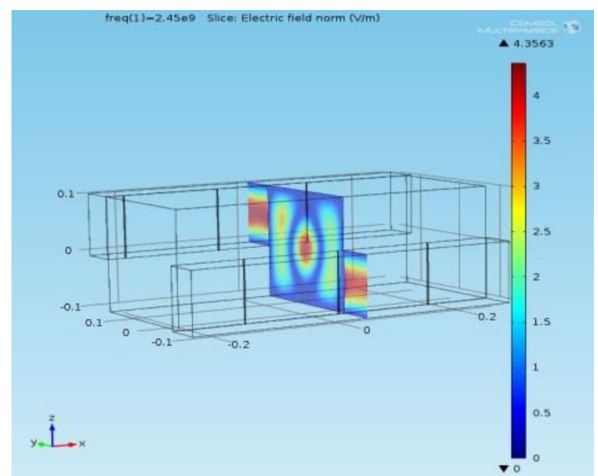
MG : Magnetron (2.45GHz)
WL : Water Load
WG1 & WG2 :Wave guides (WR340 a= 109mm and b= 54.5mm)
S : Slots {2mm (width) x 109mm(height)}
λ_g : Wavelength of the waveguide (148mm)

FEM Modelling Results



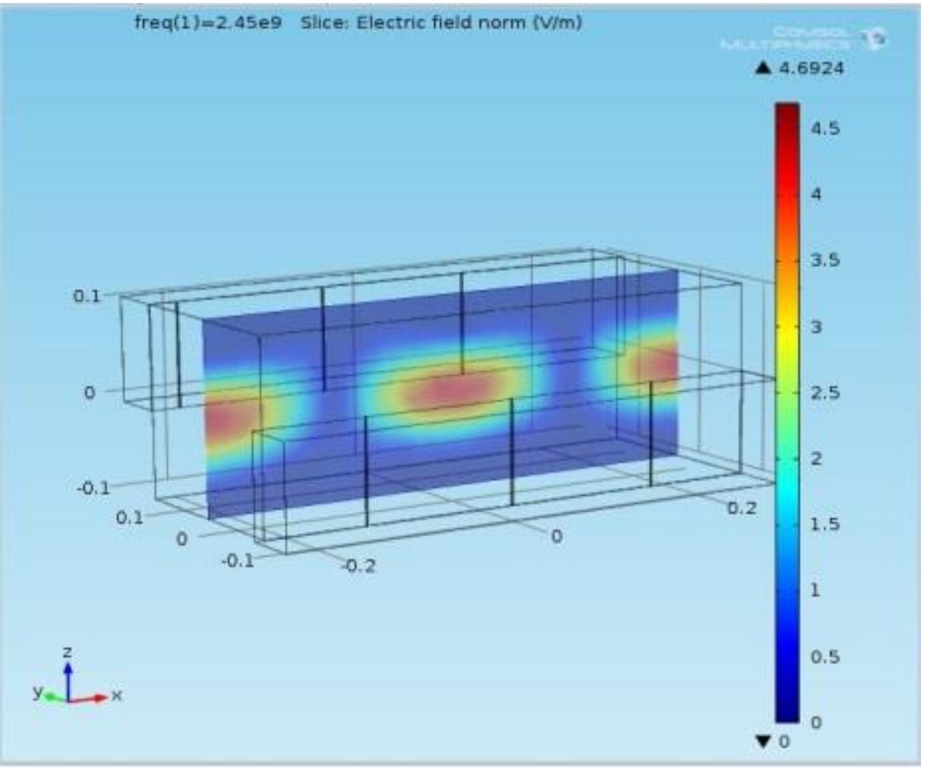


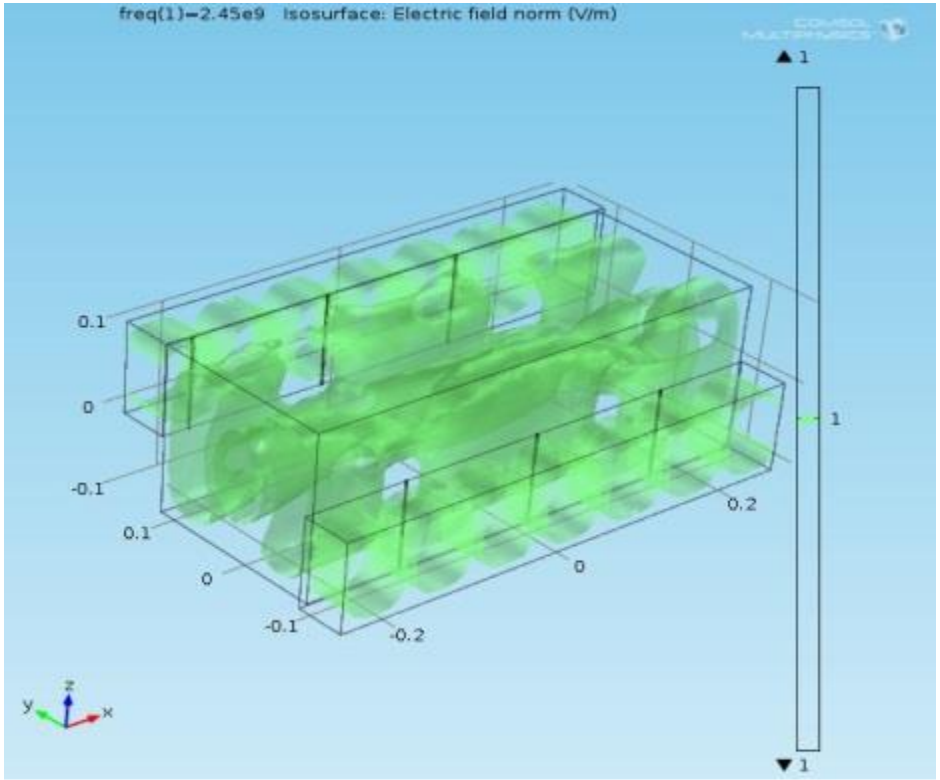




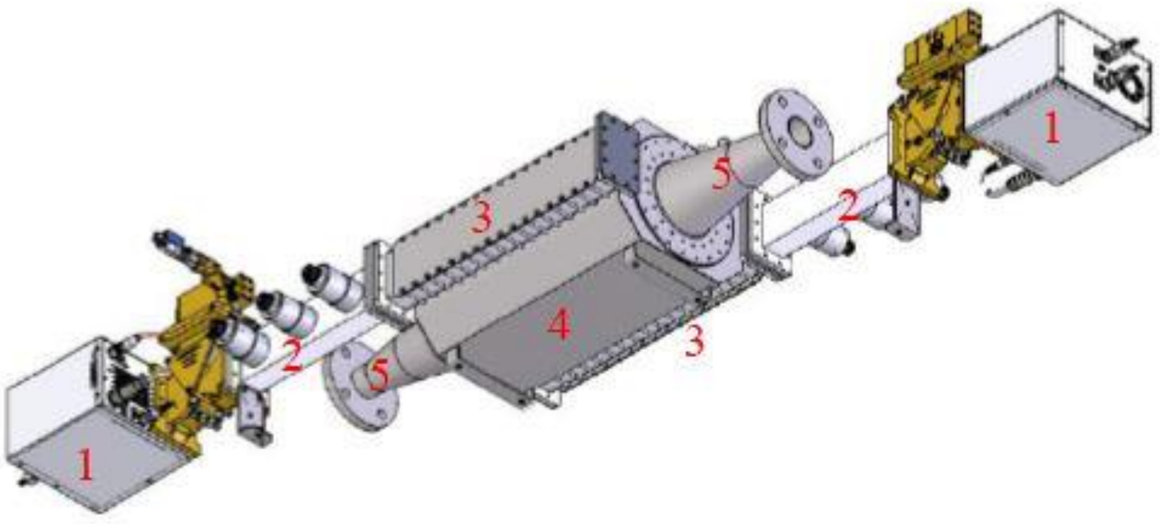
COMSOL multi-Physics software

FEM Modelling Results



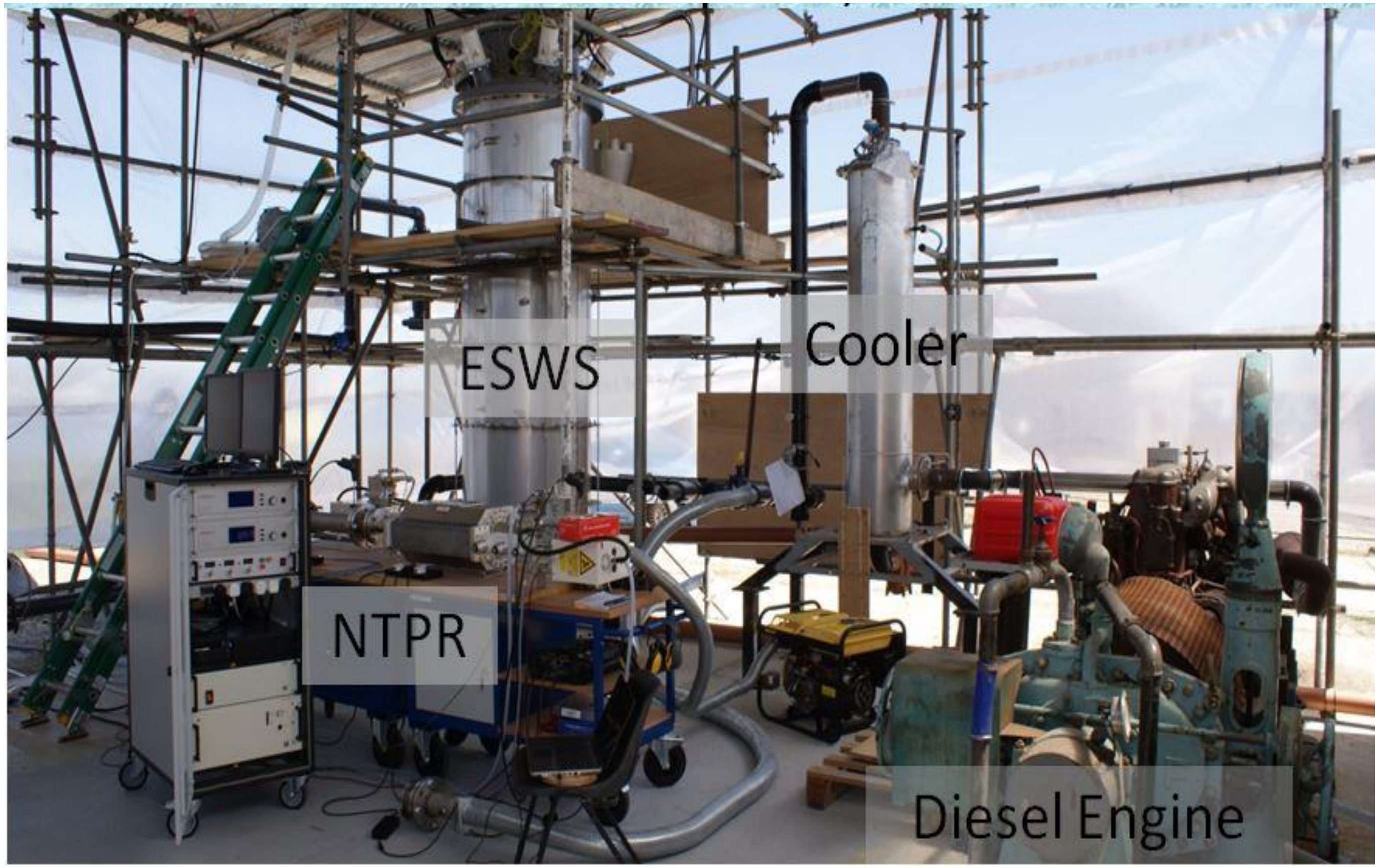


Schematic of Pilot Scale NTPR



Brunel pilot scale NTPR MW system:
1- microwave generators (Magnetron, Isolator, Water cooling and MW power measurement);
2-Stub Tuners; 3- Waveguides; 4 -Multi-Mode Cavity;
5 -Gas inlet/outlet.

Pilot Scale Southampton experimental site

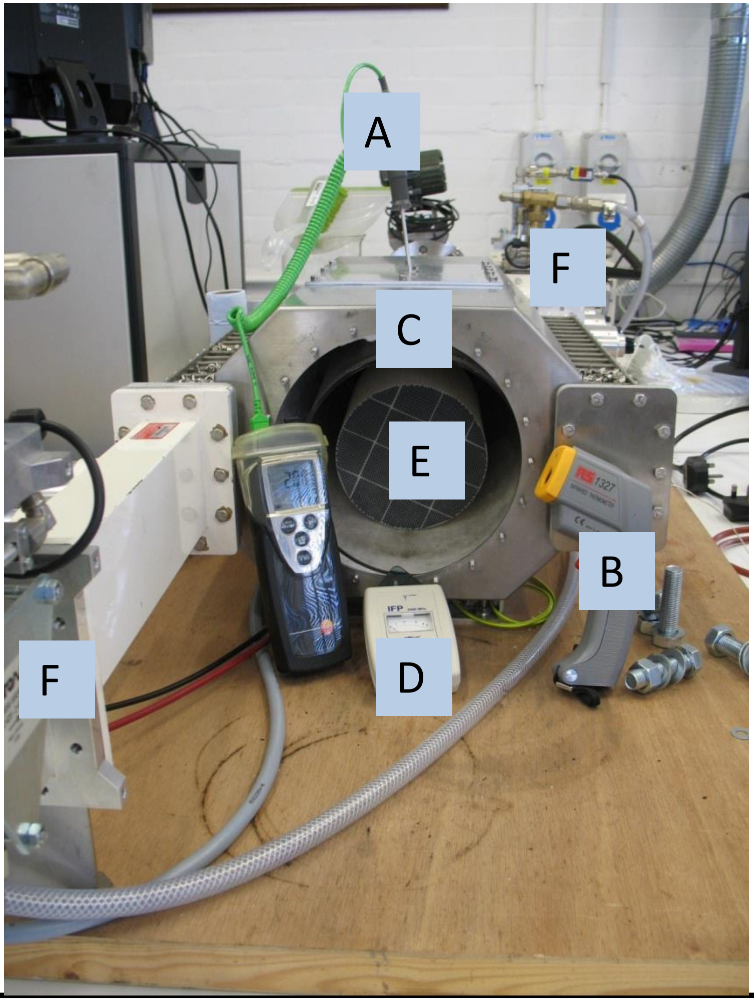


Engine capacity - 266kW

Experimental set-up

DPF Microwave Regeneration
2.45 GHz
2000kW (x2)
Multimode Microwave Cavity

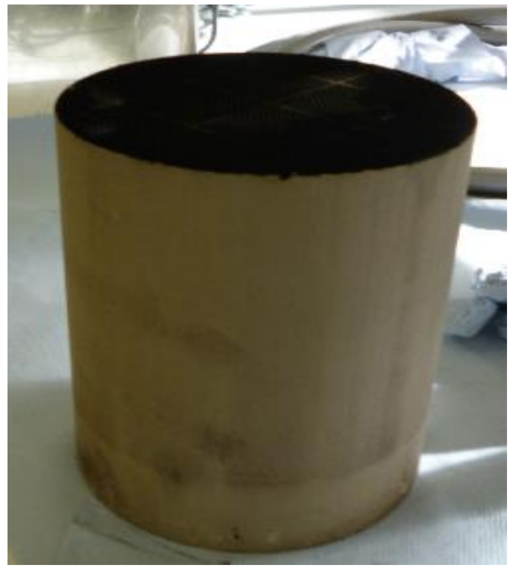
A - Surface probe temperature measurement
B - Infrared temperature measurement (RS 137)
C - Microwave multi-mode cavity (insulated (Durablanket Insulator) Quartz tube + DPF)
D- Microwave leak measurements
E- DPF positioned within quartz tube
F- MW source



DPF Regeneration Attempted in the Microwave cavity (Opened)

New Project: MAGS – Soot Removal
Early results

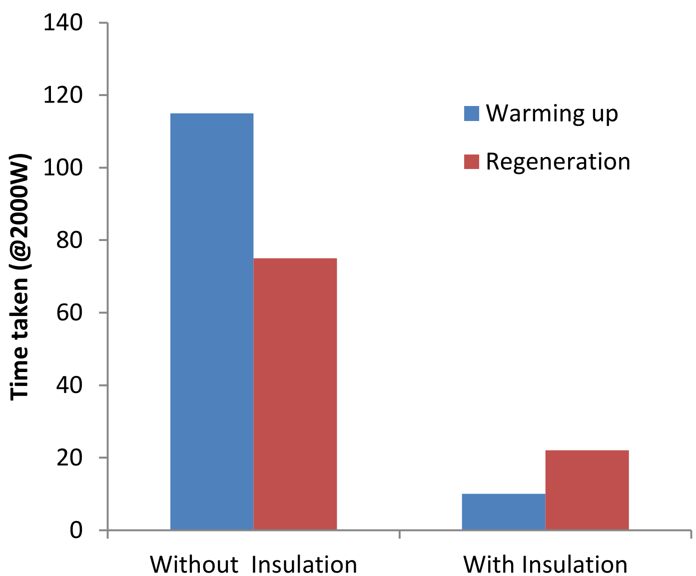
JM SiC non-catalyzed DPF
Length = 18.2cm,
Diameter = 14.4cm
Mass – 1830 g



The soot loaded
DPF before
regeneration
Mass- 1849g

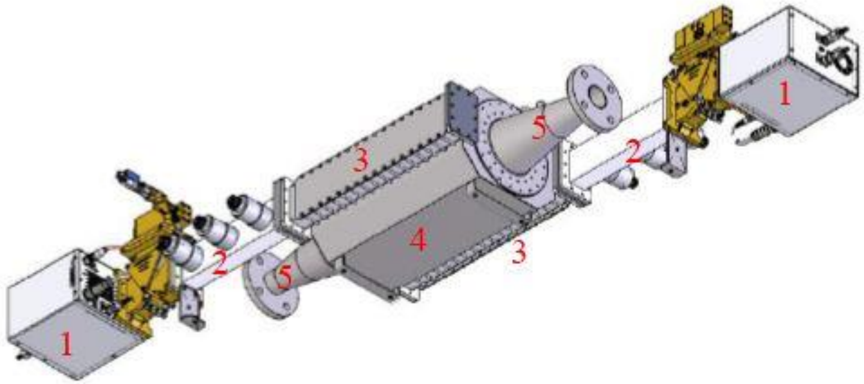
Glow while MW is ON

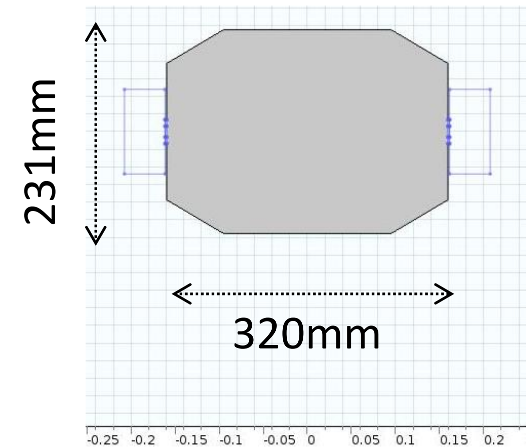
Summary of Experimental Results



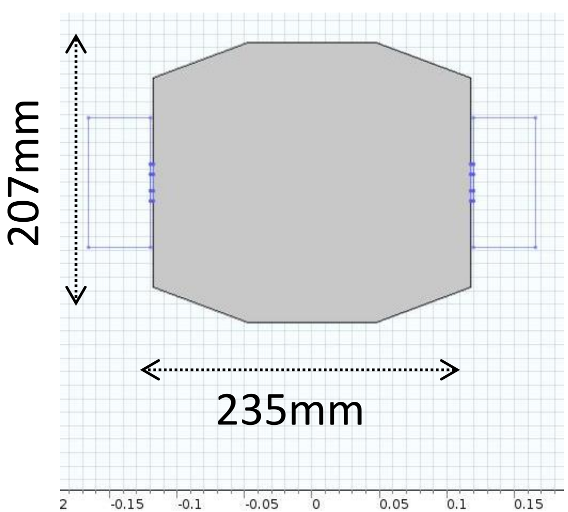
Mass of the SiC DPF	**1830g**
Mass of soot removed	10 g
Total MW energy supplied	3840kj
Temperature rise	550^0C
Energy used by DPF	755kj
% efficiency of the MW system	20%

First set of FEM modelling of Microwave Cavity using COMSOL

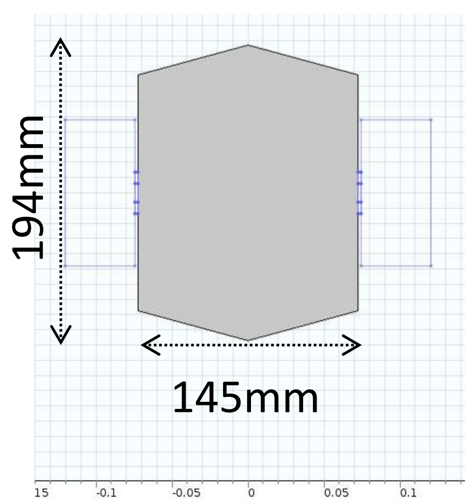




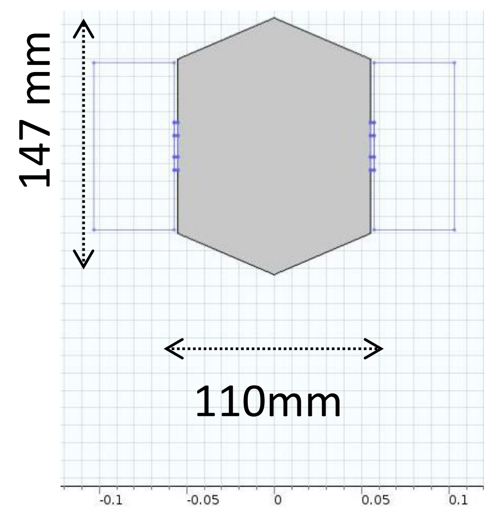
Existing MW cavity NT



A



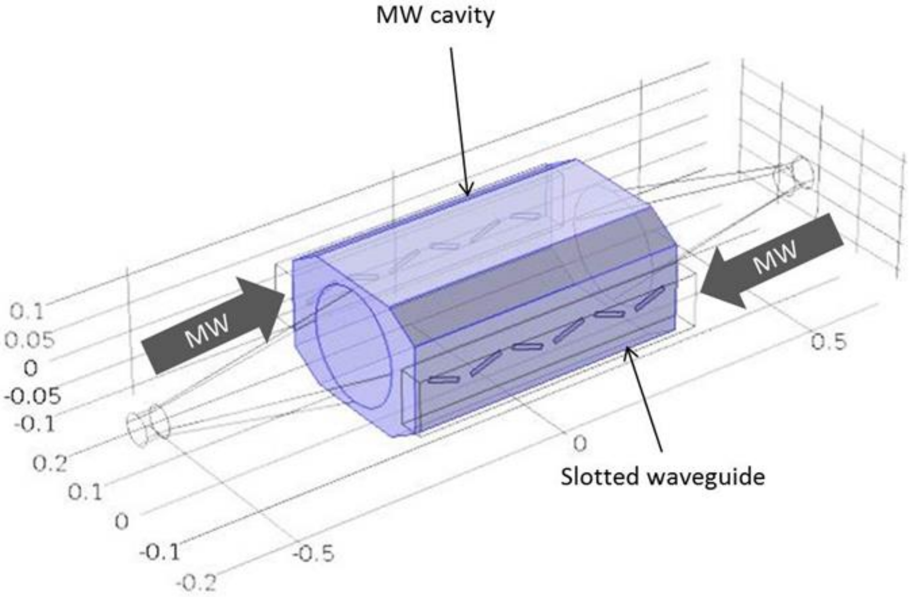
B



C

New Dimensions

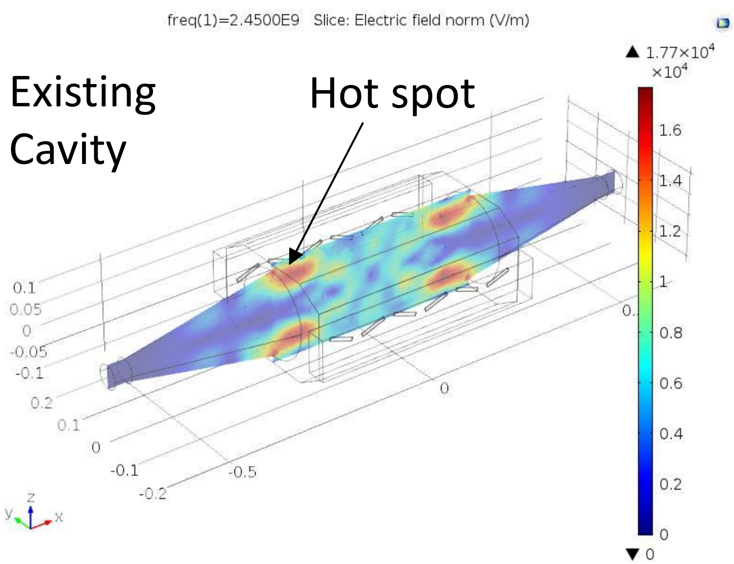
COMSOL Geometry



- Microwave excited ports
- Parametrised octagonal cavity

Simulation Results - Electric field Distribution

Existing Cavity



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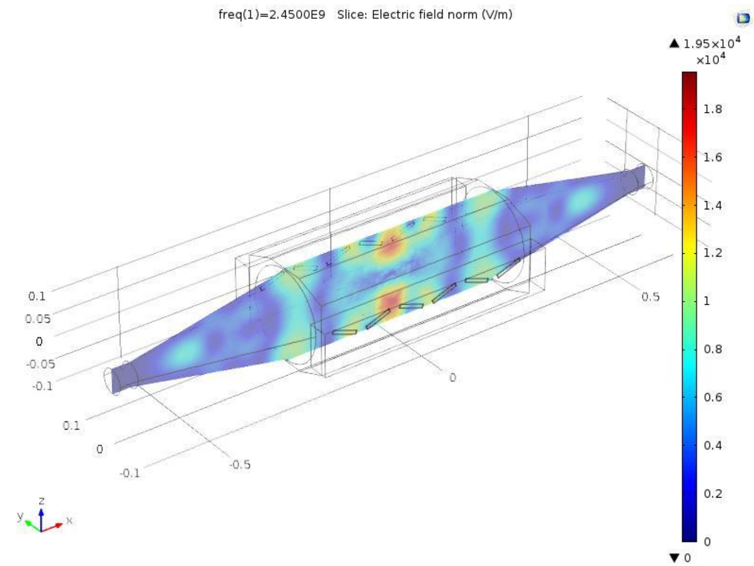

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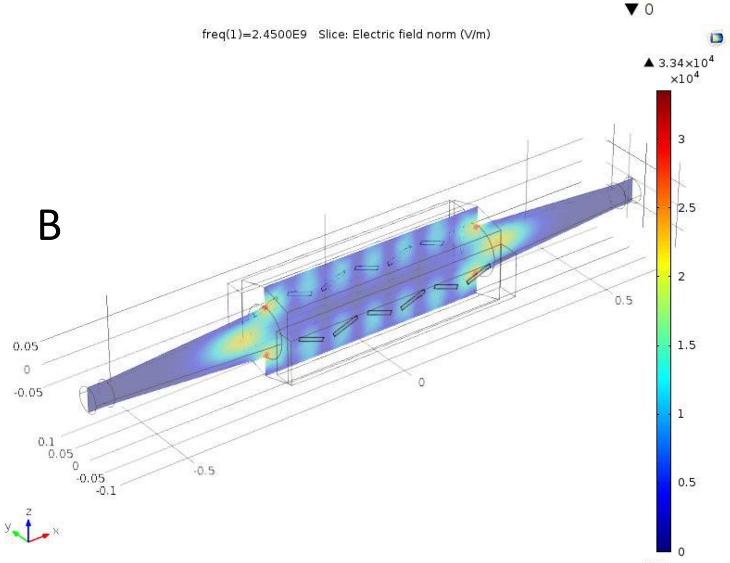

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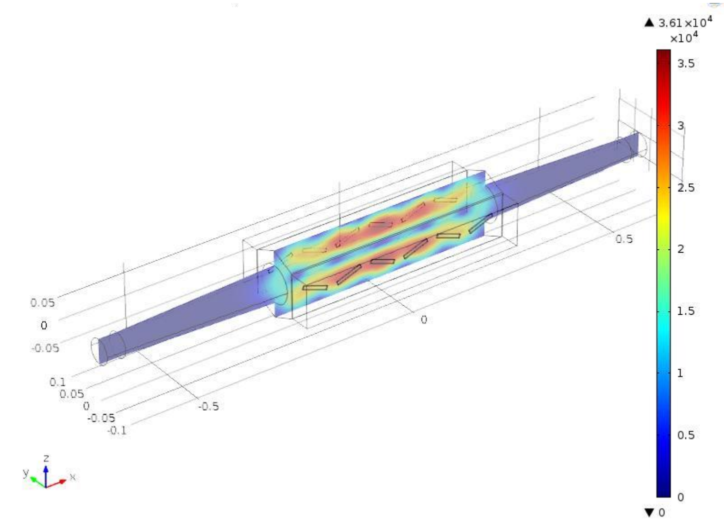
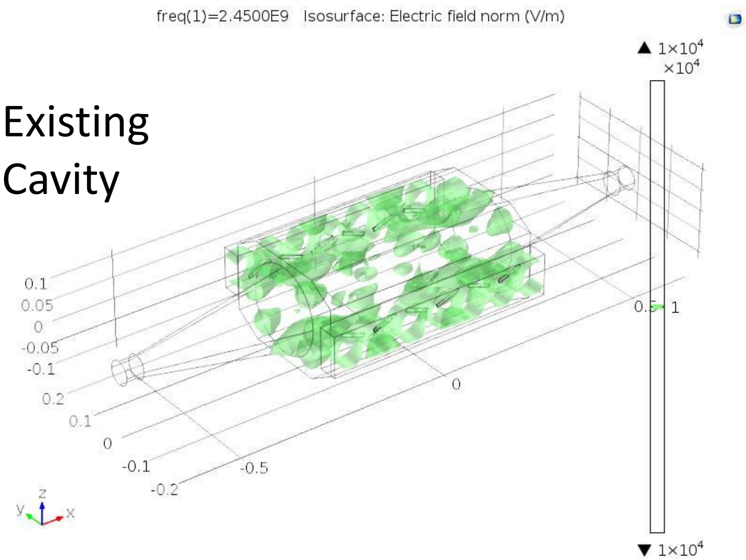


Simulation Results - Electric field Distribution

Existing Cavity



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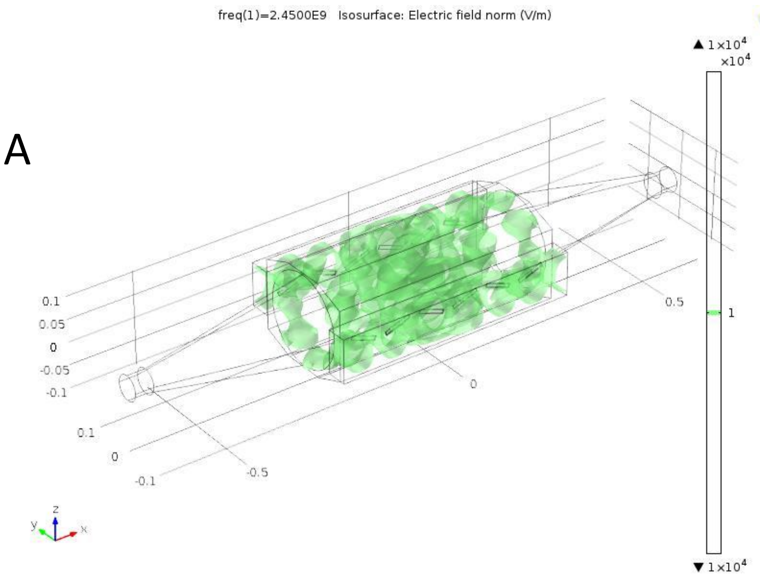

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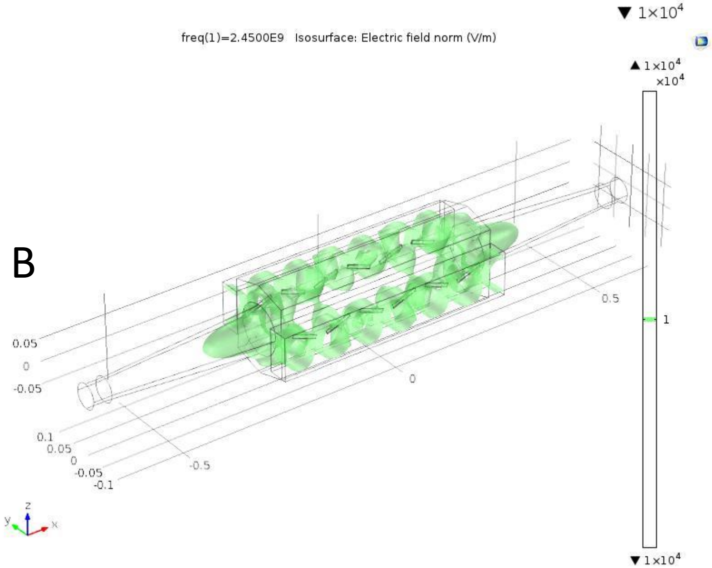

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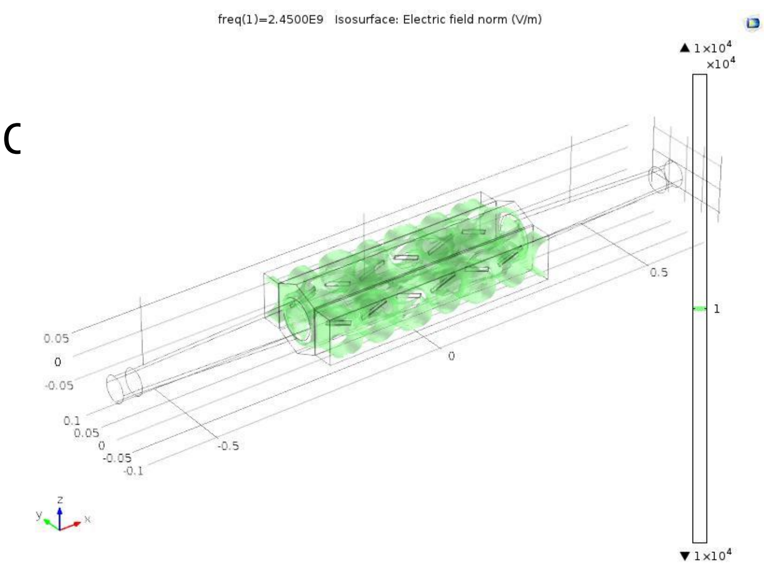


Simulation Results -Electric field Distribution

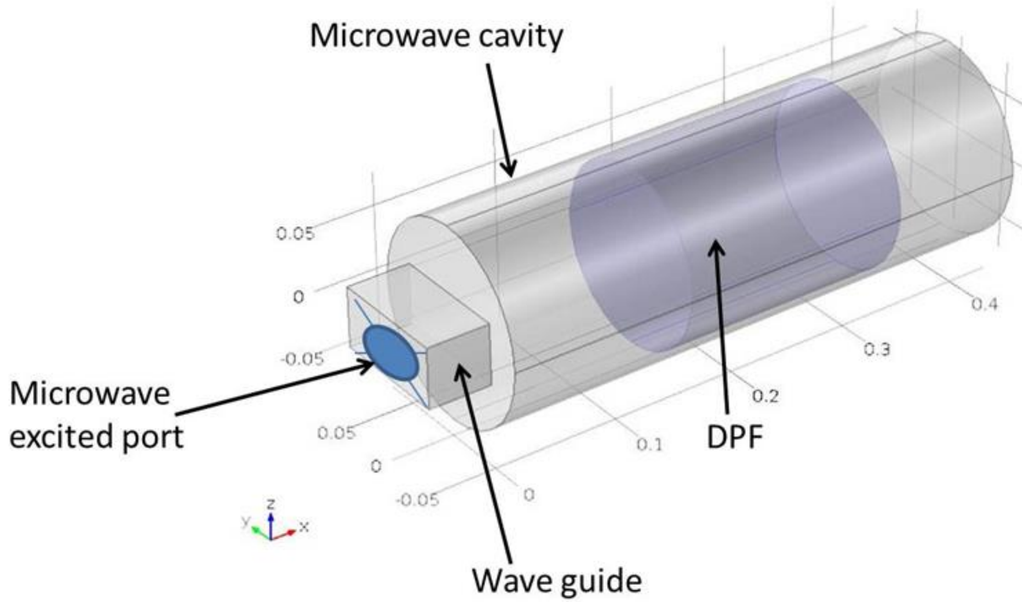
	Max Electric Field within the cavity (V/m)	Average Electric Field within the cavity (V/m)
Existing Cavity	1.5×10^5	6.4×10^4
A	4.0×10^5	7.9×10^4
B	8.9×10^4	6.3×10^4
C	2.7×10^5	16.2×10^4

- Homogenous Electric Field ensures homogenous heating of DPF - 'C' is the best
- Heating of dielectric material (SiC) directly proportional to square of Electric field.

$$P = 2\pi f \varepsilon_o \varepsilon'' E_{rms}^2 V$$

where, P - power dissipated in the material [W/m3], f - microwave frequency [Hz], ε_o - electric permittivity of vacuum [F/m], E_{rms} - root mean square value of electric field strength with in the material, V - volume of the material and Ɛ'' - dielectric loss factor (= σ/(2Лf).

First set of FEM modelling of Microwave Cavity using COMSOL



	Property	Name	Value	Unit
✓	Relative permittivity	epsilonr	30-11*j	1
✓	Relative permeability	mur	1	1
✓	Electrical conductivity	sigma	0.001	S/m
✓	Thermal conductivity	k	120	W/(m·K)
✓	Density	rho	3000	kg/m^3
✓	Heat capacity at constant pressure	Cp	750	J/(kg·K)

Physics of the Model
Coupled Model

- Electro Magnetic wave propagation

Governing equation

$$\nabla \times \mu_r^{-1}(\nabla \times \mathbf{E}) - K_0^2\left(\epsilon_r - \frac{j\sigma}{\omega\epsilon_0}\right)\mathbf{E} = 0$$

Where μ_r - permeability of the medium, ε_o - permittivity of the medium, **E** - electric field vector, σ - density of the medium, K_0 – wave number.

Boundary Condition of the walls

$$\mathbf{n} \times \mathbf{E} = 0$$

where ***n*** – normal vector to the walls.

Physics of the Model

- Heat Transfer in Solids (ignored other form of heat transfer)

Governing equation

$$\rho C_p . \nabla T = \nabla.(k\nabla T) + Q$$

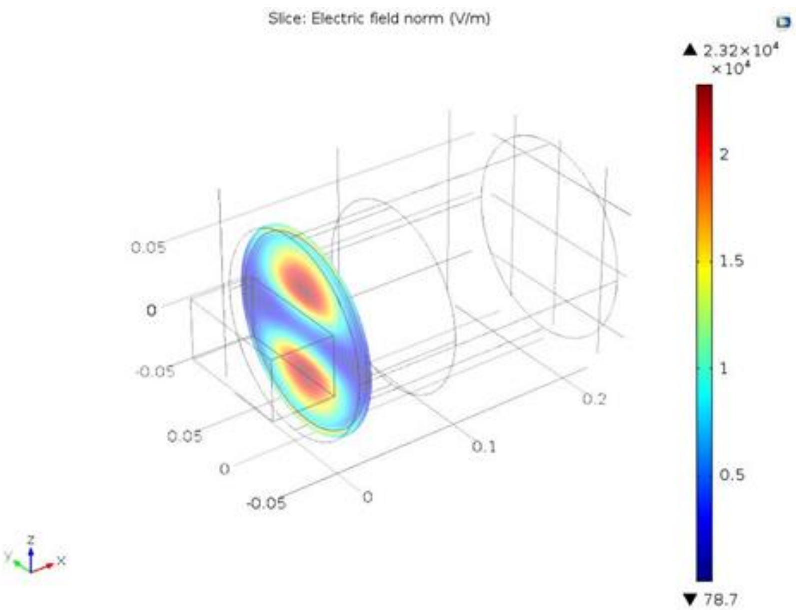
$$Q = Q_{rh} + Q_{ml}$$

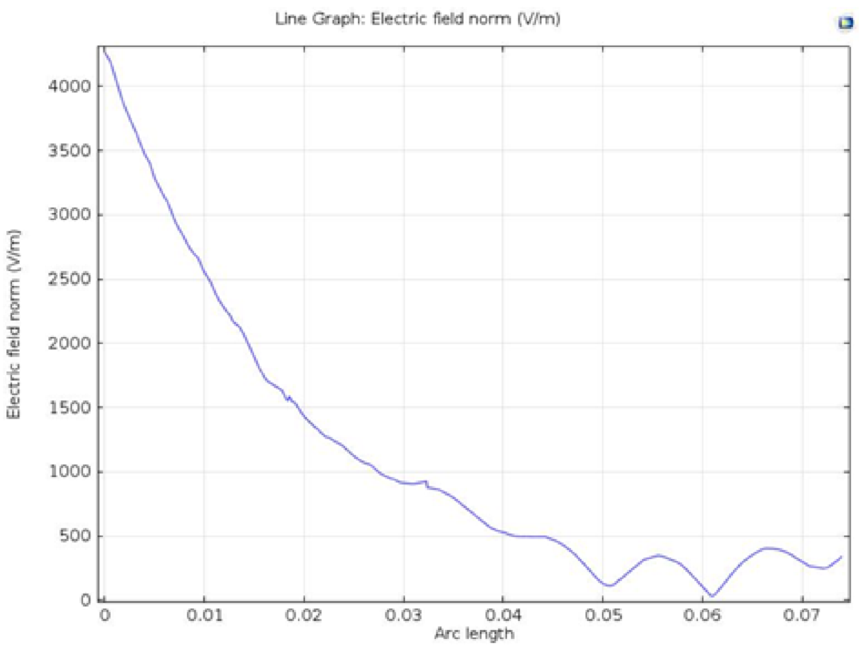
$$Q_{rh} = \frac{1}{2}\mathrm{Re}(\mathbf{J}.\mathbf{E}^*)$$

$$Q_{ml} = \frac{1}{2}\mathrm{Re}(\mathbf{B}.\mathbf{H}^*)$$

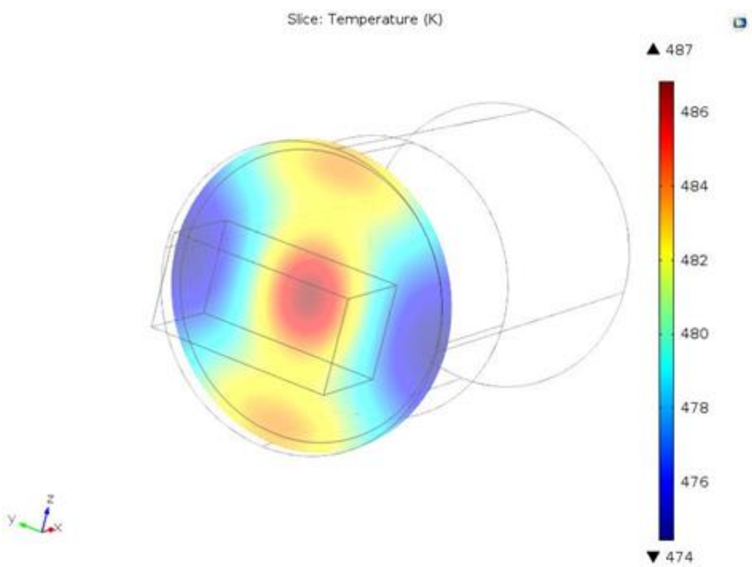
where, ρ is the density of the material, C_p is specific heat capacitance at constant pressure (1 atm) and Q is the heat source.

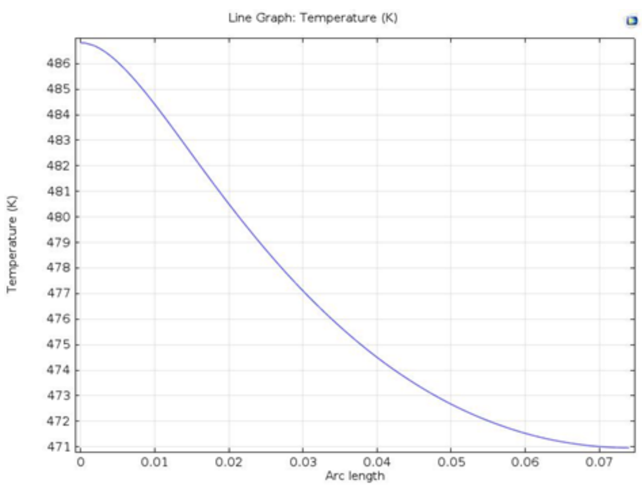
Simulation Results Electric filed



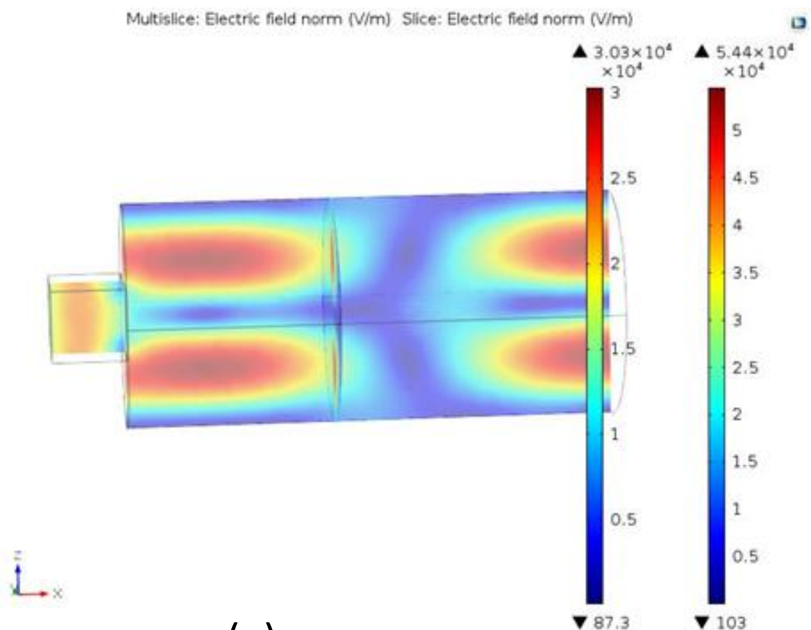


Simulation Results- Thermal Profile

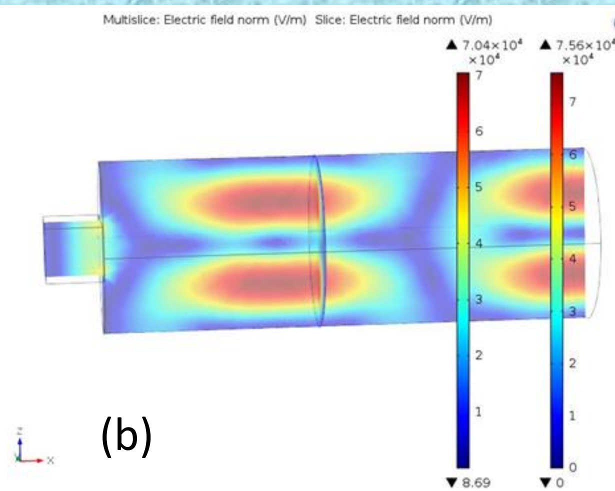




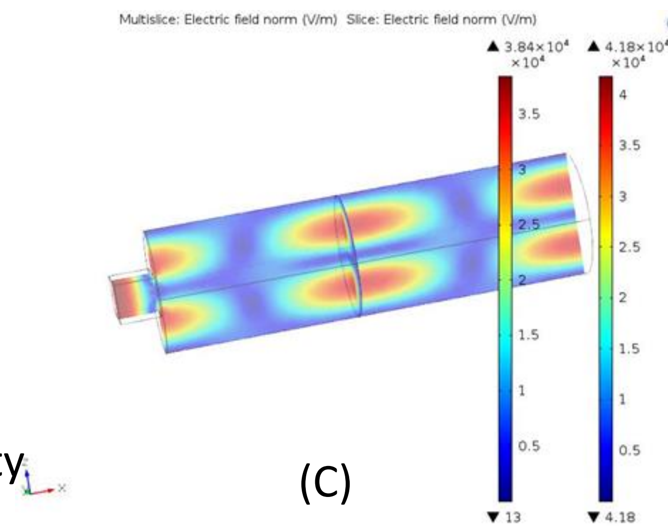
Simulation – Various Cavity Length



(a)



(b)



(C)

Electric field for various dimensions of the cavity
(a) 333mm (b) 433mm and (c) 533mm

Conclusion

- Design of DPF regeneration cavity
- Electric field calculations
- Thermal profile of cavity and DPF
- Challenges
    - Accurate model of DPF (Cell structured (600 cpi))
    - Large number of boundary surface and domain
    - Computer RAM issues ?

Acknowledgements

InnovateUK (TSB) for the financial support provided to the project 'Marine Exhaust Gas Treatment System (MAGS) {grant reference number 42471-295209}'

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Thank you for the attention!