Non-thermal Plasma System for Marine Diesel Engine Emissions Control

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Abstract -- **Air pollutants generated by ships in both gaseous and particulate forms, have a long term effect on the quality of the environment and cause a significant exposure risk to people living in proximities of harbors or in neighboring coastal areas. It was recently estimated, that ships produce at least 15% of the world's NOx (more than all of the world's cars, buses and trucks combined), between 2.5 - 4% of greenhouse gases, 5% black carbon (BC), and between 3-7% of global SO_2 output. Estimation of contribution of maritime shipping to global emissions of VOC and CO is not yet available. In order to reduce the environmental footprint of ships, the International Maritime Organization (IMO) recently issued the legislation of Marpol Annex VI guidelines which implies especially the introduction of, inter alia, stricter sulphur limits for marine fuel in ECAs under the revised MARPOL Annex VI, to 3.50% (from the current 4.50%), effective from 1 January 2012; then progressively to 0.50 %, effective from 1 January 2020, subject to a feasibility review to be completed no later than 2018. The limits applicable in Emission Control Zones (ECAs) for SOx and particulate matter were reduced to 1.00%, beginning on 1 July 2010 (from the original 1.50%); being further reduced to 0.10 %, effective from 1 January 2015. The Tier III controls apply only to the specified ships built from 2016 while operating in Emission Control Areas (ECA) established to limit NOx emissions, outside such areas the Tier II controls apply. The United States and Canada adopted national regulations enforcing IMO Tier III equivalent limits within the North American ECA effective 2016. The US Environmental Protection Agency (EPA) rule for Category III ships, however, references the international IMO standards. If the IMO emission standards are indeed delayed, the Tier III standards would be applicable from 2016 only for US flagged vessels. One of the proposed solutions towards marine diesel emission control is the non-thermal plasma process. We designed and built a non-thermal plasma reactor (NTPR) using a combination of Microwave (MW) and Electron Beam (EB) for treatment of marine diesel exhaust gas. A numerical model has been developed to better understand the marine exhaust gas/plasma kinetics. The reactor modelling and design can sustain 10kW of combined MW and EB power with a gas flow rate of 200l/s. The removal of NOx and SOx was continuously monitored using a portable dual Testo gas analyzer system while all other parameters (MW power, EB power, gas temperature/flow rate, etc.) were remotely recorded & stored through a Labview DAQ system. The reactor performance in NOx and SOx removal will be tested on a 200 kW two stroke marine engine. This study is a part of the DEECON (Innovative After-Treatment System for Marine Diesel Engine Emission Control) FP7 European project.**

Index Terms— **Electron Beam, Exhaust abatement, Marine diesel engine exhaust, Microwave, Non-thermal plasma, NOx, Numerical modelling, SOx.**

I. INTRODUCTION

International shipping traffic presents itself today as a major challenge in terms of impact on environment and human health which entails severe economic consequences. The most widely adopted and efficient systems for main ship propulsion are two or four-stroke diesel engines fuelled with relatively "inexpensive" heavy-fuel oils (HFO), which lead to substantial emission of pollutants in the diesel exhausts. The primary air pollutants emitted by diesel engines are SOx, NOx, Particulate Matter (including Black Carbon (BC)), CO and volatile organic compounds (VOC or HC).

A. *Economic Impact*

Considering the above pollutants Economic Valuation of Air Pollution model (EVA) [1] predicts that due to a general increase in the ship traffic worldwide the total external pollution costs in Europe will increase to 64.1 billion Euros (€)/year in the year 2020 from 58.4 billion €/year costs in the year 2000. If we examine the relative external costs from all international ship traffic, it is responsible for an estimated 7% of the total health effects in Europe due to air pollution in the year 2000, increasing to 12% in the year 2020 [2]. Costs from international ship traffic in the Baltic Sea and the North Sea was 22.0 billion €/year for the year 2000, decreasing to 14.1 billion Euros/ year for the year 2020 due to impending legislation to be implemented in European Union (EU) following MARPOL Annex VI guidelines.

B. *Legislation*

As of March 2014 the ECAs established to limit SOx and particulate matter emissions are: Baltic Sea area – as defined in Annex I of MARPOL; North Sea area (including the English Channel) – as defined in Annex V of MARPOL; North American area (entered into force on 1st August 2012); and United States Caribbean Sea (entered into force on 1st January 2014). However, regulatory frameworks and industrial benchmarks do not include CO, polycyclic-aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), metals, heavy metals, dioxins, and secondary organic aerosols (SOA) or related external costs on the natural environment or climate. CO, HC and PM1 are considered priority for EU and the US environmental agencies. In 2012, diesel particulate have been classified as carcinogenic to humans by the World Health Organization (WHO) [3]. Since 2011, IMO instituted a commission to address measures to contain BC emission from ships, since BC is considered the second most important climate forcing agent with warming effect; its removal contributes to an equivalent reduction of greenhouse gases, together with CO_2. To comply with the existing and the future IMO regulations, all existing and future ships must adopt measures to reduce their specific emissions (gram of pollutant emitted for each kWh). This means that while new ships should be properly designed to reduce such emissions, existing ships must be retrofitted.

C. Retrofit vs fuel switching

To be more effective, ships have to become more environmental friendly and more energy efficient. Energy efficiency can be achieved reducing the specific energy demand of ships, through new concepts of engine design, naval architecture and routing. Energy efficiency is also achieved by assuring the best use of the worldwide energy mix. In this sense, also the intermediate fuel oil (IFO) commonly adopted by ships as cost effective fuels has a limited market and whose conversion into diesel is expensive and ineffective, over a certain percentage. To date, internal maritime traffic within EU ports requires use of costly low sulphur fuels, whose impact on the shipping economy is significant. Industry experts believe ship owners will opt for marine gasoil (MGO) in 2015 or alternative fuels such as LNG is still limited because of high investment costs and lack of appropriate infrastructure. In this scenario there are many favorable predictions towards marine scrubbers to become the 'dominant technology' in cutting marine fuel emissions.

D. Retrofitting technologies

Currently there are 300 scrubbers being commissioned in EU ECA for various engine sizes with a total manufacturing value of £4 million/unit. It is estimated that by 2020 a total of 80 000 ships would require retrofitting worldwide in order to meet emissions regulations. The state-of-the-art conventional technologies for flue gas treatment aimed at SOx and NOx emission control are wet, dry and semi-dry flue gas desulphurization (FGD) and selective catalytic reduction (SCR). To date, ships retrofit for atmospheric emission control is focused on SO_2, NOx and coarse PM (>1µm) removal. Scrubbers can be suitably adopted to remove SO_2 and PM, while Selective Catalytic Reduction reactors (SCR) are demanded to the removal of NOx. Scrubbers and SCR systems (e.g. MAN diesel SCR system ≈85% NOx reduction) are expensive and the retrofit operation quite complex due to the high footprint and volume of the equipment. The overall capital cost of a scrubber system is largely related to that of system auxiliaries. Operational costs of scrubbers are mainly related to the water needs, (on average 48 T/MWh), who's large amounts lead to complex and expensive wash water treatments. SCR systems have high operational costs related to the periodic catalysts substitution and are in need of urea or ammonia for NOx conversion before the gas stream reaches the catalyst. These substances need to be stored on ships in significant volumes while operating the SCR unit.

Recently Wärtsilä proposed a new open loop scrubber system while its hybrid scrubber has the flexibility to operate in both open and closed loop. These systems performance limits to SOx removal ≈97% and PM ≈85 % and require significant levels of water, several types of collection tanks (e.g. sludge tank, holding tank) and caustic soda as reagent (for scrubbers using fresh water). Clean Marine offers a similar solution in shape of a hybrid system while focusing its efforts to increase PM capture, developing a wet scrubber design with a high speed cyclone based on the AVC (Advanced Vortex Chamber) principle and technology.

E. Non-thermal plasma

Non-thermal plasma as a dry or wet system is an emerging technology for a feasible VoC, SOx and NOx emission control with low power consumption and by-product production. The fundamental nature of non-thermal plasma is that the electron temperature is much higher than that of the gas temperature, including vibration and rotational temperature of molecules. High energetic electrons induce molecular excitation, ionization and dissociation, and at the same time, the attachment of lower energy electrons that form negative ions in the discharge area. Secondary plasma reactions will be initiated by dissociated molecules, radicals and ions by radical–molecule reactions and ion–molecule reactions in the downstream afterglow discharge region. Several solutions combined with other processes such as adsorption or wet-type chemical scrubbing have been proposed some which are now at pilot scale plant test [4].

Electron beam (EB) flue gas treatment technology is among the most promising advanced technologies of the new generation [5, 6]. This is a dry-scrubbing process for simultaneous SO_2 and NOx removal where no waste except the by-product is generated. The energy of the incident electron beam is absorbed by components of stack gas in proportion to their mass fraction. The main components of stack gas are N_2, O_2, H_2O and CO_2, with much lower concentration of SO_2 and NOx. Electron energy is consumed in the ionization, excitation and dissociation of the molecules and finally in the formation of active free radicals $OH^{\cdot}$, $HO_2^{\cdot}$ $O^{\cdot}$, $N^{\cdot}$ and $H^{\cdot}$. These radicals oxidize SO_2 and NO to SO_3 and NO_2 which, in reaction with water vapor present in the stack gas, form H_2SO_4 and HNO_3, respectively and break VOC bonds promoting their conversion to CO and CO_2.

Microwave (MW) irradiation is a viable and promising method for flue gas cleaning in view of the reduction of power consumption of the gas treatment process. The absence of internal electrodes removes a source of contamination and makes the reaction chamber simpler for microwave induced non-thermal plasma. MW irradiation produces much higher degree of ionization and dissociation that commonly gives 10 times higher yield of active species than other types of electrically excited plasma.

Brunel University as part of the DEECON FP7 EU project has designed and built a non-thermal plasma reactor (NTPR) as a combination of EB and MW which will be used to treat exhaust gases from a 200kW two stroke marine engine. The main goals of the NTPR will be the abatement of submicron particulate matter (removal efficiency 90% in number and the removal of harmful gases, with particular attention to nitric oxide and nitrogen dioxide (removal efficiency 98%). The NTPR module will be further integrated with an Electrostatic Sea Water Scrubber (ESWS) developed by our project partners coupled together with other components aim to provide a complete sustainable solution for marine diesel exhaust abatement.

II. ELECTRON BEAM SYSTEM

Brunel University in partnership with The Welding Institute (TWI), Cambridge, UK has designed, modelled and built a custom EB system to suit the project targets. Its main components are sourced from Cambridge Vacuum Engineering, UK, encased in 14.3 mm stainless steel casing and additional led shielding to avoid any possible X-ray leakages when running at maximum power. The EB gun is powered by a HiTek power supply of 60kV, 66.6mA with a total output power of 4kW as seen in Figure 1. A custom control for the input/output current and voltage supplied to the gun was built. The vacuum was maintained during operation at 10^{-6} Torr by an Edwards Vacuum pump system. The grid cup and the anode elements have been custom designed and built such that the geometry and distances between key elements such as cathode, anode and grid cup electrode are optimized for avoiding high voltage stresses and voltage breakdown. The e-beam runs in continuous mode not pulsed thus a main challenge is to develop a suitable solution to transmit the beam from vacuum into the atmospheric diesel exhaust gas running conditions through the NTPR. We have explored several electron beam window options from silicone nitrate, aluminum, graphite to diamond. This proved to be an extremely difficult task because the window has to comply with: electron transmission efficiency, easy dissipation of high temperatures, sustain differential pressure (atmospheric/vacuum) and avoid contamination. Figure 2 illustrates efficiency running tests performed with the EB gun and electron transmission efficiency test of a diamond window using a Faraday Pail set-up. An efficient heat sink design was set in place to dissipate the high temperatures rising in the EB window at the passing of the continuous beam. We are currently developing a beam magnetic deflection system so that we extend the thermal window life span and control the duration in which the electron beam plasma is active within the NTPR. The thickness of the windows tested depended on the material type and varied between 100 nm to 30 µm.

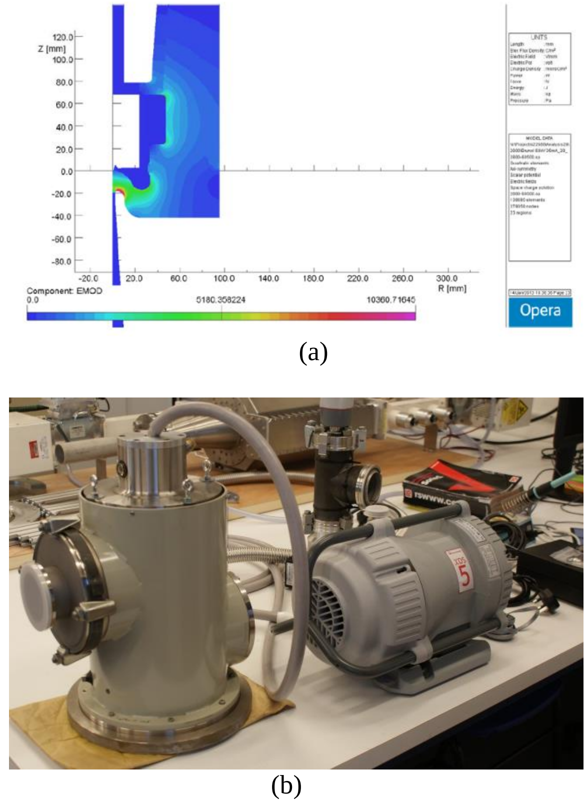


Fig. 1. a) Electron beam shape and electric field intensity modelling for 1.1kV bias voltage b) EB gun and vacuum pump.

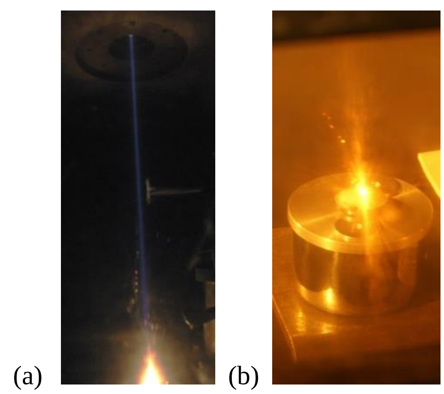


Fig. 2. a) Electron beam testing in vacuum and argon environment courtesy of TWI, UK; b) diamond window efficiency testing in vacuum courtesy of Element 6&TWI, UK.

For the available beam power the window should be far smaller than 27.2 µm, as almost all the EB gun beam power will be lost due to gun height and windows thickness. Losses in a 3µm thickness window can be expected to be approximately 10% with the gun running at maximum power.

III. MICROWAVE SYSTEM

The final design of the MW based NTPR (reactor and waveguide) is given in the Fig. 3. As it is shown, gas inlet and outlet ports are conical in shape in order to avoid the MW leakage through. The diameter of a circular waveguide should be less than 70 mm to avoid any MW leakage as calculated from the following equation:

$$d > 3.6824c/(2\pi f_c) \qquad (1)$$

where f_c – upper cut off frequency of MW and c- speed of light. The diesel exhaust gas passes through a quartz tube 20cm in diameter, 50cm length and 5mm thick to accommodate flow rates up to 200l/s; resist vibrations and non-thermal plasma& marine exhaust gas temperatures. Inside the NTPR hexagonal cavity (50 cm long, 25 cm wide and 25 cm length) non-thermal plasma chemistry reactions will take place. The major reason for the choice of quartz tube is that it allows good MW transmission and stops the exhaust gas to flow into waveguide and magnetrons avoiding contamination and potential damage to the magnetrons. The reactor design allows the quartz tube to be easily cleaned or replaced. Microwave energy is injected into the cavity through a number of slots from two parallel waveguides placed each on one a lateral side of the reactor (Fig. 3). There are six slots on each waveguide and they are slanted at 19.9^0 to horizontal and curved at the both ends (semicircles with radius of 8mm). The slots are separated by the half-wavelength of waveguide, λ_g, to have maximum MW energy injected through the slots. The wavelength of the waveguide is calculated from the following equations;

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

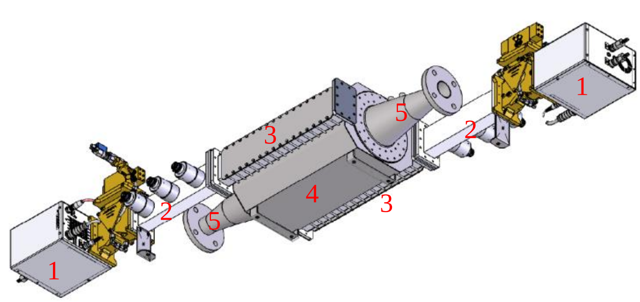


Fig. 3. Brunel Pilot scale NTPR and 4kW power MW system: 1- microwave generators (Magnetron, Isolator, Water cooling and MW power measurement); 2-Stub Tuners; 3- Waveguides; 4 -Multi-Mode Cavity; 5 - Gas inlet/outlet.

where λ_o = wavelength of microwave (= 122mm), a is the longest length of the rectangular cross section. In the current set-up, a=96mm and the resulting λ_g is 158.8mm.

The MW system was supplied by Sairem, France and comprises of one 2kW power supply for each 2,45 GHz magnetron, manual stub tuners to regulate the amount of reflected power and parallel MW launching waveguides designed to create areas of maximum MW energy concentration within the NTPR.

A computer FEM model was developed for the Brunel pilot scale NTPR using COMSOL Multi-Physics software. The main objective of the simulation is to showcase the electric field distribution within the multi-mode cavity, especially in the quartz tube area. The electric filed strength within the cavity means that more MW energy transfer to EB injected electrons thus the non-thermal plasma formed enhances the radical formation. The following equation was solved in frequency domain by COMSOL to determine the electric field distribution in the waveguide and NTPR:

$$\nabla \times \mu_r^{-1}(\nabla \times E) - K_0^2\left(\epsilon_r - \frac{j\sigma}{\omega\epsilon_0}\right)E = 0 \qquad (3)$$

where μ_r - permeability of the medium; ε_0 - Permittivity of medium; E - Electric field vector; σ - Density of medium, K_0 – Wave number. The walls of the wave guide and NTPR are assumed to be perfect conductors and the following boundary condition was applied:

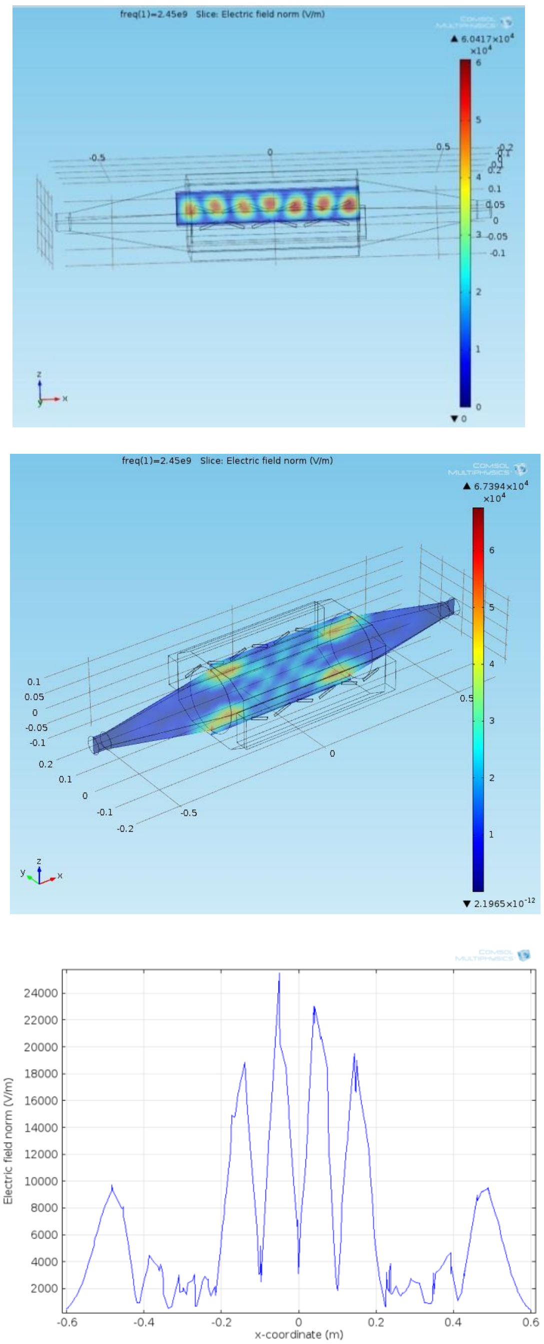
$$n \times E = 0 \qquad (4)$$

where n – normal vector to the walls.

A number of simplification steps were taken to increase the simulation speed due to available computing power without losing any significant accuracy in the results:

- Magnetrons, water cooling, isolator, 3-stub tuner are not included in the model as they are not going to influence in any way the electric field pattern.
- Multimode cavity, inlet/outlet ports and waveguide were considered to be perfect conductor, so that no energy is lost at these boundaries.
- All MW power is going into the waveguide.

The simplified geometry of the model is shown in Figure 4 below.



(a)

(b)

(c)

Fig. 4. MW field modelling: a) Electric field in waveguide (zx plane); b) Electric field in NTPR (xz plane); c) Electric field (Line scan across middle of the NTPR).

Standing wave pattern of Electric field in waveguide is shown in Fig. 4(a), where it displays the slot location in relation to the high intensity field. It was found that when the centers of the slots are located at the nodes of the standing wave pattern a stronger electric field is obtained in the cavity. Fig. 4(b) shows the electric filed pattern in the two planes of the cavity. The plots clearly show that there is no electric field in the gas inlet and outlet cones of the NTPR, thus no MW leaks in the system. Fig. 4(c) shows a line scan in the middle of the NTPR showing that the highest electric field strength is within the quartz tube middle section.

IV. EXPERIMENTAL SET-UP

Figure 5 shows the integrated MW and EB systems with the NTPR. The exhaust gas is generated from a 2kW diesel generator which on high loads provides up to 80l/s gas flow rate and high levels of NOx, CO, and HC depending on fuel type. This solution was chosen for performance and overall NTPR functionality tests as being more sustainable than a diesel premix gas set-up. Gas analysis is performed at the inlet & outlet of the NTPR with two Testo portable gas analyzers. (Testo AG, Germany). Both analyzers have a set of

Fig. 5. Experimental Set-up: 1 – Power Supplies and DAQ control rack; 2 – gas extraction; 3- Flow meter; 4 – MW&EB NTPR; 5 – Testo gas analyzer.

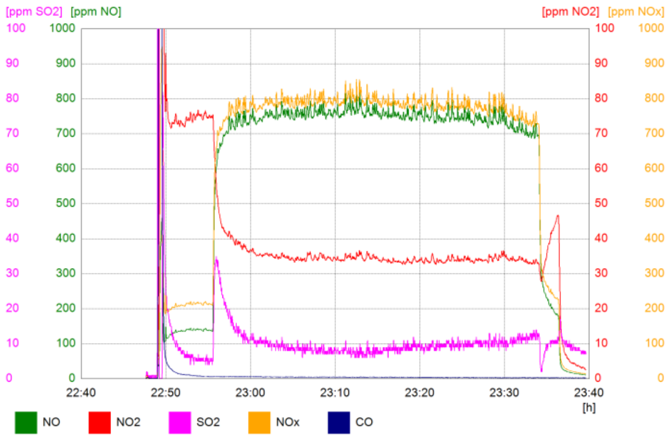


Fig. 6. NOx and SO2 levels at the NTPR inlet using 2kW gen-set at high load.

six sensors which can detect: NO, NO_2, SO_2, CO, HC, O_2 levels. Temperature at inlet/outlet is measured by the Testo systems in addition to temperature sensors. MW outlet/reflected power, EB beam voltage and current, EB grid voltage, EB vacuum levels, flow rate, gas/plasma temperature are recorded and stored through a dedicated custom programmed Labview DAQ system. Grounded meshes were placed at the inlet and outlet of the NTPR gas path to avoid any plasma leakages. While we developed the EB system several other plasma ignition sources were tested in conjunction with the MW system: AC/DC Corona Discharges and High Frequency AC Spark plugs. Figure 6 shows a typical gas analysis at the NTPR inlet using low sulphur diesel fuel, running the 2kW gen-set, at high load for 30 minutes. The diesel exhaust inlet temperature was constant at 195 °C while the outlet varied between 120-170°C depending on the MW power applied and duration and plasma ignition. Figure 7 shows a combination of MW and DC Corona set-up. A DC corona electrode system is placed within the quartz tube of the NTPR.

We used various DC electrodes designs within the NTPR from needle, saw tooth to tungsten wire while their positioning within the MW field was dictated by the modelling results of that particular geometry. There were no significant results on the gas abatement mainly because the MW leaked through the high voltage connection as the electrodes acted like antennas while the high soot levels contaminated quite quickly the electrodes in place, thus the discharge taking place did not present itself with enough energy to ignite the plasma.

V. Experimental Results and Discussion

During the building and development of the pilot scale NTPR system we have modified a commercial MW oven 1,8 kW power with a AC Corona system, 48kV, 5Mhz. Due to modifications and the nature of the multimode cavity the MW field distribution was random. However when occasionally the MW field hit the location of the AC discharge we

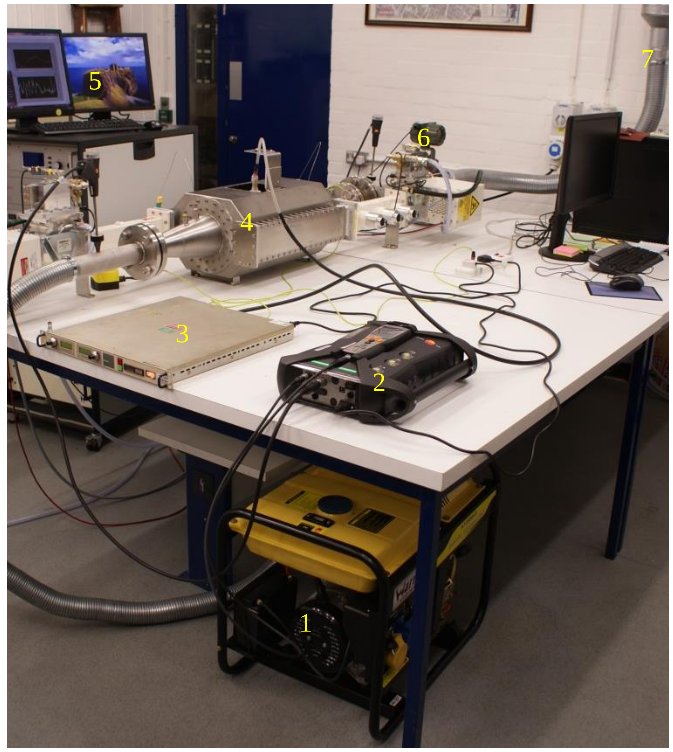


Fig.7. DC Corona and MW NTPR: 1-2kW gen-set; 2 – Testo gas analyzer at inlet/outlet of NTPR; 3 – Spelman 30 kV DC power supply; 4 – MW based NTPR; 5 – Sensors data acquisition; 6 – Flow meter; 7 – Gas extraction.

obtained >95% reduction of NOx and SO_2 for a short duration of time (≈30 seconds). These findings were reported in [7] and presented at the TRA 2014 Conference in Paris, France.

Fig. 8. NTPR MW set up using passive electrodes.

The pilot scale reactor has a fully controlled MW system that can be very fine tuned from the stub tuners to generate constant and powerful MW fields. We have designed a set of passive electrodes of saw tooth geometry to be inserted in this high intense MW field (Fig. 8). If enough power is supplied the sharp tips and geometry of the electrode will ignite the plasma as seen in Figure 9.

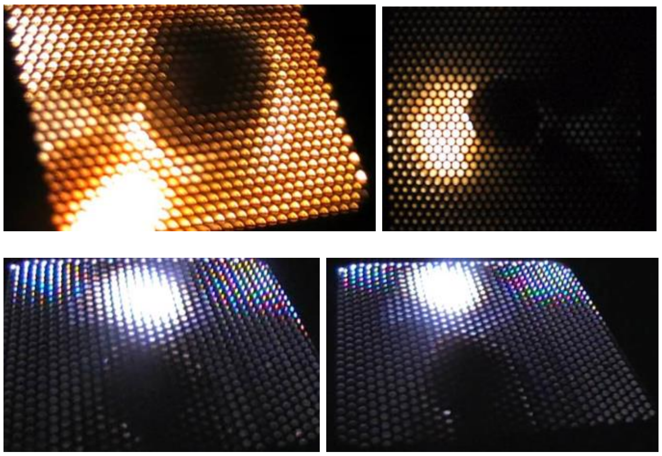


Fig. 9. Plasma fireballs formed by the microwave interference in diesel exhaust gas.

Figure 9 displays two types of MW plasma ball phenomenon that occurs in the same time within the NTPR reactor as the diesel exhaust passes through. One is Microwave Fireball plasma, yellow-orange in color which is ignited by the passive electrode and which will burn the soot, unburned fuel, lubrication oil, hydrocarbons and other gas components of the diesel exhaust thus increasing the NOx output from the NTPR. The other Microwave plasma ball, purple-blue in color if kept stable will, in conjunction with the passive electrode design and position within the MW field, reduce the NOx and mainly NO to 0.

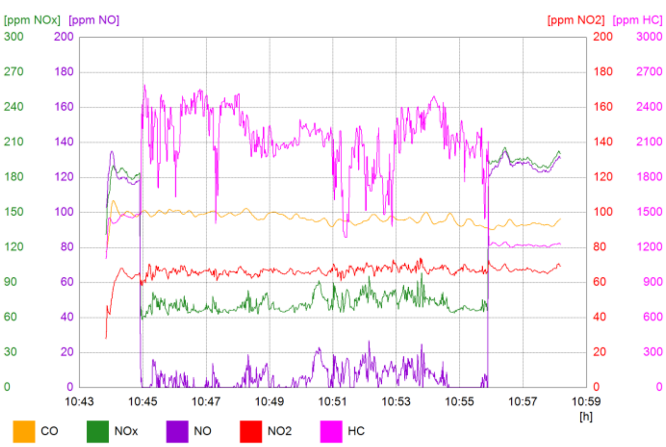


Fig. 10. NO reduction using 2,45 GHz MW at 2kW total power as a purple ball.

For Figure 10 we had the following input conditions: 1,8 kW total MW power at 2,45 GHz, low sulphur diesel fuel in the 2kW gen set running at low load (≈180 ppm NOx), gas inlet temperature 100 °C/ outlet 70°C. One magnetron was set-up at 1 kW power and had 0.2 kW reflected power, while the other magnetron was set-up at 0.6 kW power with a 0.1 kW reflected power. The reflected power varied slightly and was controlled through the stub tuners on both magnetrons. A single saw tooth blade passive electrode 500mm length was positioned in the center of the NTPR. As soon as the MW plasma purple ball ignited and was kept stable in the same position NO drops to 0 ppm while it’s low values fluctuate between 0-20ppm due to exhaust gas flow rate which varied between 30-40 l/s and MW reflected power due to gas absorption. NO_2 was not affected as being more stable it requires more energy than the amount supplied to break into radicals. There is some HC variation as some fraction was consumed in the plasma chemical reactions. The gas analysis was performed by the Testo gas analyzer while all other parameters were recorded through the Labview DAQ system. The lifetime of the plasma ball was a little over 10 minutes, it stopped when the magnetrons were shut off and was determined from video, gas sensing and MW reflected power readings. One other occasions the plasma balls are on complicated paths following the complex electric-field patterns within the cavity for short periods of time. They vary in shape, size, intensity, color and duration.

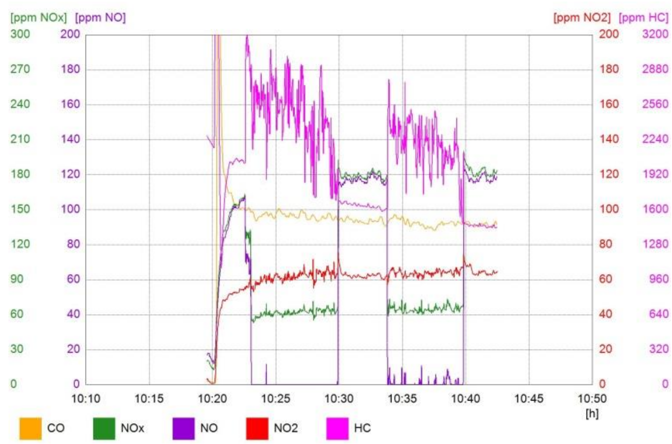
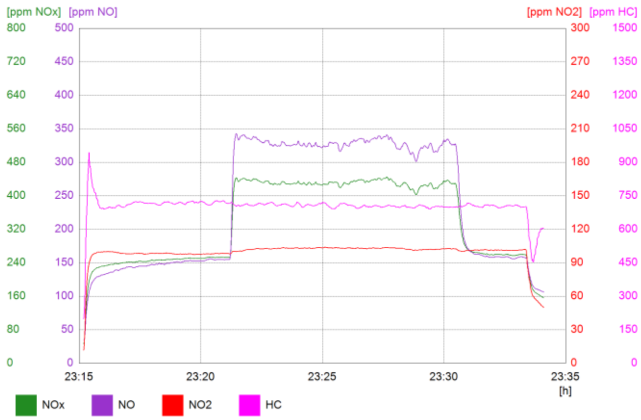


Fig. 11. NO reduction in two consecutive stable MW plasma purple balls.

Figure 11 replicates the results from Fig. 10, in the same conditions with two purple plasma balls each kept on for a duration of 5 minutes. In both cases NO drops to 0 ppm, NO2 is not affected while the HC contribute to the overall plasma chemistry.

Fig 12(a) shows the NTPR output gas analysis using the gen-set at low load with low sulphur content (240 ppm NOx). We used a cross saw tooth blade passive electrode, positioned in the center of the quartz tube increasing the area of sharp points and thus increasing the chance to ignite the plasma. The exhaust gas NTPR inlet temperature was 105 °C and outlet 40°C. While MW plasma was on temperature at outlet increased by 60°C to 106°C. One magnetron was set up at 1kW power the other at 0.6 kW while the reflected power on

(a)



(b)

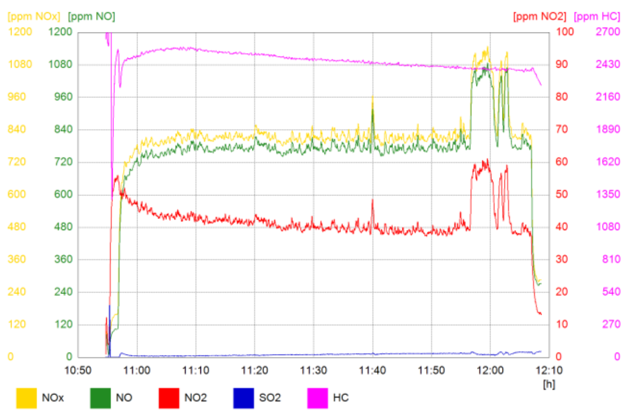


Fig. 12. NO & NO_2 increase in the presence of a yellow fireball plasma.

both oscillated slightly around the 0.3 kW value. The gas flow rate was 40l/s. On this occasion we had a powerful fireball plasma which was kept on for 10 minutes in which we measured an increase in NO due to burning of soot deposited on the walls of the quartz tube and other elements of the exhaust.

Figure 12(b) shows the NTPR output gas levels when the gen set was on high load (840 ppm NOx). We were using the same passive electrode although many of its sharp points were consumed in the previous reaction. This experiment lasted one hour in which we gradually increased the MW power on both magnetrons. NTPR gas inlet temperature was 195° C while at the output 140°C, flow rate 40l/s. There was no effect on the gas composition when using the magnetron at low power but when setting one at 1kW power and the other at 1kW power we ended with a 0.1kw reflected power on both a very powerful, short duration fireball plasmas. Both NO_2 and NO increased by 25% at the output of the NTPR.

VI. Conclusions and Further work

We have designed, modelled and built a complex non-thermal plasma pilot scale system based on a combination of EB and MW. It can sustain significant temperature variations and high flow rates ≈200 l/s. It was tested in various operation conditions (gen-set low/high load, high/low gas temperatures, plasma ignition power levels, plasma duration, flow rate variation, soot levels etc.). All sensor data is recorded in real time and stored through a Labview interface.

The EB gun is still in development as we try to improve and develop a sustainable electron beam window solution together with a beam deflection module.

AC/DC Corona plasma ignition require complex designs, ceramic insulation (any plastics materials used melted due to MW high energy levels) and its efficiency drops due to soot contamination.

The MW system is complete and has been tested in various technological configurations some which have generated some promising, repeatable results. In Brunel laboratory this pilot system can be tested with diesel exhaust premix gases or with a small gen-set (noise levels). It has a mobile platform on which it can be easily transported and connected to different types of engines.

In July-August the system will be tested with a 200kW two stroke marine engine as seen in Figure 13 and it will be integrated with other modules developed within DEECON project Consortium. In addition during marine engine tests with 1% and 3% suphur we will monitor PM <0.1 µm in number as well as SO_2 and NOx.

Fig. 13. DEECON 200kW marine engine.

A comprehensive chemical analysis is planned to be performed and asses the non-thermal plasma efficiency on NOx and SOx reduction, its impact on VoC's, HC, nitrate and sulphate production and most importantly in the types of by-product generation.

ACKNOWLEDGEMENT

The work was supported by the European Commission under DEECON FP7 European Project "Innovative After-Treatment System for Marine Diesel Engine Emission Control", contract No. 284745. The authors would like to thank Colin Ribton and Sofia del Pozo from TWI Ltd. for their valuable assistance in the design, building and testing of the Electron Beam gun. We are also grateful to Dr Marilena Radoiu, R&D Director of Sairem for her professionalism and knowledge exchange regarding the Microwave system. A big thank you goes to Dr Jeremy Ahern and David Brennan for their continuous assistance and support with experiments and logistics.
It is noted that this paper is a conference paper and gives a draft of the whole research. A complete report will be submitted to IEEE Transactions on Industry Applications.

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