Oxidation of Soot Particles in Diesel Exhaust Emission using Plasma Source

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Abstract— Fossil fuels are the main source of energy that can be extracted to other mechanical energies in less complicated format. Automobiles as well as industries utilize this energy transformation process for getting required energy. Internal combustion engines were developed with the aim that maximum energy must be used while certain fixed quantity of fuel is combusted. Compact design of engines helped to have efficiency above sixty percentages. But there had been waste products, when the fossil fuels are burnt. These were not eco-friendly. During first half of 20th century, there witnessed non eco-friendly gas amount at marginable limit. This resulted to have restriction of emission of certain gases into atmosphere. This project work is focused on oxidation of soot particles that may present in the diesel engine exhaust gas. Mostly soot particles are developed due to incomplete combustion of fuel. Several techniques introduced to control emission: Exhaust Gas Recirculation, Selective Catalytic Reduction etc. for further reduction of pollutants. But individual Technique has some range of temperature & pressure to give their best performance. Soot Particles are one among the component in Particulate Matter. They can be burnt into CO_2 with additional energy.

Key words: Soot Particles, Particulate Matter, Selective Catalytic Reduction, Exhaust Gas Recirculation

I. INTRODUCTION

Soot is an impure carbon particle resulting from the incomplete combustion of hydrocarbons. Usually, soot (C_8H) is found [6] in exhaust gas during rich mixture combustion. During rich mixture running condition amount of oxygen present in the Air/Fuel mixture will be very low, which results incomplete combustion of the fuel. There originate the carbon soot particles in exhaust gas.Only solution to soot particle reduction is complete combustion of fuel. If the fuel is not completely combusted inside the engine cylinder, arrange facility to oxidize them outside the cylinder.

Plasma source with highly excited electrons will have tendency to react with any gas which are in contact with them [3], [10]. When incomplete gases passes through them, they will react with these charged particles then soots will oxidized into oxides of carbon and hydrogen.

II. COMPOSITION OF EMISSION GASES

The composition of exhaust gases in an automobile is as shown in Fig. 1. It can be noticed that oxides of Sulfur, Nitrogen, carbon monoxide, Hydrocarbons and Particulate matter comprise only 0.3%. Contents of Particulate matter include mainly soot particles.

The diesel engine's reputation as a noisy, smoky, and sluggish power plant (the reasons for this have been explained in Chapter 1) has changed due to modern diesel engine technology which allows one to combine the inherent low fuel consumption with excellent driving performance and low emission characteristics [44].

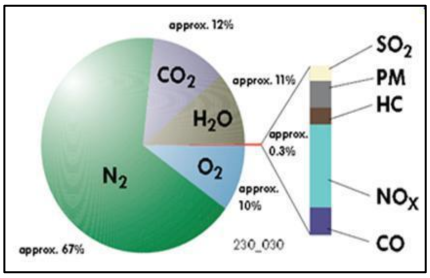

Fig. 1: Composition of Exhaust emissions of Diesel Engines

After carbon dioxide (CO2) was identified as a greenhouse gas contributing to global warming, diesel engines have emerged as an alternative to gasoline engines due to their low fuel consumption and hence low CO2 emission. While carbon monoxide (CO) emissions are negligible in CI engines due to lean operation and emissions of un burnt hydrocarbons (uHC) can be handled with oxidation catalysts, the emissions of oxides of nitrogen (NOx) and particulate matter (PM) are of particular concern and therefore the topic of this chapter. With respect to after treatment solutions, the focus will be on NOx traps because their regeneration requires tight control over the air path and constitutes the main motivation for this dissertation. The formation of NOx as well as PM is closely linked to the combustion process (cf. Section 2.1) which depends on engine design variables such as combustion chamber and fuel injector design, pressure and timing of the injection (modern injection system such as common rail also allow multiple injections), swirl ratio, valve timing, compression ratio, etc. In general, these variables can only be optimized for the reduction of one of these two main pollutants due to the so-called NOx-PM trade-off described in Section 2.1 (although there are exceptions, e. g. two-stage combustion can break the trade-off by forming a fuel rich mixture at the initial combustion stage to prevent NOx formation and inducing strong turbulence in the combustion chamber at the later stage of the combustion to oxidize the particulates [7]). Typically, the other pollutant is controlled by after treatment. Alternatively, NOx and PM after treatment solutions can be integrated which allows the combustion system and engine calibration to be optimized with respect to performance/efficiency. This chapter gives an overview of currently available after treatment techniques. Concerning in-cylinder emission reduction techniques, only exhaust gas recirculation (EGR) and fuel composition (especially water emulsions) will be discussed

III. ANSYS MODEL

Ansys model has been created with the physical dimensions mentioned above. Ordinary case there will only be the emission tube. But in the special there must include additional tube along the path way in order to pass the plasma into the emission tube. Diameter of Plasma emission tube is selected to be 2 cm. Physical shape of the above mentioned structure is as shown in fig. 2.

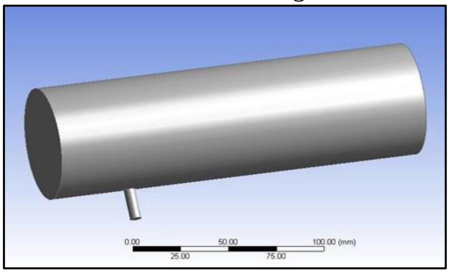

Fig. 2: Physical model attached with Plasma tube

The Physical structure with 2 inputs & 1 output are indicated by red faced opening & blue faced openings respectively [Fig. 3]. 2 inlets are for emission gas inlet and Plasma medium inlet. Outlet is for the combination of the two [Fig 4].

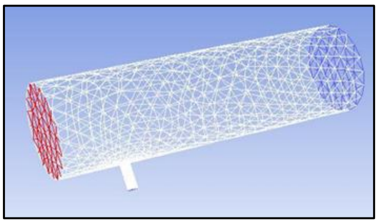

Fig. 3: Inlets marked by red outlet by blue.

The flow direction and combining junctions are shown in the following fig. 4 also.

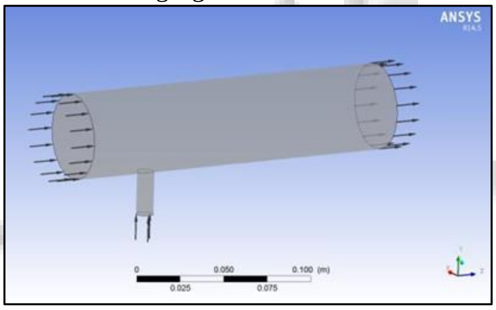

Fig. 4: Direction of flow of Gases through the Model

The meshing along the specified tube is as shown in fig. 5 crowded meshing can be found along the junction of Plasma tube and emission pipe.

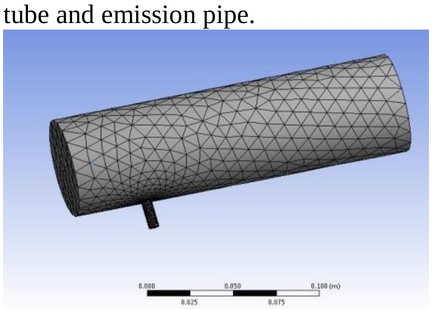

Fig. 5: Meshing on the Physical model

A. Nature of Emission Gas Flow

In order to analyze the flow of the emission gas along the tube with an additional source of Plasma medium, it must be found, whether the flow is laminar or turbulent. Reynolds number of fluid discriminate the flow into laminar & turbulent.

Reynolds's Number,

$$Re = □.v.D_H/□ \quad (3)$$

$$= [1.437 * 10.91 * 0.0635] / 0.0153$$

$$= 65.1034$$

Where, Density of emission gas (kg/m^3).

v: Velocity of the fluid, D_H: Diameter of emission pipe (m).

□: Viscosity of the fluid.

Since Reynolds's Number is less than 3600, the flow is laminar in nature. Surface to Surface radiation model is preferred, since it needs to represent the variation of amount of gases as well as the temperature & pressure inside the emission tube.

IV. ANSYS MODEL COMPOSITION OF GASES IN ORDINARY CASE

The analysis is carried out at 470^{0}C temperature and 3atm pressure. Mass fraction of gases like C_8H, CO, CO_2, O_2 & H_2O in an ordinary case is as shown in individual diagram [Fig. 6, Fig.7, Fig.8, Fig.9 and Fig.10]. Surface to Surface model of radiation is preferred, since there is no loss of energy in the form of radiation within the tube, even though there is reflection within the surfaces.

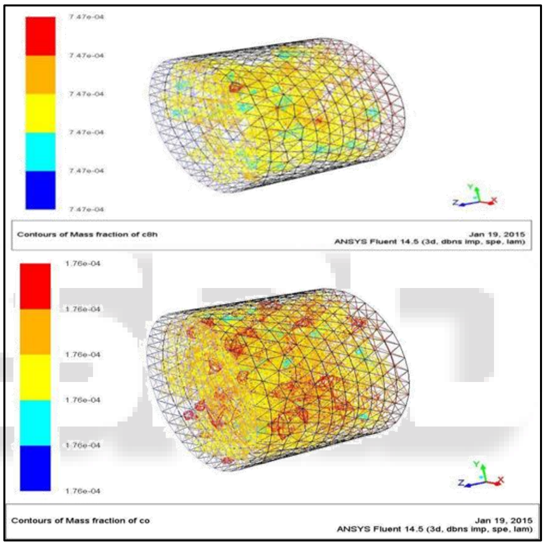

Fig. 6: Contours of Mass fraction of C_8H

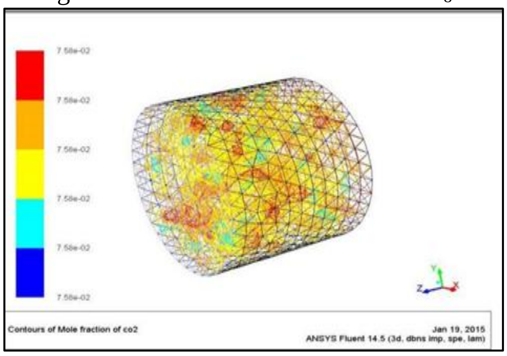

Fig. 7: Contours of Mass fraction of CO

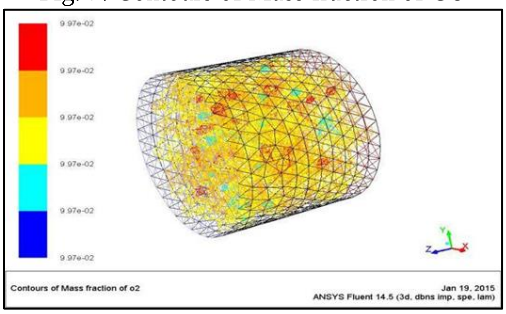

Fig. 8: Contours of Mass fraction of CO_2

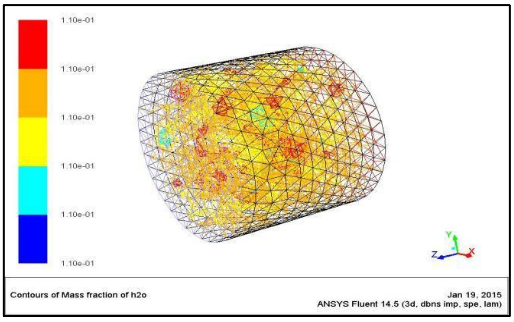

Fig. 9: Contours of Mass fraction of O_2

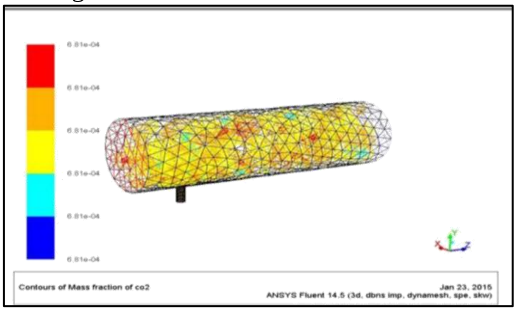

Fig. 10: Contours of Mass fraction of H_2O

V. ANSYS MODEL COMPOSITION OF GASES WITH PLASMA SOURCE

Mass fraction of gases; C_8H, CO, CO_2, O_2 & H_2O with plasma source attached to the tube is shown in Fig.11

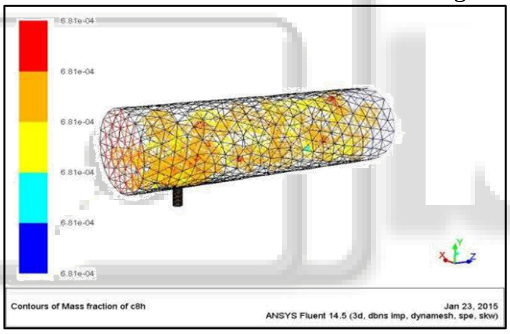

Fig. 11: Mass fraction of gases; C_8H, CO, CO_2, O_2 & H_2O with plasma source attached to the tube is shown

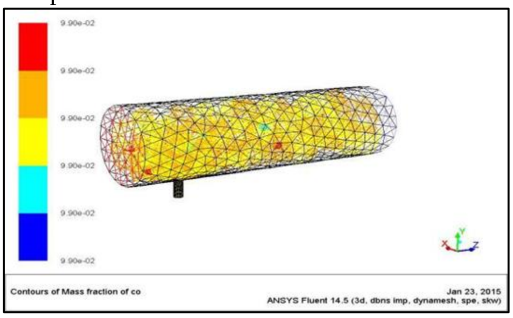

Fig. 12: Contours of Mass fraction of CO

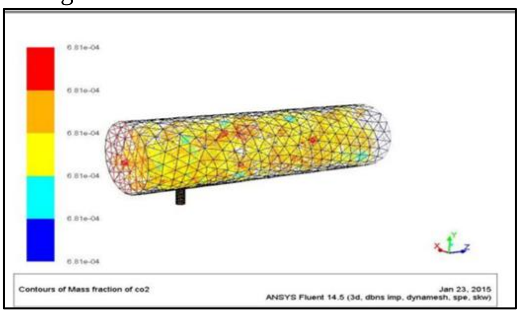

Fig. 13: Contours of Mass fraction of CO_2

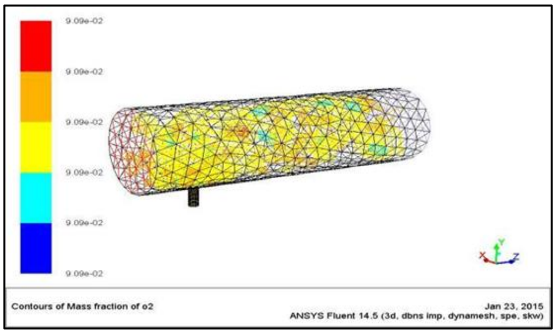

Fig. 14: Contours of Mass fraction of O2

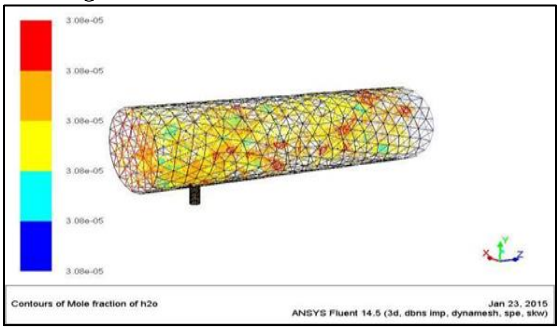

Fig. 15: Contours of Mass fraction of H2O

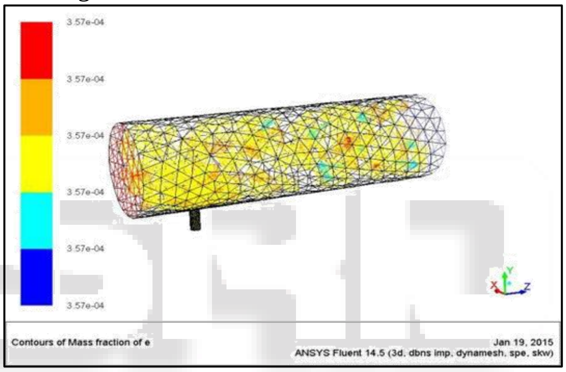

Fig. 16: Contours of Mass fraction of Electrons

Excited electrons in the plasma can react with C_8H, CO, CO_2, H_2O & O_2. Amount of soot, O_2, H_2O & CO_2 are reducing whereas that of CO increasing as a result of intermediate reactions [1], [4]. Amount of gases at ordinary case and special case are listed in the Table 1.

Sl. No.	Content in emission gas	Mass fraction in ordinary case	Mass fraction in Special case
1.	C_8H	7.47e-4	6.81e-4
2.	CO	1.76e-4	9.90e-2
3.	CO_2	7.58e-2	6.81e-4
4.	O_2	9.97e-2	9.09e-2
5.	H_2O	1.10e-1	3.08e-5
6.	Electrons	0	3.57e-4

Table 1: Amount of gases at ordinary case and special case are listed

VI. CONCLUSION

Atmospheric pollution is the most challenging problem that Automobile industry is facing. While restricting the limit of pollution gases allowed to release into atmospheric, new technology is developed. This paper is based on control of emission of Soot particles, when rich mixture is combusted in diesel engines. Plasma can be used as a source to supply additional energy into unburnt soot particles. This additional energy will be captured by electrons, oxygen atoms, soots etc. They react each other and forms oxides of carbon. Thus level of amount of poisonous soot particles can be reduced. This will be practically verified in the final stage of this project.

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