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Design and CFD Analysis of an Exhaust Carbon Filter Pipe for Use in SI and CI Engines to Eliminate Emissions

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Abstract: This project deals with combustion generated engine emissions and approaches the subject from the point of fundamentals of engine combustion processes. The engines are therefore, categorized based on the mode of ignition employed viz., 'Spark Ignition (SI) Engines' and 'Compression Ignition (CI) Engines'. Diesel particulate filters (DPF) also called as 'particulate traps' have been developed to filter out PM from the diesel exhaust gases to meet very stringent emission limits. Alumina coated wire mesh, ceramic fiber, porous ceramic monoliths etc., have been studied as filtration media. Presently, ceramic monolith of honeycomb type structure is used to trap the particulate matter as the gas flows through its porous walls. These filters are also termed as 'ceramic wall flow filters'.

Keywords: SI and CI combustion chamber, Carbon Utilization Pipe, CFD Analysis, Emissions, Reaction Process, Exhaust Gas Particles

1. INTRODUCTION

Diesel motors are assuming a fundamental part of Road and ocean transport, Agriculture, mining and numerous different businesses. Thinking about the accessible fuel assets and the present mechanical improvement, Diesel fuel is obviously imperative. In spite, we can't disregard the destructive impacts of the extensive mass of the consumed gases, which disintegrates the immaculateness of our condition regular. While consistent research is going ahead to decrease the harmful substance of diesel fumes, the diesel control packs discover the regularly expanding applications and request. This undertaking is an endeavor to lessen the lethal substance of diesel fumes before it is transmitted to the air. This framework can be securely utilized for diesel control packs which could be utilized as a part of inflammable airs, for example, refineries, chemicals handling enterprises, open cost mines and other restricted. Zones, which requests the requirement for diesel.

1.1 IC Engine Classification based on Combustion Process

IC Engines may be classified based on the state of air-fuel mixture present at the time of ignition in the engine cycle, the type of ignition employed and the nature of combustion process subsequent to ignition of the air-fuel mixture.

A. Physical State of Mixture

- Homogeneous Charge

a) Premixed outside(conventional gasoline and gas engines with fuel inducted in the intake manifold)

b) Premixed in-cylinder: In- cylinder direct injection and port fuel injection

- Heterogeneous Charge

B. Ignition Type

- Positive source of Ignition e.g., spark ignition
- Compression ignition

C. Mode of Combustion

- Flame propagation
- Spray combustion

1.2 Principal Engine Emissions

SI Engines	CO, HC and NOx
CI Engines	CO, HC, NOx and PM

CO = Carbon monoxide, HC = Unburned hydrocarbons, NO_x = Nitrogen oxides mainly mixture of NO and NO2, PM = Particulate matter other engine emissions include aldehydes such as form aldehyde and acetaldehyde primarily from the alcohol fuelled engines, benzene and polyaromatic hydrocarbons (PAH).

1.3 Emissions and Pollutants

Engine emissions undergo chemical reactions in atmosphere known largely as '***photochemical***' reactions and give rise to other chemical species which are hazardous to health and environment. Linkage of engine emissions and air pollutants.

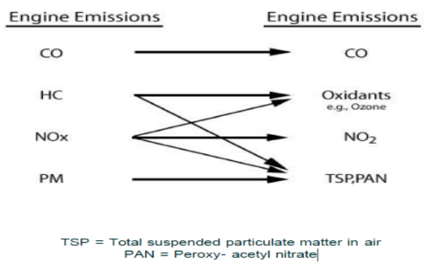

Fig.1 Engine emissions and air pollutants

Chen et al. [1] prepared different slurries from biomass char, a low rank coal char and subbituminous coals. The slurries were prepared by mixing them with water after milling and including a range of additives, such as polyacrylic acid, charged copolymers D101 and D102, and sucrose. The effect of the solid type, particle size distribution, and additives, on the preparation of highly loaded slurries with the desired rheological behavior, was systematically examined, in terms of the apparent viscosity and yield stress. It was reported that, for low rank coals such as lignite, thermal and densification treatment would be essential to achieve the solid loading of slurry fuel. Dincer et al. [2] investigated the effects of different chemicals that were used as dispersing agents and stabilizers on the stability and viscosity of coal water slurry (CWS). In the investigation, they used Anionic type of chemicals-polyisoprene sulphonic acid soda (Dataflow-K), a derivative of carboxylic acid (AC 1320) and naphthalene sulfonate formaldehyde condensate (NSF) as dispersing agents. In the same study, they used the sodium salt of carboxymethyl cellulose (CMC-Na) as a stabilizer. They used bituminous coal (thermal code no. 434) of Turkish origin, with a medium volatile matter as a sample. They reported that the polymeric anionic dispersing agent such as Dyna flow, showed a greater effect on the viscosity and stability of coal water slurry. Gu Tian-ye et al. [3] reported that when the proportion of coal was more than 30% in the coal water slurry (CWS), all its properties had improved, and it met the requirements for use as a fuel. Coali fication, porosity, surface oxygenic functional groups, zeta potential and grind ability had a great effect on the performance of blended coal CWS. They also reported that this led to some differences in the performance between the slurry made from single coal and that made from blended coal. They affirmed that, coal blending might effectively reduce the concentration of the oxygen functional groups and enhance the absorbing ability of the coal surface for anionic additives, which would enhance the slurry ability. The zeta potential of a coal surface was related to the coal rank and particle size. It was reported that the use of a dispersant could increase the absolute value of the zeta potential, which would give a well dispersed and low viscous CWS. It was reported that, the addition of coals having different properties could effectively enhance the slurry ability. K. S. UMESH et al. [4] in internal combustion engines, the exhaust manifold is critical to lowering the engine's fuel consumption. The performance of the engine is improved by a well maintained exhaust manifold. The research focuses on minimizing backpressure in the exhaust manifold to improve fuel economy, both experimentally and analytically. This study looked at eight different exhaust manifold types and came up with the optimal design for the least amount of fuel usage. The current tendency in the automobile industry is to use computational fluid dynamics (CFD) to reduce the cost of analyzing various models based on fluid flow. When the CFD findings are compared to experimental values, they are found to be very close. Backpressure and exhaust velocity experimental and computational data are compared against matching experimental values at all loading circumstances for comparison. The pressure contour and velocity contour illustrate the decrease in backpressure and increase in velocities. Kihm et al. [5] the droplet size characteristics near the tip of intermittent sprays of diesel fuel injected from an electronically controlled accumulator injection system were studied. The Saunter Mean Diameter (SMD) was measured at a low obscuration without multi- scattering bias. The investigation results revealed that the spray tip SMD increased with the ambient gas density and axial measurement location, and fell inversely with injection pressure. The dependence of SMD on the nozzle orifice diameter was negligible for fully developed sprays. The results indicated that the droplet SMD of diesel sprays was always smaller than those of CWS and spray tip SMD. The results also indicated that the spray-tip SMDs increased with the distance downstream from the orifice exit and decreased with injection pressure. Khodakov [6] In his report, he also stated that a technology was developed for utilizing coal slurry, in which coal was enriched, hydraulically extracted, and transported from a colliery. Further, he confirmed that many researchers and process engineers working at research centers owned by public and private companies were assigned with the task of developing industrialgrade technologies for obtaining the CWF that would be an alternative to petroleum products. After the year 2000, research works on the utilization of CWF became fewer in number, and have now ceased almost completely. This is because, first the technical problems related to the development and utilization of CWF was not resolved and, the second, this kind of fuel turned out to be economically inefficient even at very high prices compared to petroleum. Industrially developed countries have chosen the path of developing technologies for using renewable energy carriers. Kanupriya Bajpai et al. [7] one of the most important parts of an IC engine is the exhaust manifold. The exhaust manifold's operation is complicated, and it is influenced by a number of factors such as back pressure, exhaust velocity, and scavenging. The performance of a four-stroke four-cylinder gasoline engine exhaust manifold was investigated in this study utilizing three distinct fuels - gasoline, alcohol, and LPG - to estimate flow characteristics, temperature properties, and minimum back pressure. Creo2.0 is used for manifold modeling, and ANSYS is used for meshing and analysis.

2. METHODOLOGY

2.1 Working Principle

The exhaust gas is allowed to enter the tailpipe's entrance. Because of the conical portion, pressure is reduced and gas velocity is increased. Inside the tailpipe, the flowing exhaust gas is free to move in any direction. Because exhaust gas travel is not abruptly blocked anywhere along its path, back pressure is kept to a minimum. The rushing gas goes via a trap installed in the tailpipes inside.

2.2 Control of CI engine emissions

For emission control in the CI engines, usually called as the diesel engines the following are important;

- CI engines emits pollutants in solid (soot), liquid (poly aromatic hydrocarbons, fuel and oil components, sulphur acids) as well as those in gaseous (CO, HC, NO_x) state.
- Emissions of nitrogen oxides and particulate matter from diesel engines are of main concern.
- Emission regulations do have limits for CO and HC as well from the CI engines, but concentration of their emissions is rather small and these have been relatively easy to control through improved engine and fuel system design.
- NO_x - PM trade off (discussed in Module 2) governs selection and optimization of many engine design variables e.g., injection timing, injection pressure, boost pressure etc. as change in some engine variables may although causes reduction in NOx but increases PM and vice versa.
- Engine design changes to reduce NO_x emissions many a times result also in higher brake specific fuel consumption (BSFC). This is important as the emissions of the greenhouse gas,
- CO2 are also to be reduced.

The development efforts like for the SI engines have been focused on reduction of engine-out emissions and treatment of the exhaust gases. Improvements in fuel quality also have been made to meet the needs of advanced emission control technology.

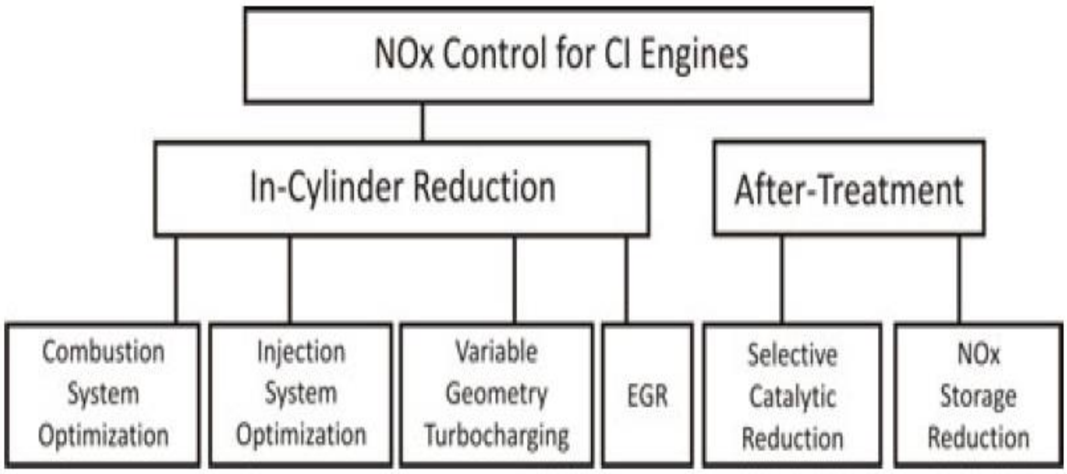

Fig.2 An overview of NOx reduction techniques in CI engines

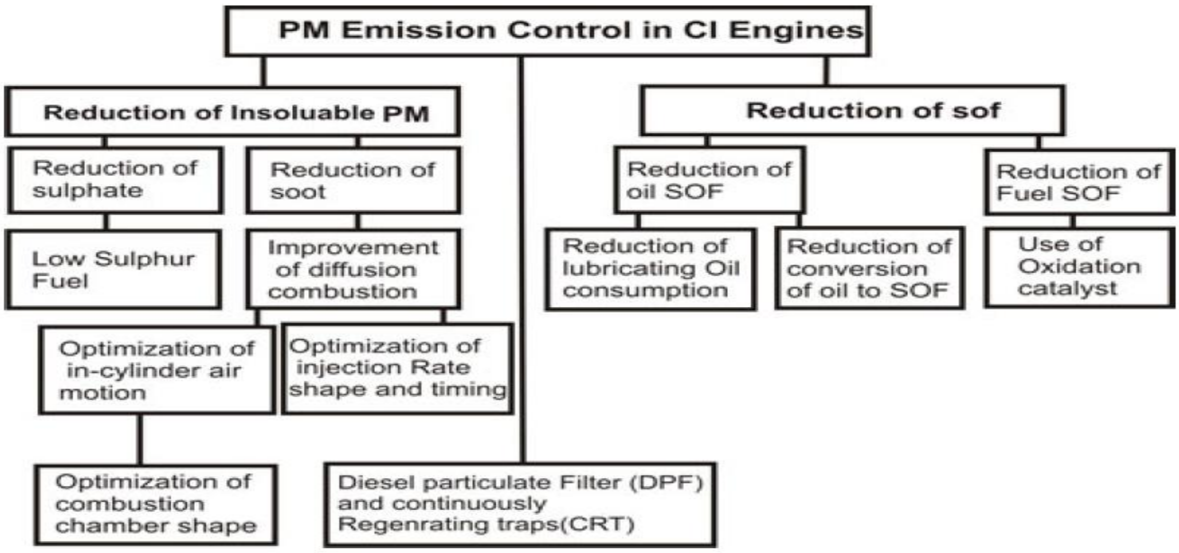

Fig.3 technologies used for control of PM emissions are presented

2.3 Emission Formation in SI Engines

NOx and CO are formed in the burned gases in the cylinder. Unburned HC emissions originate when fuel escapes combustion due to several processes such as flame quenching in narrow passages present in the combustion chamber and incomplete oxidation of fuel that is trapped or absorbed in oil film or deposits.

- NOx is formed by oxidation of molecular nitrogen. During combustion at high flame temperatures, nitrogen and oxygen molecules in the inducted air breakdown into atomic species which react to form NO. Some NO2 is also formed and NO and NO2 together are called as NOx.

- CO results from incomplete oxidation of fuel carbon when insufficient oxygen is available to completely oxidize the fuel. CO rises steeply as the air-fuel (A/F) ratio is decreased below the stoichiometric A/F ratio.
- HC originates from the fuel escaping combustion primarily due to flame quenching in crevices and on cold chamber walls, fuel vapour absorption in the oil layer on the cylinder and in combustion chamber deposits, and presence of liquid fuel in the cylinder during cold start.

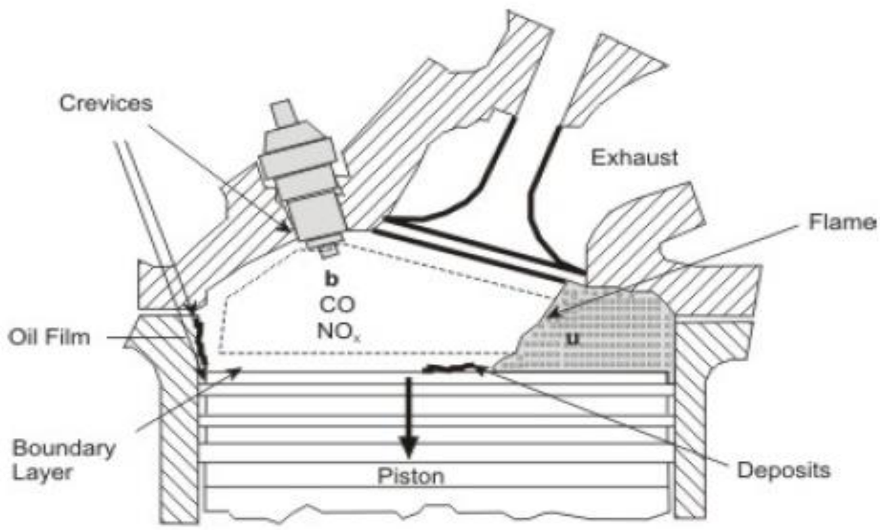

Fig.4 Schematic of progress of combustion in SI engine and pollutant formation

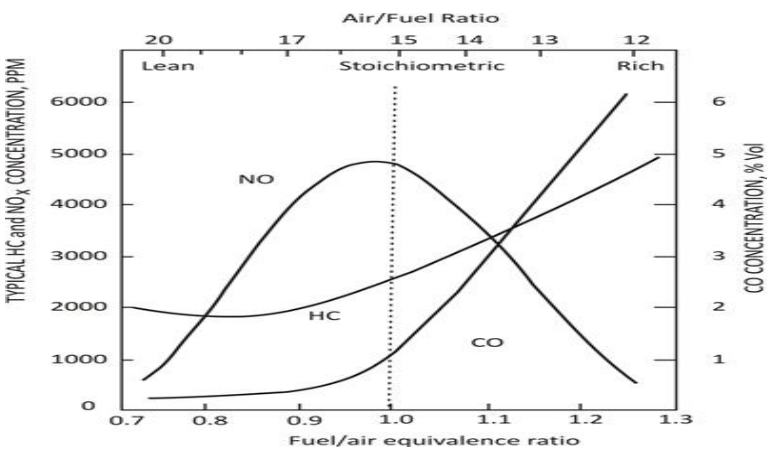

Fig.5 Variation in CO, HC and NOx emissions for a SI Engine

3. DESIGN OF CARBON FILTER FOR EXHAUST SYSTEM

An exhaust system is usually piping used to guide reaction or burnt exhaust gases away from a controlled combustion inside an engine or stove. The entire system conveys burnt gases from the engine and includes one or more exhaust pipes. Depending on the overall system design, the exhaust gas may flow through one or more.

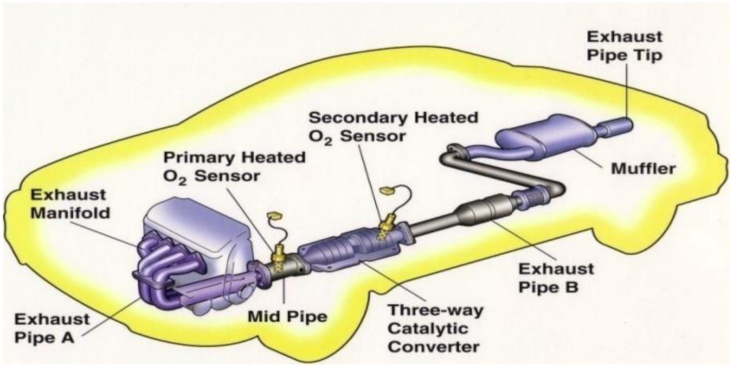

Fig.6 design of carbon filter for exhaust system

3.1 Parts of an Exhaust System

a) Exhaust Manifold

b) Flange and Clamp

c) Catalytic Converter

d) Muffler

e) Connecting Pipe

f) Resonator

g) Tail Pipe

3.1.1 **Exhaust Manifold**

In automotive engineering, an exhaust manifold collects the exhaust gases from multiple cylinders into one pipe .The exhaust manifold collects the burned gases as they are expelled from the engine cylinders and directs them to the exhaust pipe. Exhaust manifolds are generally simple cast iron or stainless steel units which collect engine exhaust gas from multiple cylinders and deliver it to the exhaust.

3.1.2 Flange and Clamp

Flange and clamp are used to connect the exhaust pipe from exhaust manifold to catalytic convertor. A flange is a plate or ring which is used to form a rim at the end of a pipe when fastened to the pipe to prevent leakage and for easy flow of gases through it. A clamp is a fastening device used to hold or secure objects tightly together to prevent movement or separation through the application of inward pressure.

3.1.3 Catalytic Converter

To meet stricter emission control standards, in 1975, manufacturers began to install catalytic converters on domestic automobiles. Located between the exhaust pipe and muffler, this device converts harmful carbon monoxide and hydrocarbons into carbon dioxide and water vapour. Newer converters also change nitrogen oxides into harmless oxygen and nitrogen. By law, these catalytic converters must remain on the vehicle.

3.1.4 Muffler

The muffler lowers noise through the use of perforated tubes and baffles that permit the exhaust gases to expand into the area between the tubes and the outer shell of the muffler. This expansion slows and cools the exhaust gas flow, thus reducing noise without obstructing the flow of gases.

3.2 Purpose of Exhaust System

The purpose of Vehicle Exhaust System is to

- Carry exhaust gases from the engine.
- Reduce the noise level of the engine.
- Protect the vehicle occupants from noxious exhaust gases.
- Reduce the level of environmentally polluting emissions.

4. MODELLING AND FABRICATION

4.1 3-D Model

3D model is constructed using Solid works and the model is shown below:

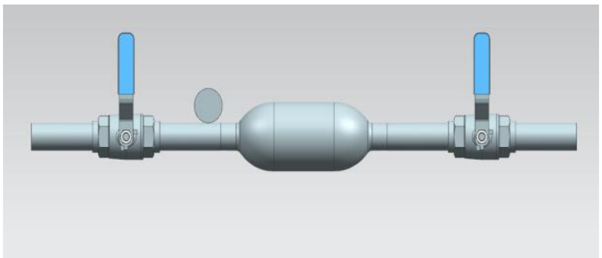

Fig.7 3-D Model

4.2 Regenerative Process for Carbon Dioxide Capture

To simulate the hydrodynamic behavior of the riser, it was assumed that there was no solid in the riser and the concentration of CO2 was zero at time zero. A second order discretization scheme was used to discretize the governing equations throughout the domain including 34x1200 uniform rectangular cells

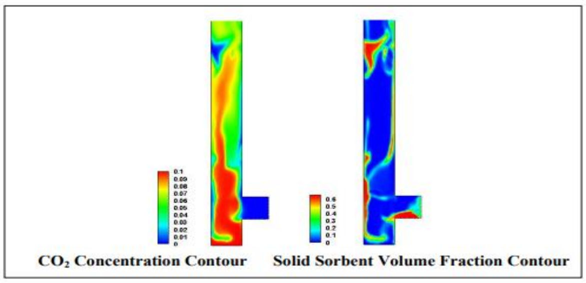

Fig.8 Regenerative Process for Carbon Dioxide

4.3 Performance Analysis of Catalytic Converter

A device that is used to reduce pollutants and toxic gases in the exhaust gas from the combustion engine by chemical reactions is known as a catalytic converter. These converters need a temperature of 426-degree centigrade so that it can convert harmful gases into non-toxic gases, so these are placed as close as possible to the engine to get enough temperature which it requires**.**

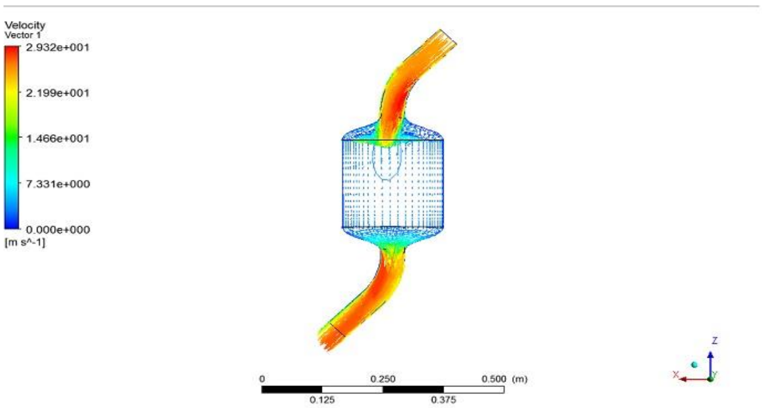

Fig.9 Performance Analysis of Catalytic Converter

4.4 Flow Analysis of Catalytic Converter

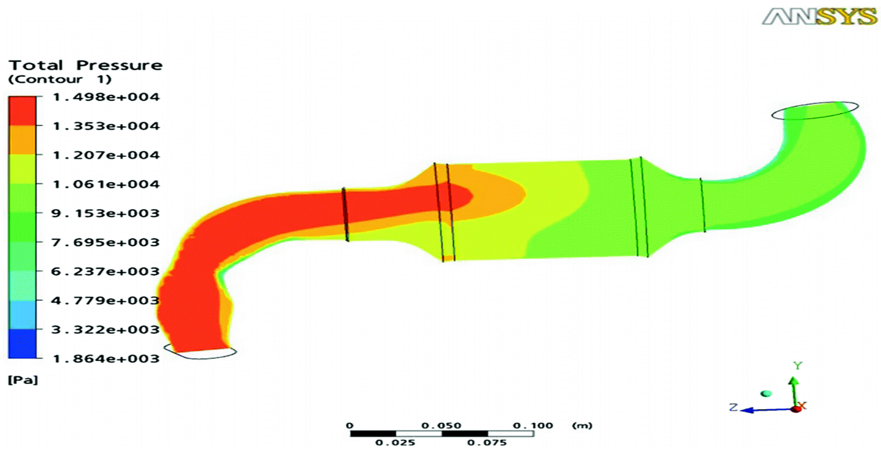

Fig.10 Flow Analysis of Catalytic Converter

4.5 Modeling Pollutant Emissions of Flameless Combustion

The Flameless Combustion (FC) regime has been pointed out as a promising combustion technique to lower the emissions of nitrogen oxides (NO_x) while maintaining low CO and soot emissions, as well as high efficiencies.

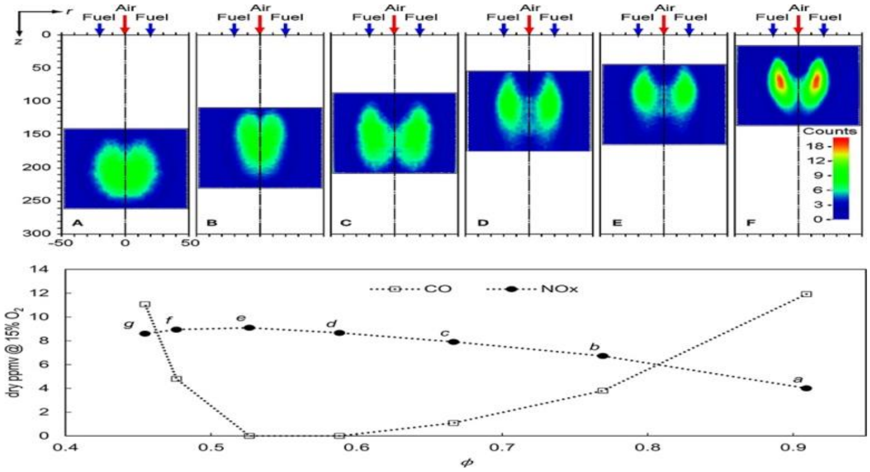

Fig.11 Flow Analysis of Catalytic Converter

5. CONCLUSION

From the results, the paper concludes that the emission of Carbon dioxide from the vehicle is reduced by maximum of 48% and apart from the reduction of carbon dioxide emission some amount of Hydrocarbons has been reduced. This process of adsorption won't affect the increase in emission of other gases. We present a 3D CFD numerical model of a spark ignition engine powered by syngas derived from woodchip gasification. The engine under consideration is actually mounted in an integrated layout aimed at producing combined heat and power, combining a gasifier, a syngas cleaning system, a spark ignition engine, and a power source. Measurements taken to define the geometrical grid are used to model the numerical grid. Characteristics of the combustion chamber, and the 3D CFD model is initialized with the help of a suitable 1D model created within the GT-Power environment. Due to the adsorption process we can recycle the catalyst used and the adsorbed carbon dioxide can be utilized so this process of adsorption will not affect the environment. Exhaust manifolds with reducers allow for lower backpressures and higher exhaust velocities, lowering emissions and assisting in the establishment of emission regulations. The amount of unburned gasoline inside the chamber is reduced, resulting in more power with less fuel consumption, boosting the chamber's fuel efficiency.

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