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Electrical pulse discharge plasma augmented catalysis and adsorption for NOx /CO abatement from stationary diesel engine exhaust – Effect of system configuration, exhaust composition and concentration

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A detailed investigation on the removal of pollutant (NOx & CO) from the exhaust of a stationary diesel engine is being carried out using pulse dielectric barrier discharge plasma augmented catalysis and adsorption techniques. The objective of the study is to explore the Effect of exhaust composition, operating scheme, effect of exhaust concentration, Effect of energy density and type of material on pollutants removal. The investigation is being carried out with many system configurations involving electrical pulse discharge plasma augmented catalysis and adsorption. To study the effect of exhaust composition experiments conducted on both filtered & raw exhaust, further experiments are carried out at different loads to study the effect of exhaust concentration on the pollutants removal. Finally comparison of various systems configuration is made and results are discussed.

Keywords: *Dielectric Barrier Discharge (DBD), plasma augmented catalysis and adsorption.*

1.0 INTRODUCTION

Diesel engines, the major source of power in industries and automobiles, play a significant part among man-made pollution sources. Successful control of the emissions from combustion engines, particularly from diesel engines, is yet to be achieved. One of the most harmful pollutants present in the diesel engine exhaust is NOX and CO these are mandated to meet the regulations.

The conventional techniques which are available to control the emission, now are either difficult to operate or does not satisfy the stringent emission standards. Reducing the diesel engine exhaust pollutant to meet the future emission standards is a challenging task and there is need for better after treatment techniques [1].Controlling emissions from combustion engines particularly from diesel driven ones is a challenge to the researchers across the globe. In case of diesel engines despite the modifications in engine design and improvement in after treatment technologies, large amount of NOx and CO continue to emit and attempts to develop new catalysts to reduce these Pollutants have been so far less successful.

The electrical discharge plasma (non-thermal plasma) is a prominent non-conventional technique, which can produce chemically active species that can facilitate the removal of NOx and other pollutants within diesel exhaust [2, 7].

Further, plasma promotes catalysis and adsorption when it is cascaded with a catalyst and an adsorbent are gaining lot of importance [18, 26]. However, majority of the research work on actual diesel engine exhaust has been done at exhaust temperatures higher than 150°C making use of proprietary catalysts with the use of additional hydrocarbons the results reported have limitations with regard to pollutant removal

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efficiency, byproduct formation, pollutant initial concentration, energy consumption and operating temperature window.

In the present work, a detailed study on the removal of pollutants from the exhaust of a Stationary diesel engine was carried out using electrical discharge plasma hybrid techniques. The objective of the study is to explore the effect of exhaust composition, loading and configuration on the pollutant removal efficiency of electric discharge plasma augmented catalysis and adsorbent configurations.

Many researchers are on simulated gas only& few are working on actual engine exhaust in those most of the researchers working on lower flow rate under no load condition (say 2 & 4 LPM), in our paper we are worked on suitability of configuration at higher flow rare ie 8LPM with 27% engine loading condition using waste by product red mud as catalyst which is produced in the Bayer process & shows performance of the same catalyst for removal of CO at different flow rates.

2.0 EXPERIMENTAL SET UP

The schematic of the diesel engine exhaust treatment setup is shown in Figure 1 & 2 which has following components

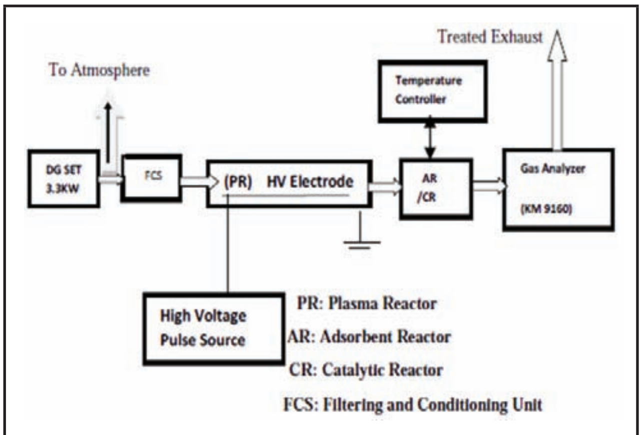

FIG. 1. DIESELENGINEEXHAUSTTREATMENTUSING SINGLE STEP PLASMAAUGMENTED CATALYSIS/ADSORBENT TECHNIQUE

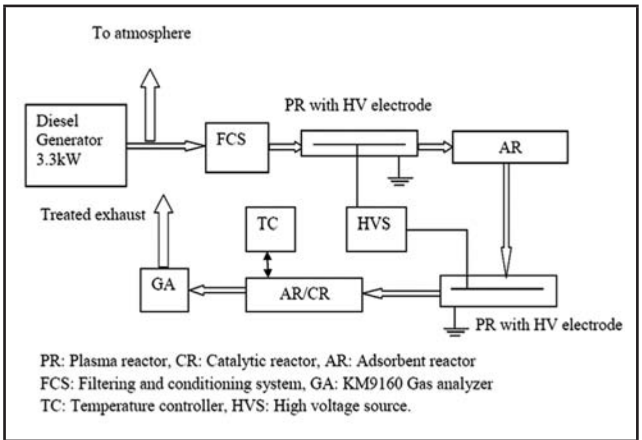

FIG. 2. DIESEL ENGINE FILTERED EXHAUST TREATMENT USING DOUBLE STEP ELECTRICAL DISCHARGE PLASMA AUGMENTED ADSORBENT/CATALYSIS TECHNIQUE.

2.1 High Voltage Pulse Source

Generation of high voltage is important in generation of radicals which is responsible for oxidation & reduction of exhaust pollutants A 30 kV pulse source was used in the studies. Throughout the experiments, the frequency of the pulses was kept constant at 100 pps (pulses per second). This pulse voltage applied to the plasma reactors.

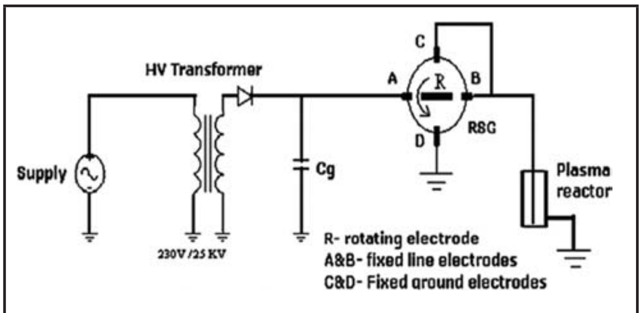

FIG. 3. BASIC DIAGRAM OF HIGH-VOLTAGE REPETITIVE PULSE GENERATOR.

2.2 Diesel Engine Set

A 3.3 kW diesel engine was used as the exhaust source. The whole of the exhaust from the engine was not treated in view of infrastructure limitation in the laboratory. Further, as our objective is to examine the underlying principle involved in the exhaust treatment, only a part of the main exhaust from the engine was treated and the exhaust flow rate was controlled and varied from 2lpm to 8lpm.

Electrical loading (Lamp load) is applied for generator. In this study 27.27 % (900W) load is connected to the generator throughout the experiments to know effect of plasma/ plasma augmented catalyst/adsorbent on loading condition.

2.3 Plasma Reactor

A dielectric barrier electric discharge reactor (referred to as plasma reactor (PR)) was employed in the present studies. The plasma reactor was a cylindrical glass tube (inner diameter: 15 mm and outer diameter: 17 mm) consisting of a stainless steel wire of thickness 1 mm as the inner electrode and aluminium foil wrapped over the glass tube as the outer electrode. The effective length of the reactor where discharge took place was 30 cm. The experiments involving plasma reactor were carried out at room temperature.

Dimension plays a very vital role in removal efficiency as effective length is increases pollutants retention time which leads to reactions in reactors & also removal efficiency, but as increase in reactor length will draw more power hence we optimization of reactor length.

2.4 Adsorbent & Catalytic Reactor

A non-conventional commercially available red mud as catalyst and MS13X molecular sleeves and Activated alumina balls were used as adsorbent al are in the form of pellets were placed inside the quartz glass tube of 30 cm length and 15 mm diameter. This is referred to as catalytic/adsorbent reactor (CR/AR).

The adsorbent reactors were operated at room temperature, whereas the catalytic reactor was operated at temperatures varying from room temperature to 400°C.

2.5 Filtering and Condition Unit

In the experiments filtering of the exhaust was done first, using Filtering & Conditioning Unit (FCS). The filtered exhaust was then allowed to enter the treatment zone. The exhaust gas was made to pass through a tube containing steel wool, in order to filter out oil mist and macro-sized particulate matter. The exhaust was then passed through filtering and conditioning system (FCS). The FCS consists of three filters and a moisture separator. The function of the FCS is to filter out the carbonaceous soot, any coarse particles, oil mists and water from the exhaust gas. Proper care has been taken in the development of this conditioning system to not affect the sample gas components.

In the experiments with raw exhaust, the exhaust from the engine was taken directly to the plasma reactor and then the filtered exhaust was allowed to pass through the catalytic/adsorbent reactor.

2.6 Measuring Equipments

The measurement of NOx, and other gaseous pollutants present in the diesel engine exhaust gas was carried out accurately using a QUINTOX KM 9160, Kane International UK gas analyzer. This gas analyzer uses a combination of infrared sensors and electrochemical sensors for the analysis of different gases in the diesel exhaust.

Power consumed by plasma reactor is measured by using watt meter connected at primary side of the transformer.

3.0 RESULTS AND DISCUSSION

The schematic of experimental setup used for the present research work is shown in Figure 1&2. All the experiments were carried out at the laboratory scale.

Before treating the exhaust gas, the concentrations of CO, CO_2, NO, NO_2, NOx, & were measured. Table 1 shows the typical concentrations of the pollutants under no load& load (27.27%) conditions.

In Table 1, NOx means sum of concentrations of NO and NO_2. The concentrations of NO and NO_2 were measured individually and then added to get the NOx concentration.

TABLE 1 INITIAL CONCENTRATION OF POLLUTANTS/COMPONENTS PRESENT IN DIESEL ENGINE EXHAUST		
Main Pollutants	No load	27.7% Load
CO_2	1.7%	3.2%
CO	410ppm	311ppm
NO	127ppm	284ppm
NO_2	93ppm	262ppm
NOx	220ppm	546ppm
O_2	18.6%	15.8%

In the present paper the pollutant removal performance of electrical discharge based hybrid system is investigated for various system configurations, exhaust composition & engine loading condition. The results are presented for different applied pulse voltages& specific energy density (SED).

Specific energy density & %removal efficiency is calculated by using following equations

$$SED = \frac{Power input to the reactor\ or\ Discharge power (Watt)}{Gas Flow rate (\frac{ltr}{Sec})} J/L$$

$$\%\ Removal Efficiency = \frac{Initial concentation\ (I) - Concentration after treatment (F)}{Initial Concentration (I)} \times 100$$

3.1 Effect Of Systems Configuration

The plasma augmented catalysis & adsorption for the removal of NOx has been investigated in two different configurations- single step & double step. The superior performance of plasma augmented (assisted) adsorbent process has already been well established [26-27]. In this paper this philosophy has been investigated at higher flow rate & under load conditions for the two different types of configurations single & double step.

The Figure 4 gives the NOx removal performance of single & double step plasma augmented adsorbent (AAB) process. It is observed that for a flow rate of 8LPM & SED of 60 J/L the NOx removal is higher with double step plasma augmented adsorbent. This can be attributed to the increased residential time of exhaust & decreased exhaust concentration entering the second stage. Similar NOx removal performance in observed in the case of plasma augmented adsorbent (MS-13X) process which is shown in Figure 5.

Comparing Figure 4 & 5 it is further observed that for the same flow rate & energy the NOx removal using MS-13x adsorbent is better compared to AAB adsorbent for both single & double step configuration, this is due to the fact that MS-13X has a large internal surface area compared to AAB, which increases the adsorption capability.

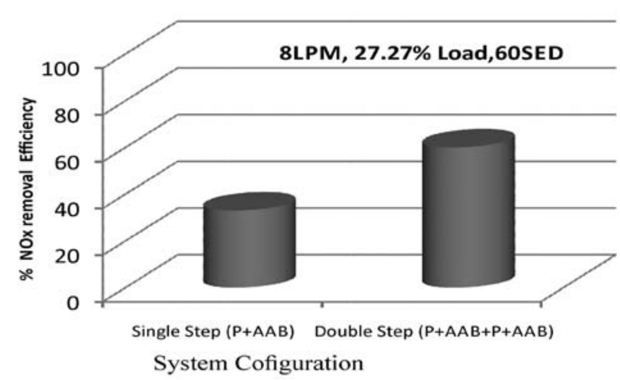

FIG. 4. EFFECT OF SYSTEM CONFIGURATION ON PLASMA AUGMENTED ADSORBENT (AAB) PROCESS

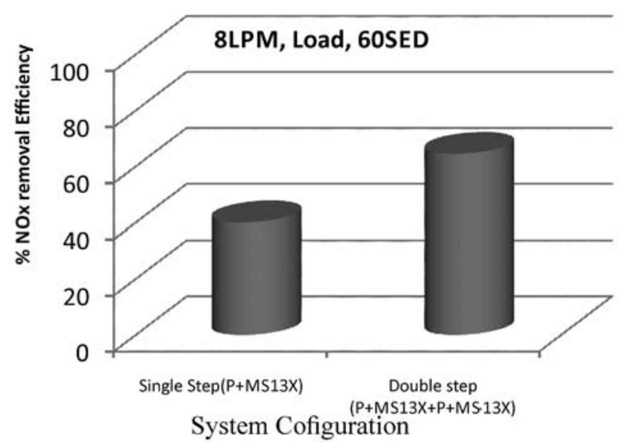

FIG. 5. EFFECT OF SYSTEM CONFIGURATION ON PLASMA AUGMENTEDADSORBENT (MS-13X) PROCESS

3.2 Effect Of Exhaust Composition

The effect of exhaust composition on NOx removal performance of plasma augmented catalyst (Red Mud) process is shown in the Figure 6 for both single & double step configuration.

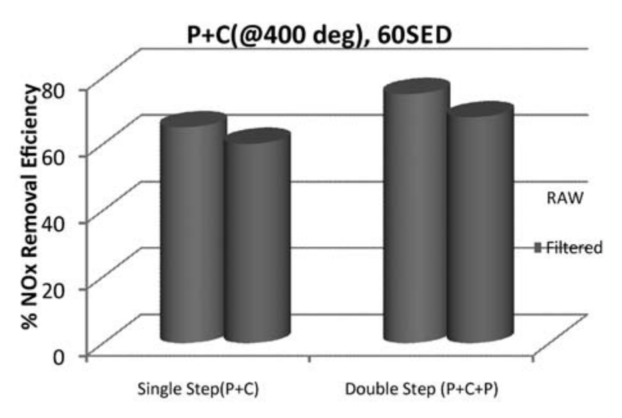

FIG. 6. EFFECT OF EXHAUST NATURE ON PLASMA AUGMENTED CATALYSIS PROCESS.

From the above Figure it is observed that NOx removal is not much affected by the exhaust composition (Raw/Filter) in case of both Single & double step confutation this can be explained as below

When plasma augmented catalyst treats raw exhaust the improved NOx removal by plasma [28] is compensated by decreased NOx removal by the catalyst as exhaust entering the catalyst is filtered & contains less concentration of aldehydes [29-30] this makes the catalyst less active. However plasma augmented catalyst process treats filtered exhaust the NOx removalby the plasma is comparatively low but the plasma produces more aldehydes the exhaust contains more aldehydes when enters the catalyst thus catalyst activities increases thus increase in NOx removal, hence the overall NOx removal of combined process remains almost the same.

From the above it can be stated that the exhaust composition has little effect on NOx removal performances of plasma augmented catalytic-single step & double step process.

3.3 Effect Of Pollutants Concentration (Loading)

Figure 7 shows effect of exhaust concentration on plasma augmented adsorbent(AAB) system the NOx removal is plotted with respect to applied voltage, from the figure it is observed that at any applied pulse voltage the NOx removal is decreases with the load condition this can be explained below.

Under the load condition the NOx initial concentration in the exhaust increases which will affect the NOx removal performance of plasma augmented adsorbent (AAB) process. Similar trend is observed in case of plasma augmented catalyst (Red Mud) process which is shown in the Figure 8

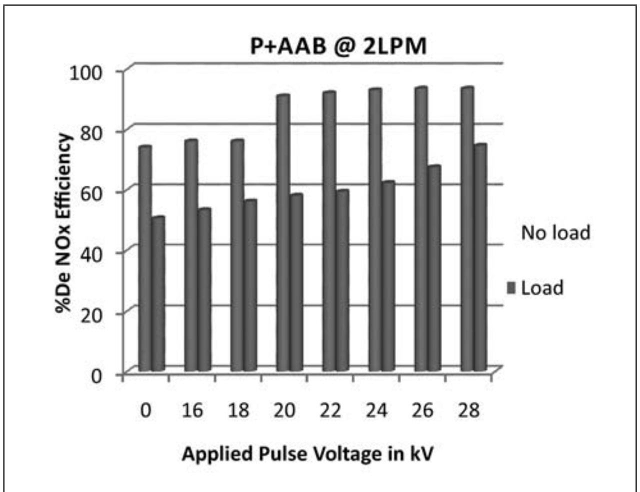

FIG. 7. EFFECT OF EXHAUST CONCENTRATION ON PLASMA AUGMENTEDADSORBENT PROCESS

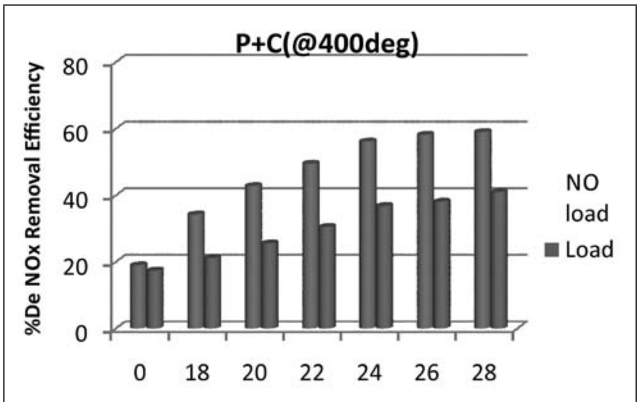

FIG. 8. EFFECT OF EXHAUST CONCENTRATION ON PLASMA AUGMENTED CATALYTIC PROCESS

Figure 9 shows the CO removal by plasma augmented catalyst (Red mud) single step configuration for various flow rates. It is observed that for lower flow rates (2&4LPM) CO removal is 100% & the CO removal is decreases for higher flow rates this can be attributed to decreased retention time of exhaust at higher flow rats

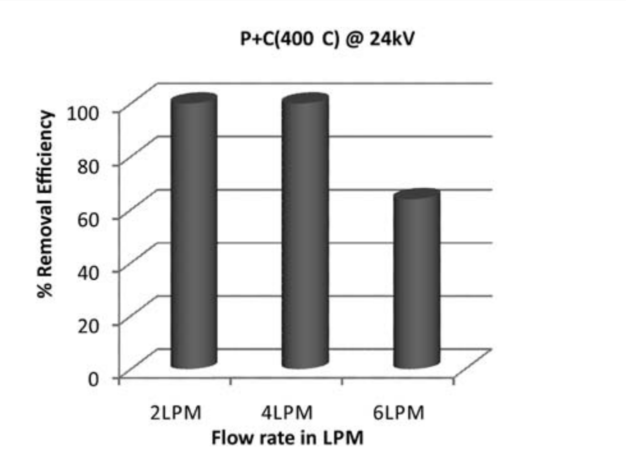

FIG. 9 EFFECT OF FLOW RATE ON CO REMOVAL IN PLASMA AUGMENTED CATALYTIC PROCESS

4.0 CONCLUSIONS

Studies were conducted on filtered andunfiltered (raw) stationary diesel engine exhaustusing electrical discharge plasma augmented plasma adsorbent/catalyst processes. The majorinferences drawn from this work are summarizedas below

At higher flow rate under loading condition double step plasma augmented adsorbent process shows better NOx removal efficiencythis aspect becomes morerelevant in a practical situation where the flow rate of theexhaust to be treated is significantly high. Further at a given energy density MS-13X adsorbent shows better NOx removal efficiency compared to AAB adsorbent.

Nature of exhaust composition has little effect on NOx removal in both single & double step plasma augmented catalyst configurations.

Under engine loading condition for a given pulse voltage NOx removal efficiency decreases for both plasma augmented adsorbent/ catalyst process.

100% CO removal is achieved in plasma augmented catalysis(red mud) process at lower flow rates &removal efficiency reduces at higher flow rates.

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