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Diagnostic approach for side effects of backpressure on stationary CI engine due to after treatment Devices

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ABSTRACT– *All objectives and operational parameters requirements of an effective after treatment systems must be considered while designing. Most significant parameters for energy efficient exhaust system development requires minimum fuel consumption and maximum utilization of exhaust energy for reduction of the exhaust emissions and also for effective waste energy recovery system such as in turbocharger, heat pipe etc. from C.I. engine. Techniques used for after treatment, especially Diesel Particulate Filter, backpressure problem is a subject of specific interest for design and development of Particulate Matter emission control activities. In this research paper, effect of back pressure variations on the C.I. engine performance, with and without the use of a specially designed Diesel Particulate is done. Experiments show that positive rise in backpressure causes increase in fuel consumption so in any case backpressure rise must be strictly banned. Cleaning or regeneration process in complete exhaust system must be economically done immediately and on regular basis, to avoid any type of exhaust flow restrictions. All the parts of after treatment devices should be designed for smooth, uniform exhaust flow from all cylinders to control backpressure. It has been observed that design of each device should offer minimum pressure drop across the device, so that it should not adversely affect the engine performance.*

Key Words - DPF, Stationary C. I. engine, regeneration, Backpressure, filtration efficiency.

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I. INTRODUCTION

The increased use of diesel driven vehicles for all categories of commercial automobiles and even for private cars is the major trend observed worldwide over the last two decades in transportation field. While the energy advantages of the diesel engines are unquestioned, lower cost of diesel fuel is also responsible for its increasing popularity, particularly with respect to the less developed countries. Although, inherently cleaner than gasoline engines from the standpoint of view of carbon monoxide (CO) and hydrocarbons (HCs), diesels produce more aldehydes, sulfur oxides (because of the higher sulfur content in diesel fuel) and nitrogen oxides. Offensive smoke and odor emissions are also a problem of great concern, most importantly; however, uncontrolled diesel engines emit significant amounts of particulate. These particulate emissions are a direct health concern as well as a serious source of overall environmental degradation. In this way, despite the technical and commercial advantages of diesel engines over the conventional gasoline fueled Otto cycle power-plants, concerns became to grow as early as in 1980's over the environmental consequences of increased dieselization.

AFTERTREATMENT STRATGIES:

The basic purpose of using after treatment devices in spark ignition and compression ignition engines is the same, to convert the harmful combustion byproducts into harmless products, but the combustion of spark ignited gasoline engines and diesel engines vary considerably. Modem gasoline engines with closed loop emission controls produce exhaust i.e. near chemical stoichiometry and at temperatures of 375 to 850^0 C. The exhaust contents significant amount of hydrocarbon (HC), carbon monoxide (CO) and oxides of nitrogen (NO_x) that must be reduced using a catalytic converter; in order to meet the current emission norms requirement. Gasoline engine particulate emissions are within current emission norms requirement. Whereas Diesel engines, combusts with lean air-fuel mixture of less than 20:1 that produce exhaust temperatures of 100 to 400^0 C. This exhaust contains significant amount of particulates that may require an after treatment device such as catalytic converter, DPF etc. in order to meet current emission norms and pending requirements.

However, the concentrations of HC, CO, and NO_x in diesel exhaust are typically below the current light duty and heavy-duty requirements. S.I. engine After treatment devices works mainly to convert harmful gaseous emission such as HC, CO, NO_x into harmless products i.e. H_20 vapor, $C0_2$ and N_2, which requires reactions in between exhaust emission and catalyst system, so the reaction takes place between gaseous phase and solid phase catalyst. Whereas after treatment devices for C.I. engine, works mainly to convert harmful particulate emissions and also with the gaseous emissions like HC, CO, NO_x, though in less amount, into harmless products.

This conversion requires chemical reaction between particulate emission (i.e. ash, carbon, sulfate, organic matters and other), gaseous emission and a solid catalyst. Thus the reaction does not occur only between gas-solid phases, because emissions can exist in all the three phases, in the exhaust system. Therefore, the difficulties involved in reaction mechanism are different than the case for the S. I. engines.

SYSTEM INTEGRATION:

To develop application specific view, it is very important to consider overall effects of each component added to the system, so as to improve the overall system performance. In this case of after treatment devices used in exhaust system of engine, it is important to understand the effect of installation on the overall performance of the engine. Considering automobile power plant as a complete system, it is a complex system made up of several other equally complex sub-systems, each is distinct from the others but they all share some common features and goals that allow them to work together.

II- DESIGN CRITERIAS FOR EXHAUST SYSTEM COMPONENTS:

Loss of power due to gas exchange process is due to pumping gas from lower inlet pressure to higher exhaust pressure. The gas exchange processes affect the volumetric efficiency of the engine. The performance of the engine, to a great deal, depends on the volumetric efficiency. All the parts of after treatment devices should be designed for smooth, uniform exhaust flow from all cylinders to control backpressure. This is the pressure that tries to force the exhaust back in to the engine. The net work output per cycle from the engine is dependent on the pumping work consumed. Therefore the exhaust system component and devices such as Particulate Trap, catalytic converter etc., must be designed for minimum backpressure so that it should not disturb the engine as well as other subsystems operation. The amount of conversion of the harmful byproducts into harmless products, in the after treatment devices used in exhaust system of C .I .engine, is dependent on two parameters - (1) Feed stream, and (2) Component design.

1. FEED STREAM :- Condition of feed stream at the inlet of the After treatment devices used in exhaust system of C.I. engine is dependent on various factors such as type of engine, Properties of fuel and quality of air supply to the engine and operating condition of engine decides the condition of exhaust at the outlet of the engine cylinder and also on the position of After treatment devices installed in the exhaust system. The data required for after treatment device design, consist of the temperature, pressure, composition and flow rates of the feed streams.

All the parameters vary greatly throughout the operating range of the engine and during the engine useful life because in general old engine produces more pollutants than the new ones. The main cause of variation in temperature, pressure, composition and flow rates of exhaust from engine cylinder is that the air-fuel ratio requirement varies with the different operating conditions of engine i.e. load and speed variations and also during the flow of exhaust from the engine cylinder up to the inlet of the After treatment devices. The temperature, pressure changes, which is dependent on the heat transfer and flow distribution through the exhaust system and design of exhaust system components, in between cylinder exhaust and inlet to the After treatment devices, so the position of the installed device is also one of the important aspect which determines the final feed stream parameters at the After treatment device inlet.

Study of the effects of variation in operating conditions of the engine on the feed stream parameters is very important data for the design of after treatment devices for any specific engine.

2. COMPONENT DESIGN :- Design of after treatment devices are responsible for obtaining the desired processes, important factors are briefly described below -

a) Space Velocity consideration: - Space velocity consideration is one of the important parameter for determining after treatment device volume required for carrying out the desired reactions. Residence time for exhaust in the device is dependent on feed rate and device volume. Feed rate is dependent on engine operating condition, hence the space velocity always must be such that the feed rate of reactants should coincide with the rate of reaction actually existing in the device volume, so as to provide necessary reaction time for maximum conversion of the pollutants in the feed stream to the After treatment devices.

b). Durability consideration :- For obtaining maximum conversion efficiency during the long, trouble free operating life of the complete exhaust system components. System components should have ability to withstand vibrations and damages due to varying thermal stress conditions, without sintering, melting or change in surface structures during operation, due to fluctuating exhaust stream in each device. The main cause of deactivation in diesel after treatment devices is because of accumulation of particulate matter (i.e. ash, carbon etc.) on catalyst. Fouling may obstruct the flow path so that the design of after treatment devices must be such that to allow the flow of such particles through the device. The problem of catalyst poisoning should be properly analyzed, so as to develop proper, simple and economical techniques for regeneration or replacement of catalyst system.

c) **Flow Distribution:** - Uniform flow distribution is one of the essential factors for complete utilization of the after treatment device volume i.e. for utilization of complete catalyst surface area available, which results in maximum conversion. Uniform flow distribution allows same residence time for each molecule and thus maximum conversion can be obtained without deactivation of specific portion of after treatment device due to over heating of catalyst surface in action. Uniform flow distribution also reduces backpressure on the engine, due to reduced pressure drop across the device. Maximum production rate requires both a favorable product distribution and high conversion. If the activation energies are such that a favorable product distribution is obtained at a high temperature, then we should use the highest allowable temperature, because then the rates of reaction are high and the required reactor size is small.

For multiple reactions, both reactor size and product distribution are design objectives. Heat and mass transfer within the reactor is greatly affected due to flow distribution pattern and it is also important for early light-off temperature achievement. Flow distribution depends on geometrical construction of the device i.e. design of cones, shell and catalysts system structure which in turns, depends upon dimensions of flow paths and number of paths provided etc.

d) **Light-off Temperature** : -Feed stream temperature is an important parameter for early light-off temperature achievement in the after treatment devices. The extent of reaction possible is dependent on the temperature and residence time for reactants, in the device. The temperature range for obtaining potential catalyst activity, decides the useful operating temperature range for the after treatment devices. If the reaction is exothermic and if heat transfer is unable to remove all of the liberated heat, then the temperature of the reacting fluid will rise as conversion rises. By similar arguments, for endothermic reactions the fluid cools as conversion rises. It is important to know the temperature change with the extent of conversion.

When the heat absorbed or released by reaction can markedly change the temperature of the reacting fluid, this factor must be accounted for, in design. Thus we need to use both the material and energy balance expression rather than for the material balance alone. One important conclusion i.e. a high temperature favors the reaction of higher activation energy; a low temperature favors the reaction of lower activation energy. Thus temperature is important parameter to be controlled for keeping it within useful range, to prevent the undesirable reactions. The necessity to control temperature is, to prevent loss of catalyst activity, changes in structure of the solid catalyst particles, as the temperature is increased, may reduce their activity which shortens their useful life. Excessive temperatures decreases catalyst activity and equilibrium yield is adversely affected at high temperature. It is important one in explaining the need to maintain the temperature level. Still other factors, such as physical properties of the equipments may require limiting the temperature level, where high pressure exists in the reactor and also due to high temperature the problem of regeneration catalyst to restore activity, may be a serious one, in the After treatment devices, in many cases, the catalyst is too valuable to discard.

e) **Heat and Mass Transfer Processes**: - Many variables may affect the rate of a chemical reaction. In heterogeneous systems, hence the problem becomes more complex. Material may have to move from phase to phase during reactions; hence the rate of mass transfer may become important. In addition, the rate of heat transfer, for early reaction temperature achievement may also become a factor. Thus heat and mass transfer plays important role in determining the rates of heterogeneous reactions and also the temperature, pressure and composition are obvious variables. Proper heat and mass transfer processes help to achieve early light off temperature in the after treatment devices and thus affects the conversion efficiency.

f) **Chemical Reaction**: - The time available for carrying out a chemical reaction in C.I. engine is limited, if the process is to be economically feasible. Therefore catalytic reactions are very useful for reducing the reaction time to achieve the desired objectives. The rate of chemical reaction can vary from a value approaching infinity to essentially zero. Most industrially important reactions occur at rates between these extremes and it is in these cases, that the designer must apply data on kinetics to determine finite sizes of reaction equipment. It is particularly important to know how the rate changes with operating parameters, the most important of which are temperature and composition of reaction mixture.

The desired reduction in the exhaust emissions can only be determined by the quantity of each pollutants in the exhaust i.e. its composition and finally composition suggest the extent of reactions that must be carried out in the After treatment device. At a given temperature the number of collisions is proportional to the concentration of reactants in the mixture. No matter how active a catalyst particle is, it can be effective only if the reactants can reach the catalytic surface.

The transfer of reactant from the bulk fluid to the outer surface of the catalyst particle requires a driving force, the concentration difference. Whether the difference in concentration between bulk fluid and particle surface is significant or negligible depends on the velocity pattern in the fluid near the surface, on the physical properties of the fluid and on the intrinsic rate of the chemical reaction at the catalyst, i.e. it depends on the mass transfer coefficient between fluid and surface and the rate constant for the catalytic reaction.

III-EXPERIMENTATION:

In present scenario of increasing air pollution by automobiles development of practically feasible emission control devices can be considered as one of the most challenging tasks related to the after treatment technologies. But owing to the drawbacks in catalytic after treatment such as catalyst meltdown, carbon deposit, catalyst fracture, poisoning and high cost involved with it, these are uneconomical. Hence in present work an attempt is made to use perforated copper plate arrangement (circular plates) in Diesel Particulate Filter. The trials are conducted on single cylinder, 4-stroke Kirlosker diesel engine. The different parameters are compared with the values of same parameters without using Diesel Particulate Filter, for the same engine output conditions. The speed of the engine is kept constant at 1500 rpm throughout the complete trials and also engine jacket cooling water is kept constant at 0.1666 liters/sec, so as to provide ease in comparison of different parameters, in some cases by varying the load on the engine also.

Further during the trials on Diesel Particulate Filter, a special type of regeneration technique is developed with simple nut & bolt arrangement, each times the perforated plates and rings were cleaned by water and then by carbon tetra-chloride solution and dried. While changing the number of plates and rings i.e. every times the fresh copper plates and rings were used. To reduce the backpressure on the engine, maximum no. of plates (i.e. 20 plates) provided with extra 8 no. of holes, of 5 mm diameter were used for determining the effect i.e. back pressure reduction mainly.

EXPERIMENTAL SETUP:

Figure: 1 Schematic view of experimental set up

The engine used for experimentation has following specifications

1. Make: Kirlosker, single cylinder, 4-stroke compression ignition engine
2. Rated power out put : 5 H.P
3. Speed: 1500 R.P.M.
4. Stroke length : 110 mm
5. Bore diameter : 80mm
6. Loading type : Water resistance type load with copper element and load changing arrangement
7. Moment arm : 0.2 meter
8. Orifice diameter (for air box) : 25mm
9. Co-efficient of discharge of orifice : 0.64

Diesel Particulate Filter:

1) Space velocity: 50,000 hr^{-1}
2) Catalyst used: copper based catalyst system
3) Circular perforated copper plates with 256 no. of holes per square cm and copper rings made up of 5 mm diameter rod.
4) Flange arrangement for dismantling and varying no. of perforated plates and no. of rings, more details are given in figures.

RESULTS AND DISCUSSIONS:

1) Backpressure is observed to be directly proportional to the number of plates used obviously because of increase in resistance to exhaust gas flow, at the same operating conditions. Exhaust system components such as Diesel Particulate Filter and exhaust after treatment devices are a source of engine exhaust back pressure. Increased back pressure levels cause increased emissions, increased fuel consumption, and negatively affect engine performance.

2) Fuel consumption is also observed to be directly proportional to the back pressure on the engine, at the same operating conditions. The desire for countries and automotive manufacturers to reduce emissions includes CO_2 emissions that arise from burning fuel in internal combustion engines. There is a direct correlation between a vehicle's fuel consumption and the CO_2 emitted from that vehicle.

3) Variations in exhaust emissions are compared at no load condition, using different no. of plates the conversions obtained are (NOx18.05 %, HC -56 %, C0-8.33% and smoke density -11.11%) maximum using 8 no. of plates arrangement.

4) During the complete trials the exhaust gas temperature is observed to be varying between 117^0 C to 240^0 C, exhaust gas mass flow rates are observed to be approximately constant (between 27.85 to 28.75 kg/hr), but the fuel flow rates in the engine cylinder are varying between 0.5610 to 1.4773 kg/hr, so as the air-fuel ratio is also varying, being observed to be rich at 18.36: 1 to lean at 50.26: 1. Hence there must be considerable changes in the feed stream composition to the Diesel Particulate Filter and thus the amount of pollutants would also be different at the inlet of Diesel Particulate Filter, these variations must be considered while designing Diesel Particulate Filter.

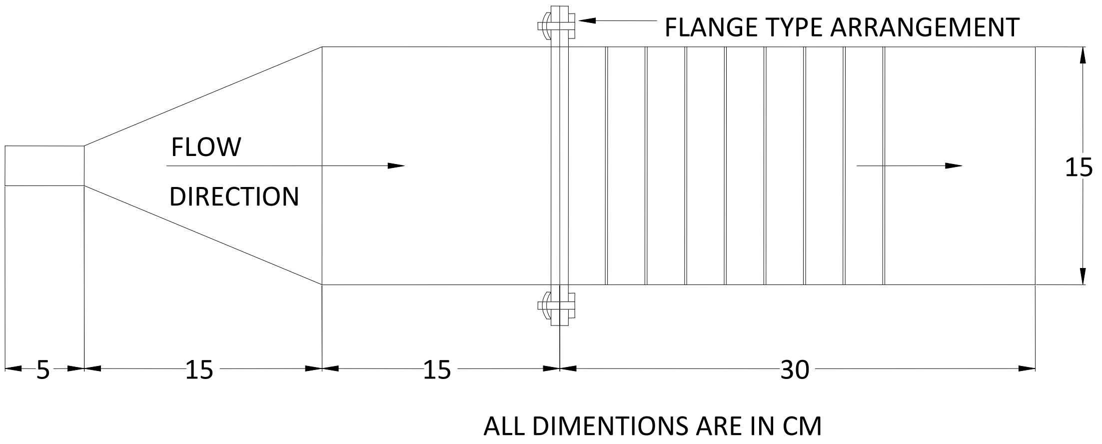
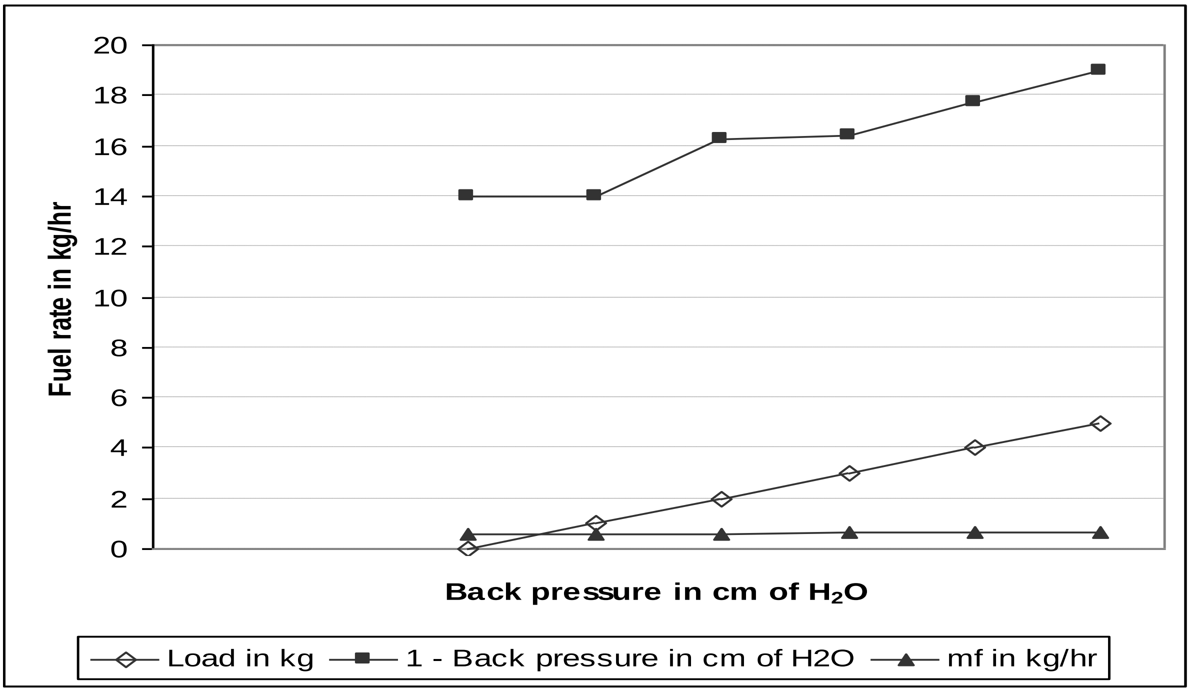
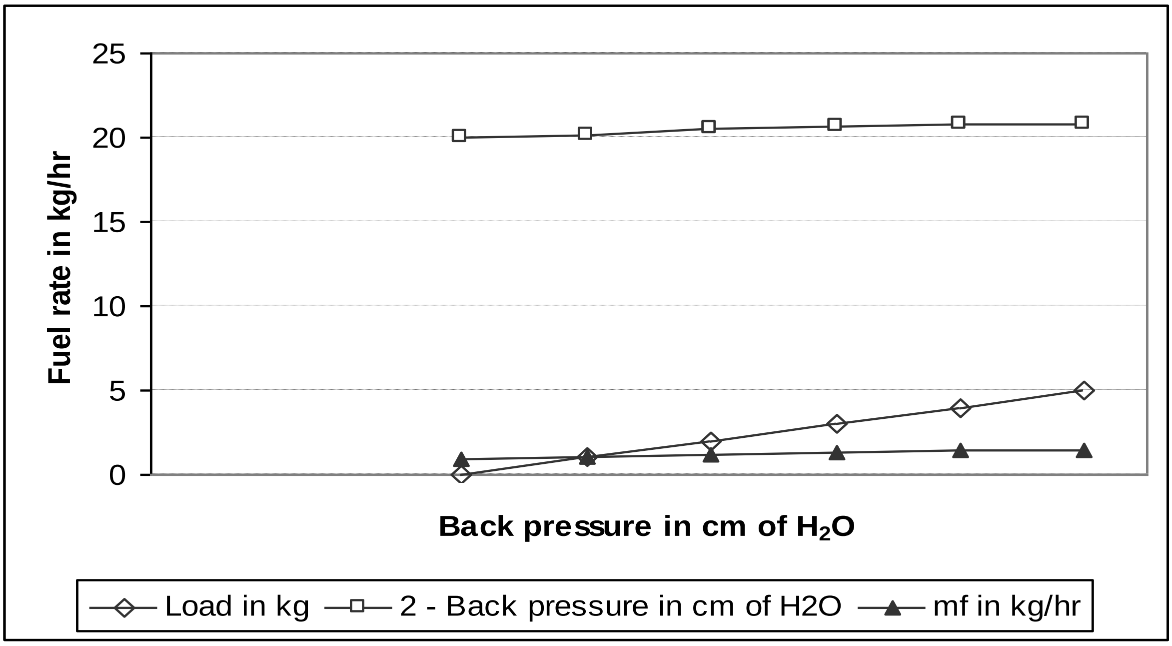


Figure: 3 View of Diesel Particulate Filter with copper plates

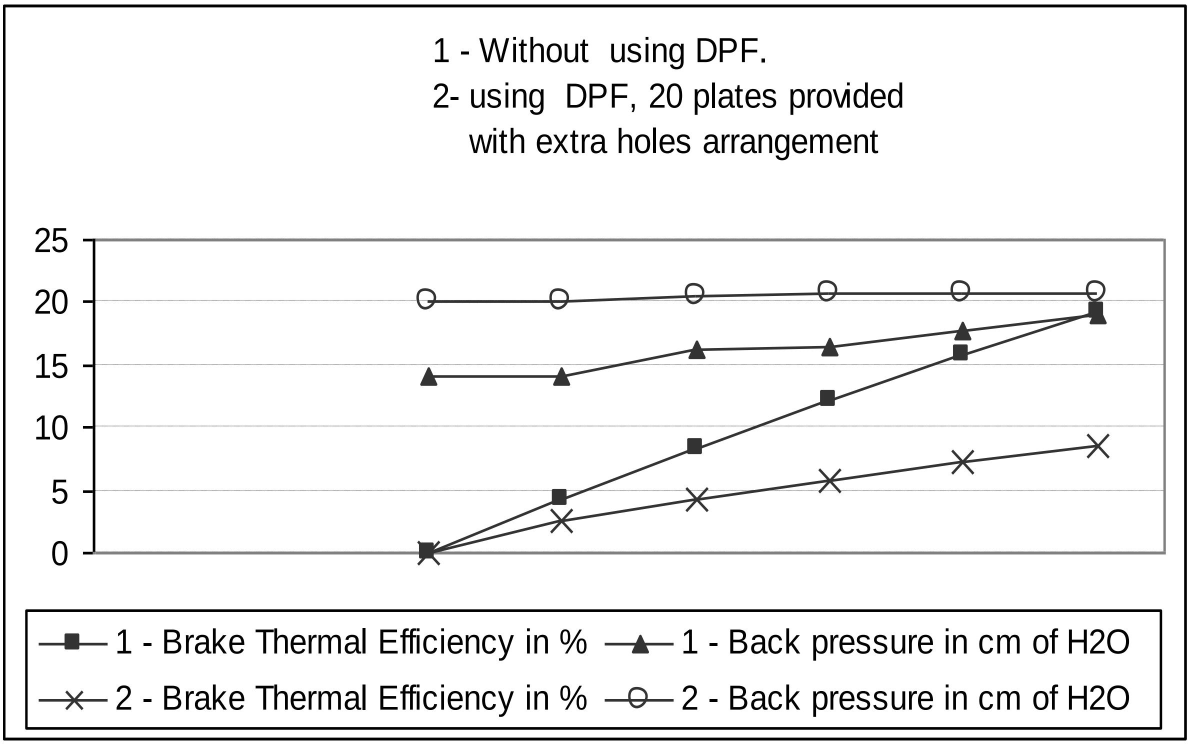
PERFORMANCE CHARACTERISTICS (at constant 1500 rpm)



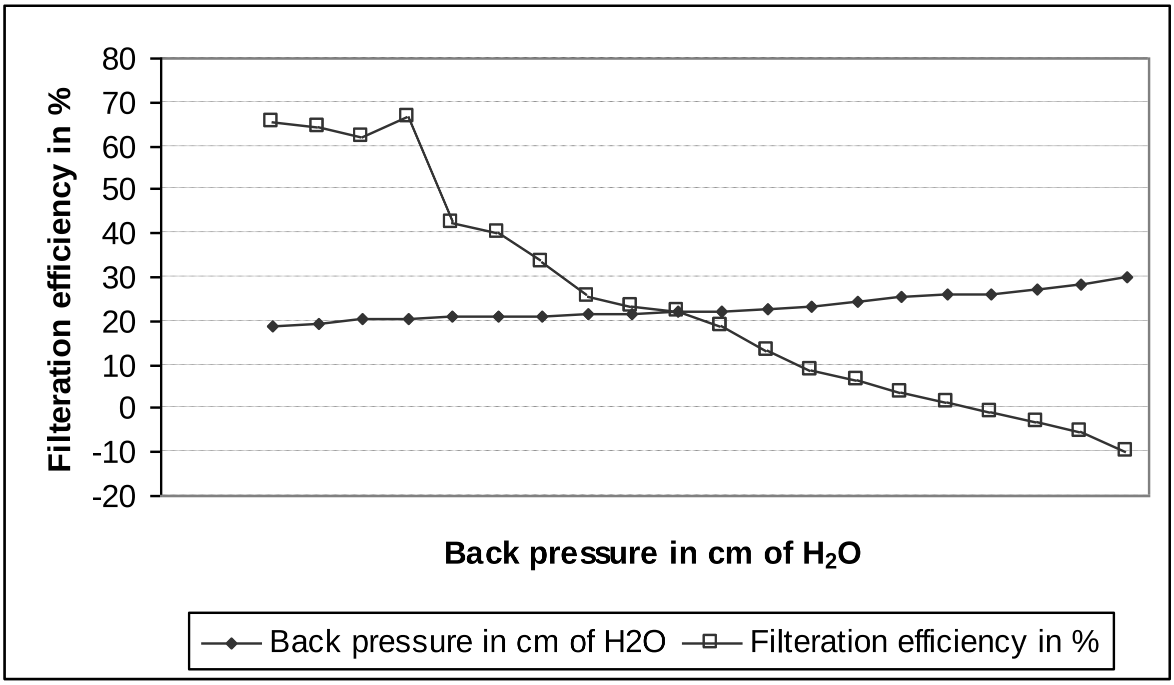
GRAPH-1 Variation in Fuel consumption and load Vs back pressure, without using DPF.



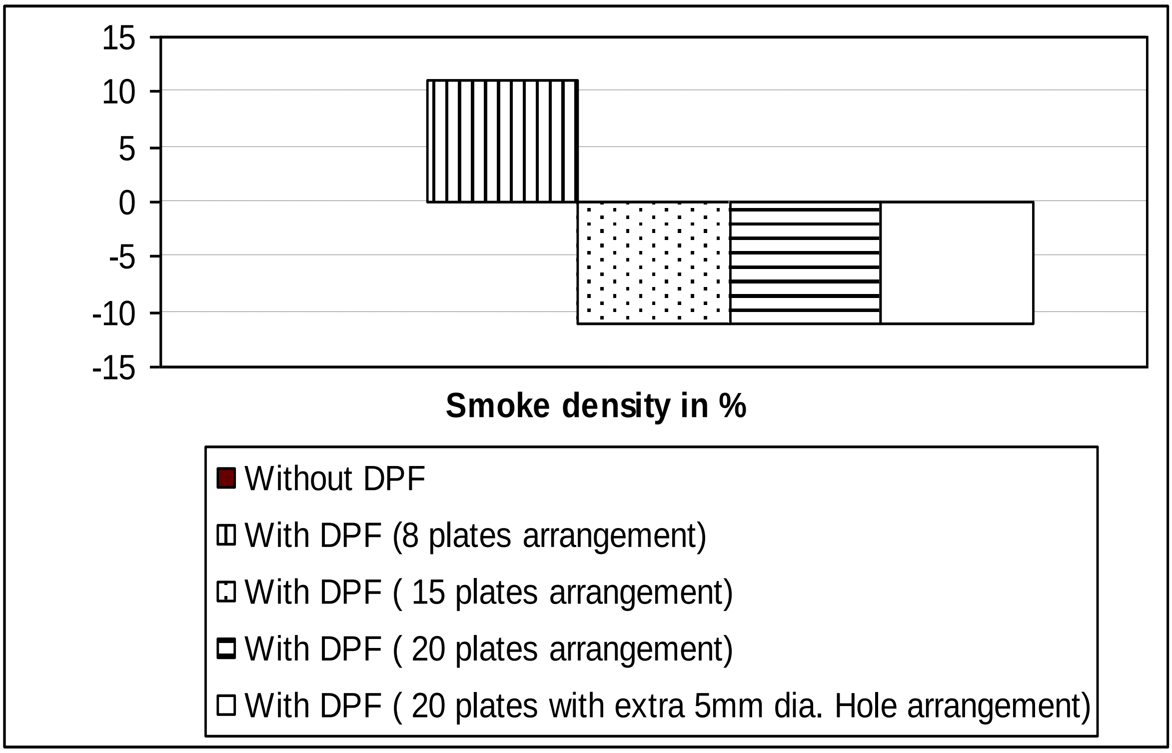
GRAPH-2 Variation in Fuel consumption and load Vs back pressure, using DPF, for 20 - plates provided with extra holes arrangement



GRAPH-3 Variation in brake thermal efficiencies Vs back pressure, 1- without using DPF & 2- With DPF, 20 plates provided with extra holes arrangement at various load conditions.



GRAPH-4 Variation in filtration efficiencies Vs back pressure, using DPF with different no.of plates arrangement.



GRAPH-5 Comparison of filtration efficiency at different exhaust conditions

CONCLUSION

It is clear from the above experimental work that in the prevailing C.I. engine exhaust conditions, removal of non-combustible compounds also using the technique as described here, 100% regeneration of DPF is possible, To minimize the pumping work, the backpressure must be as low as possible for obtaining the maximum output from the engine. The backpressure is directly proportional to the pressure drop across the Diesel Particulate Filter or design of complete exhaust system components. Therefore, exhaust system components and devices must be designed for minimum backpressure during the entire useful operating range of the specific engine so that it should not disturb the engine as well as other subsystems performance.

By keeping specific control measures, It is economically possible to reduce back pressure on old engines also Careful analysis of application environment and more stress is required, for the fulfillment of durability requirements i.e. mainly on catalyst reactivation or replacement techniques development, keeping in mind economical maximum conversion efficiency of the pollutants and effective waste heat recovery system without adversely affecting the engine performance with durability is the ideal requirement from an exhaust after treatment System.

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