Experimental Investigation on Exhaust Noise Reduction Using Particulate Trap in Direct Injection (DI) Diesel Engine

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Abstract - **Excessive pollution caused by engine emission has led to serious environmental degradation in the past three to five decades. Researchers worldwide are striving hard for reducing the emission from the engine. But the uses of diesel-powered vehicles are increasing day-by-day. The diesel engines have acquired much wider application than ever because of their main advantages of higher power and lower cost of the fuel. Although diesel exhaust is relatively clean with respect to unburnt hydrocarbons and carbon monoxide, it contains pollutants like particulate matter and oxides of nitrogen with greater exhaust noise. The paper reports on the control of the engine exhaust noise by a particulate trap for DI diesel engine. The experimental work comprises of design and development of the particulate trap for the given engine to control the exhaust noise level. The noise level reduction is also studied using a muffler. The reduction in noise level using particulate trap and muffler is experimentally investigated and compared. The noise level without particulate trap and muffler is 132 dB, with trap 116 dB, with muffler 125 dB. The percentage reduction in noise level is 12.5% with trap and is 9% with muffler.**
Keywords: **Noise, Muffler, Emissions, Particulate Trap.**

I.INTRODUCTION

In towns, the vehicle noise comes mainly from the engines, either directly from the cylinders, or from the exhaust. Brake squeal, tyre noise, transmission noise and suspension noise are other sources, some being dependent on road bumpiness, others on high speed. Commercial vehicles, specially the largest lorries, are the most unpleasant source of noise. Noise is one of the most neglected causes of the increased social malaise or enforced fall in the quality of life, and there is no doubt that legal and community action will enforce greatly improved standards. The ultimate way of reducing the dissatisfaction must be to reduce the peak emissions from vehicles passing by and the general background of the stream of vehicles by quietening the vehicles themselves. The other methods of insulating the building against sound, keeping the roads away from the buildings and using noise barriers are, at best, temporary palliatives.

Among the quests to extract more power from every drop of the fuel burnt in an internal combustion engine, the important role that the exhaust system plays in the engine had been remarkable, because it has been known that about forty percentage of the fuel energy escapes through the exhaust pipe and that a fair portion of this can be harnessed. For a long time, it has been known to engineers that the performance of an Internal Combustion Engine is materially affected by the configuration of its exhaust system. The general belief is that the one and only important point in designing an exhaust system is to reduce the backpressure to a minimum. The term "back pressure" is used to mean the resistance offered by the exhaust system to the outward flow of exhaust gases. So naturally, the tendency has been to use pipes of larger dimensions. But more recent investigations have shown that there are additional factors coming into the picture.

A.Exhaust System

The primary function of an exhaust system is to discharge the exhaust gases from the engine to a point where its rejection will not be objectionable and release it with a minimum backpressure on the engine. The exhaust system of the engine consists of an exhaust pipe extending from the engine to a silencer for damping the exhaust pressure waves, called the primary pipe and a tail pipe or a stack pipe, also called the secondary pipe.

The discharge of the exhaust gases from an engine cylinder gives rise to a vacuum at the exhaust valves. Two distinct phenomena are responsible for the above vacuum, first a sufficient sudden discharge from the cylinder gives rise to a fall of pressure below atmosphere at the exhaust valve, secondly the pressure pulse which was generated by the exhaust blow down of the engine in the exhaust system, travels from the cylinder end and gets reflected back at the free end of the exhaust pipe as a rarefaction wave to the valve end and it is once again reflected back without any change in the sign but with reduced magnitude. Thus the wave fluctuates between positive and negative values of pressure in the exhaust system. This pulse will start the gases in the pipe vibrating with a frequency dependent on the dimensions of the pipe and on the temperature of the gases themselves. The process of wave formation depends on the production of reflections of the original pulse from either end of the pipe. The time interval between each

successive reflection, which has a great influence on the shape of the final net pressure wave, is governed by the time taken by a pulse to travel from the exhaust orifice to the far end of the exhaust pipe and back again.

II.NOISE IN DIESEL ENGINES

Sound waves are a particular form of the general class of waves known as elastic waves. Elastic waves can occur in any medium having mass (inertia) and elasticity. Elasticity tends to pull the displaced particle to its equilibrium position. Because of its inertia, the displaced particle transfers momentum to adjoining particles. Noise is a mixture of various sounds, which is a source of irritation for the listener. A vibrating object creates the sound. The vibrations are transmitted to the surrounding air in the form of pressure waves. If the frequency and intensity of the pressure waves are within the specified range, they produce a sensation of sound (15-15000 Hz, 0-120 dB intensity).

The major sources of noise in diesel engine are enumerated as follows:

a) Exhaust noise: It is caused by the sudden release of the burnt gases at high temperature and pressure
b) Intake noise: It is produced by the oscillation of the air column in the intake system due to both the opening and closing of the inlet valves
c) Engine noise: It is generated because of the distortions of the engine cylinder structure by the explosive nature of the cylinder –gas pressures. This noise is increased as the compression ration and combustion pressure increase. When the engine weight is reduced this noise is further exaggerated
d) Fuel Injection Equipment Noise: The extremely sharp rise of pressure and sharp cut-off in the fuel injection system which are essential for the high combustion efficiency are the root cause of this noise
e) Piston Slap: It is introduced due to the clearance left between the piston and the bore to account for the expansion for the metals
f) Noise due to valve gear train: This is due to the play and knocking between the mating parts of the several mechanisms of the engine.

A.Exhaust Noise

The exhaust noise is the predominant of the engine noise when the exhaust is left unsilenced. The periodic noises emanating from the exhaust system can be classified into two groups:

1. Mechanical vibration of pipe work, silencer and its mounting
2. The acoustical oscillations of the gas contents of the exhaust system.

The above two groups of exhaust noise are quite different and must be treated by different approaches:

1. Origin of exhaust noise
2. Phenomenon of exhaust noise

In general, the methods of suppressing noise may be classified into three categories:

1. Noise reduction at the source
2. Noise control of the transmission path
3. The use of noise productive measures at the receiver

Choosing one of the above methods depends upon the amount of noise reduction, and on economic and operational consideration.

B.Measurement of Exhaust Noise

Engine exhaust noise can be measured by using a sound level meter. The sound level meter consists of an amplifier, alternator, microphone, weighting network, rectifier and indicating meter, etc., To measure the sound level, the meter is first placed before the source, here the engine exhaust pipe, at a distance of 0.5 to 1 meter apart in order to prevent the meter from any damage due to the exhaust from the engine. The sound is converted into electrical signal by means of the micro phone and is amplified by the amplifier, the amplified signal is sent to the weighting network where the range fixed according to the source sound intensities is set and amplified signal is measured and displayed in the indicating meter through rectifier. There are three different sound level scales like dB(A), dB(B), dB(C) for different ranges of sound intensities. Depending upon the sound intensity of the source the scale should be selected and the values are measured.

C.Particulate Trap

An exhaust treatment technology that substantially reduces diesel engine particulate emissions is the trap oxidizer. A temperature- tolerant filter or trap removes the particulate material from the exhaust gas: the filter is then cleaned off by oxidizing the accumulated particulates. This technology is difficult to implement because:

1. The filter, even when cleaned, increases the pressure in the exhaust system
2. This pressure increases steadily as the filter collects particulate matter
3. Under normal diesel engine operating conditions, the collected particulate matter will not ignite and oxidize
4. Once ignition of the particulate occurs, the burn up process must be carefully controlled to prevent excessively high temperatures and trap damage or destruction.

Trap oxidizers have been put into production for light duty automobile diesel engines. There use with heavy-duty diesel engines poses more difficult due to higher particulate

loading and lower exhaust temperatures. The various types of particulate traps are:

1. Wire mesh particulate trap
2. Silica fiber candle particulate trap
3. Ceramic foam trap and
4. Porous ceramic honeycomb particulate trap.

The following are the diesel particulate trap requirements:

1. Reduction in exhaust noise level
2. Adequate collection efficiency of about 80%
3. Low – pressure drop to ensure minimum loss in fuel economy and performance
4. Low-pressure rise rate and minimum volume of packaging
5. High temperature capability to withstand regeneration (particulate oxidation).

III. DESIGN OF PARTICULATE TRAP

A. Design Calculation

The trap is designed based on the amount of exhaust gas flow, the displacement volume of the cylinder, number of cylinders, the rated speed of the engine and the bore to stroke ratio. Based on the above parameters the particulate trap volume, V_{PT} is calculated as follows.

$$V_{PT} = \frac{n K V_{DISP}}{N} \qquad \text{-- 1}$$

Where, V_{PT} = Particulate trap volume in m^3

n = number of cylinders

k = a constant = 15000

V_{DISP} = displacement volume of the cylinder in m^3

N = Rated speed in rpm

Displacement volume of one cylinder is given by,

$$V_{DISP} = (0.7854) B^2 S \qquad \text{- - - - (2)}$$
$$= (0.7854) (0.0889)^2 (0.127)$$
$$= 0.00078831 \ m^3$$

Number of cylinders, n = 1
Rated speed, N = 2000 rpm
Constant, K = 15000

By the eqn. (1), $V_{PT} = \dfrac{n K V_{DISP}}{N}$

$$= (1) (15000) (0.00078831) / (2000)$$
$$= 0.00591233 \ m^3$$

Also the trap volume is given by

$$V_{PT} = 0.785 D^2 L \qquad \text{- - - - (3)}$$

Where L and D are length and diameter of the trap in m respectively.

Let us assume $r = L/D$

Then the trap diameter is given by the formula,

$$D = \sqrt[3]{\frac{V_{PT}}{0.7854 \ r}} \qquad \text{- - - (4)}$$

where, $r = L / D$

The value of r can be in the range of 2 to 6.

Let us assume that the ratio, r = 4

Therefore, by the eqn. (3)

$$D = \sqrt[3]{\frac{0.00591233}{(0.7854) (4)}} \qquad \text{- - - - (5)}$$

$$= 0.1235 \ m$$

Then, L = 4 D
= 4 (0.1235)
= 0.494 m

Therefore the trap dimensions are approximated as follows:

Trap length, L = 0.494 m

Trap diameter, D = 0.1235 m

The sectional view of the particulate trap is as follows:-
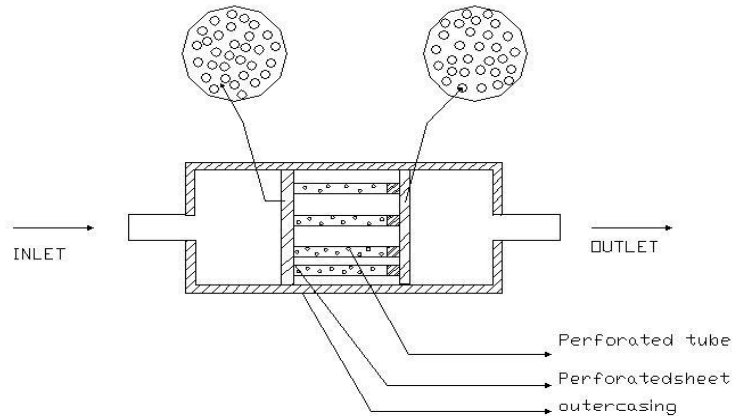

Fig.1 The sectional view of the particulate trap

IV.CONTROL OF PM AND NO$_X$ USING CATALYSTS

The accumulation of particulates on the surfaces of the exhaust pipe can increase the exhaust backpressure. The increase in exhaust back pressure can have an adverse effect on maximum power of the engine and fuel economy. Therefore, to reduce the back pressure, the accumulated particulates on the exhaust pipe should be removed. The process of periodical removal of the particulates in the trap is called regeneration. The diesel particulates ignite generally at 500 deg. C to 600 deg. C. The particulates can be removed either by raising the exhaust gas temperature or lowering the ignition temperature of the exhaust gases. The most promising approach requires the use of catalysts (either as a coating inside the trap or as a fuel additive) in order to reduce the ignition temperature of the particulate matter.

The important criteria for the selection of catalyst material are the cost and its availability. The catalysts are classified as noble metal catalyst and transition metal catalyst. Metals such as palladium, platinum and rhodium are called as noble metals. Metals such as copper, iron and nickel are called as transition metals. Selection of a catalyst depends on the following factors:

1. High conversion efficiency
2. Effective for a wide range of temperature
3. Resistance to thermal shock
4. Cheap and readily available
5. Should not release any harmful product.

Keeping in view of the above factors, transition metal catalyst is selected for the present investigation. It is found from the literature that copper and iron catalyst show higher conversion efficiency than other catalysts. They can easily mix with other catalyst materials making it possible to have bimetallic coating. The bimetallic catalyst coating can be divided into two groups:

1. Copper based catalyst
2. Iron based catalyst.

V.CONCLUSION

From the experimental investigation on the after treatment of the exhaust gas from an DI diesel engine, the following conclusions are drawn for the particulate trap and compared with the muffler:

Noise Level: The noise level of the engine when it is fitted with particulate trap is reduced by 16 dB as a maximum value at full load and by 10 dB as a minimum value at 40% loads. Using the muffler, the exhaust noise is reduced by 8 dB at load and by 4 dB at load. Thus, the particulate trap gives a maximum of 5% noise reduction than muffler.

Back Pressure: The particulate trap develops a maximum backpressure of 57 mm of Hg at 80% load which is 16 mm of Hg more than the base line. But in the case of muffler a backpressure of 47 mm of Hg as the maximum value at the same load is noted which is 5 mm of Hg greater than that of base line. Thus, the backpressure for the engine with particulate trap is 28% higher than that of muffler.
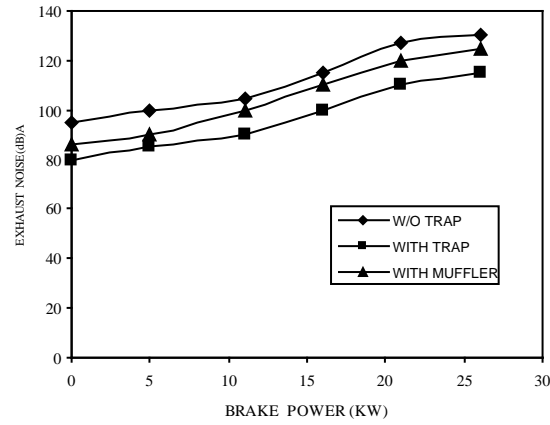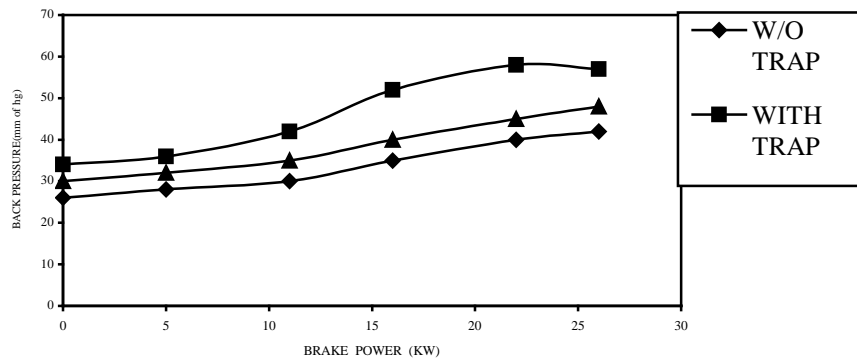
Fig 2 Variation Of Noise Level With Brake Power

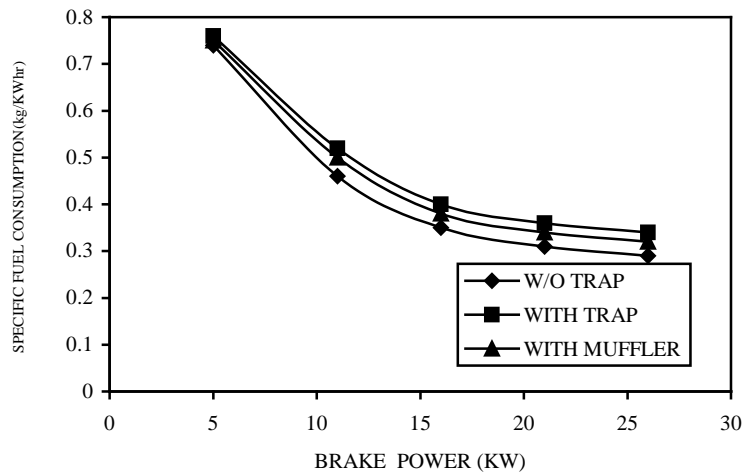Fig 3 Variation Of Back Pressure With Brake Power

Fig 4Variation Of Brake Specific Fuel Consumption With Brake Power

Brake Specific Fuel consumption: The brake specific fuel consumption for the particulate trap is 0.768 kg/kw-hr at low load as the maximum value, which is 0.018 kg/kw-hr higher than that of the base line, and the maximum value is about 0.039 kg/kw-hr at maximum load, which is 0.029 kg/kw-hr higher than that of the base line. For muffler, the specific fuel consumption is 0.759 kg/kw-hr at low load and 0.298 kg/kw-hr at high load. Thus BSFC for engine with trap is 5% higher than that of muffler at maximum load.

VI. FUTURE WORK

1. Different sound absorbing materials such as rubber, fiber, fabric, etc., can be used to study the effect on the reduction of noise, by packing on the inner surface of the substrate of the particulate trap and can be analyzed for different packing modes

2. A double wall sound barrier structures can be formed by placing a sound absorbing materials between the barrier walls. The inner wall can also be made of absorbing material that can be studied and analyzed.

3. The trap itself can be produced using different recyclable sound absorbing material such as polyester fabric fibers; phenol resins and polyethylene resin can be studied and analyzed.

4. The inner arrangement of the trap can be modified by analyzing the fluid dynamics of the exhaust gas flow and its effect on the reduction of noise can be studied.

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