REDUCING NOISE AND EMISSIONS OF AUTOMOBILES USING DIESEL PARTICULATE FILTERS

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ABSTRACT

This paper presents a new technology to reduce emissions and noise of exhausts of internal combustion engines using diesel particulate filters(DPF). Such devices used the principle of soot oxidation which consider as the main source of air pollution. The principle of this device which is similar to the catalyst is to oxidise the soot before it goes outside the exhaust system. The other main function for the DPF is to minimize noise by making noise reduction. It is found that Wave propagation through the DPF unit seeks of both attenuation and phasing shift, and both attenuation and phase shift damped as shear wave number increase. Both transmission loses and noise reduction factor for the typical filter and other types of DPFs are increasing as frequency increases. Transmission losses at the case of existing soot layer are higher than these with no soot layer. Transmission losses and NRF have a positive relationship with frequency, and wall thickness. Transmission losses and NRF have a negative relationship with porosity, number of channels per square meter, pressure drop, permeability, and channel width. There are many types of DPF it is found that - EX80:200/14 DPF type has the best capability of transmission losses, but EX80:100/17 DPF type has the lowest capability to do this, and this appears in all cases and conditions.

Keywords: noise, transmission losses, air-pollution, diesel particulate filters, noise reduction, oxidation.

1. Introduction

Sound is produced by something vibrating. It travels in all directions from the source as a pressure wave in the air, much the same as waves travel through water in a pond when a pebble is dropped into it. Sound waves travel through the air as alternating regions of compressed and rarified air. These changes in density are detected as small variations in pressure above and below the mean atmospheric static pressure. The effective sound pressure is the root mean square (rms) of the deviation in pressure over some time period. This sound pressure, by vibrating the inner ear, produces the sensation of hearing and determines the loudness of the sound as judged by the listener. Another attribute of sound is frequency, or the number of times per second that the sound pressure alternates above and below atmospheric pressure. Frequency is measured in cycles per second and has units of Hertz (Hz.). A frequency of 1000 Hz. means 1000 cycles per second. Airborne and Structure borne Sound Most noise is transmitted both as airborne and structure borne sound. For example, speech is airborne sound until it strikes a structure like a wall and becomes structure borne. Then by way of vibration, it is reradiated as airborne to the listener in an adjacent room or area. Sound travels through the air at a constant speed at a given temperature of air. The speed of sound is 1,125 ft. per second (on a average temperature day) or a little over one mile in 5 seconds. The speed at which it travels can be observed as the time lag between lightning and thunder, or as a delay in hearing an echo from a distant cliff or wall. As the sound wave moves outward, away from its source in all directions, the intensity of the wave decreases with distance from the source. Therefore, the sound or decibel level decreases in loudness as one moves away from the source. In fact, for every doubling of the existing distance between sound source and listener, the sound level decreases by 6 dB. Automobiles' engines are noisy they produced high number of dBs. They need to be controlled to reduce such noise.

One of the leading technologies for meeting future particulate matter (PM) emission standards is the diesel particulate filter, or DPF; figure (1) below. These devices generally consist of a wall-flow type filter positioned in the exhaust stream of a diesel vehicle. As the exhaust gases pass through the system, particulate emissions are collected and stored. Because the volume of diesel particulates collected by the system will eventually fill up and even plug the filter, a method for controlling trapped particulate matter and regenerating the filter is needed.

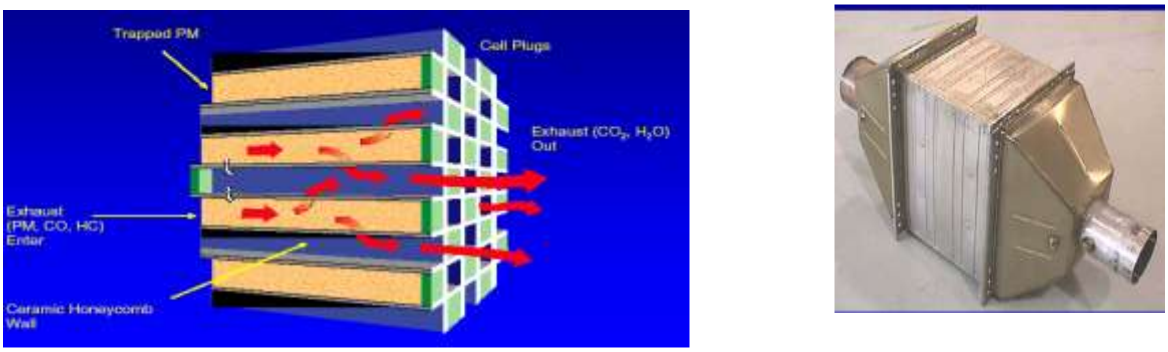

Figure 1: DPF and its work principle.

2. Noise reduction factor

Sound absorption is a process in which energy of sound is converted partly into heat (by frictional and viscous resistance of the pores of acoustical materials like porous materials (DPF unit) and partly into mechanical vibration of the materials. There are many types of equipment to absorb sound such as Helmholtz resonanators and resonator- panel absorbers which are considered as efficient tools for sound absorption at their resonant frequencies. Mufflers and DPF impede the transmission of sound but permit the free flow of air.

The sound absorption coefficient α of a material is defined as the decimal fraction of perfect absorption that it has, e.g. α=0.6 means 60% absorption. It is the efficiency of a material in absorbing sound energy at a specified frequency, and varies with the angle of incidence and the thickness of the material, also $\alpha_{Space} = 1$.

Absorption coefficient (α) is obtained by statistically averaging the ratio of absorbed to incident energy over all possible angles of incidence. The average sound absorption coefficient α' is determined by averaging the absorption coefficient over all the absorbing areas. One of efficient tool to distinguish between different types of DPF units is the use of **noise reduction factor (NRF)** which is given by:

$$NRF = TL + 10\log(\frac{\alpha}{A}) \qquad (1)$$

where A is the area of the partition. (m^2), Anechoic chamber (termination) is characterized by highly absorptive wedges or long pyramids mounted to the walls of the DPF to absorb all incident sound energy.

The decoy of sound intercity in an anechoic termination is given by

$$I(t) = I_0 e^{(AC/AV)(1-\alpha')t} \qquad (2)$$

where Io is the sound intensity in watts/m2 when the source shut off, A is the total area of wall in m^2, V is the volume of DPF unit, α' is the average sound absorption coefficient.

-Speed of sound
The speed of sound is the speed of propagation of sound waves through the given medium. The speed of sound in air is

$$C = \sqrt{\gamma P / \rho} \quad (3)$$

where: γ is the ratio of the specific heat of air at constant pressure to that at constant volume, P is the pressure in (pa), ρ is the density in kg/m^3.

-Transmission losses (TL)
It is the difference between the sound power incident on the DPF unit and that transmitted down stream into an anechoic termination. It can be given as

$$TL = 10 \log (Wi/Wt) \quad (4)$$

For DPF unit

$$TL = 20 \log (0.5 |TDPF|) \quad (5)$$

Where: TDPF is the transformation matrix.

-Noise Reduction factor NRF
Noise reduction factor is the difference in sound pressure levels LP at two arbitrary selected points in the exhaust pipe and tail pipe. It doesn't need or require an anechoic termination because it uses the standing wave pressures.
Noise reduction factor can be given as

$$NRF = LP_2 - LP_1 = 20 \log \frac{P_2}{P_1} \quad (6)$$

or

$$NRF = TL + 10 \log \frac{\alpha}{A} \quad (7)$$

-Sound damping
The sound damping compound causes the vibrational energy to be converted into heat. If this is accomplished, the need to absorb and attenuate airborne noise with sound absorption and sound blocking materials is reduced. Vibration sound damping is also used to improve the sound quality of a product. The reduction of resonant vibrations leads to a decrease in tinniness for items made from a light gauge sheet metal.

Results
Figure (3) represents the TL of different types of DPF against frequency with soot layer, it can be noticed that EX80:200/14DPF type has the best capability of transmission losses, but EX80:100/17 DPF type has the lowest capability to do this. Figure (4) shows noise reduction factor (NRF) against frequency for different types of DPF unit, with no soot layer, it can be noticed that EX80:200/14 filter type has the best capability in noise reduction comparing with other types. In the same way figure (5) proves this but with soot layer. Figure (6) shows the TL versus frequency for the typical DPF unit in hot condition, time harmonic variation case compared with results given by Allam (2006), with no soot layer, and M=0.02. From the figure a full agreement can be noticed between the proposed study and that given by Allam (2006). Figure (7) represents the relation between NRF and frequency (w), at no soot layer and with soot layer respectively. From last two figures it can be noticed that EX80: 200/14 DPF unit type is the best type in noise reduction, while RC: 200/20 DPF unit type is the less efficient type in noise reduction operation.

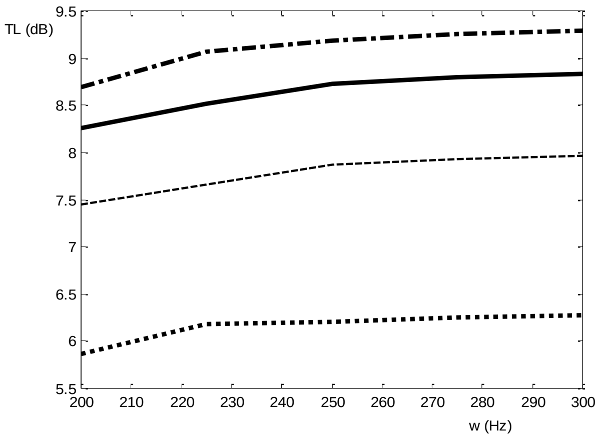

Figure 3: transmission losses vs. frequency,¯¯¯¯ for RC:200/12, -.-.-.for EX80:200/14, ……..for EX80:100/17, and----- for RC:200/20 DPF unit type in the case of cold conditions (With soot layer), and Mach=0.02.

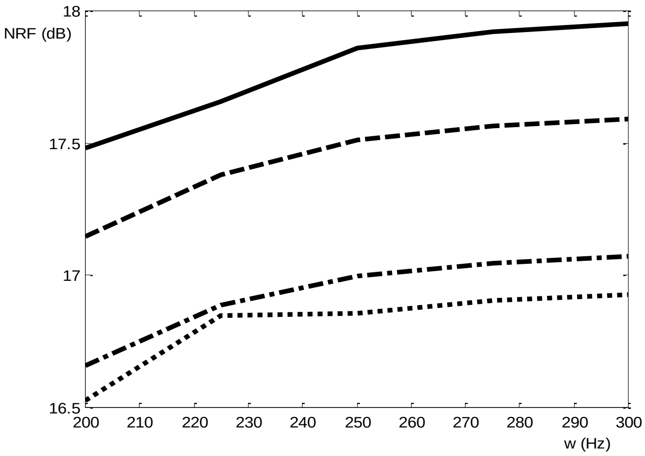

Figure 4: NRF vs. frequency, ------for RC: 200/12, ¯¯¯ for EX80:200/14, -.-.-.-.- for EX80:100/17, and……..for RC: 200/20 DPF unit type in the case of cold conditions (With no soot layer), and Mach=0.02.

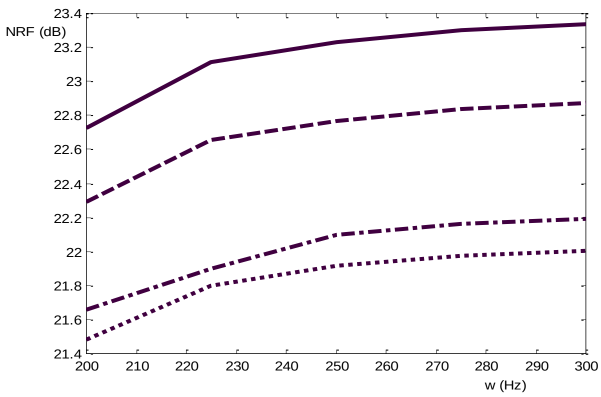

Figure 5: NRF vs. frequency, ------for RC: 200/12, ¯¯¯ for EX80:200/14, -.-.-.-. for EX80:100/17, and……..for RC: 200/20 DPF unit type in the case of cold conditions, (With soot layer), Mach=0.02, and cold conditions.

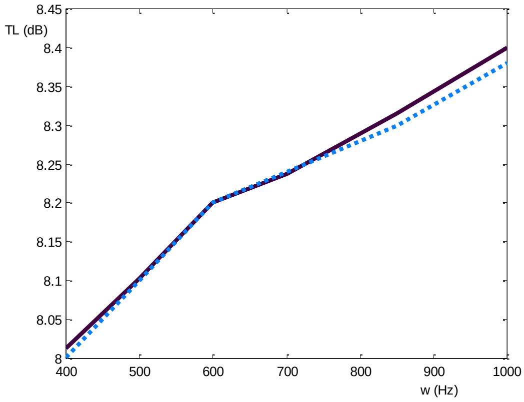

Figure 6: transmission losses vs. frequency in the case of hot conditions compared with last recent study [Allam], ----- for Allam, while—— for the proposed study, (Without soot layer) and Mach=0.02, for typical filter.

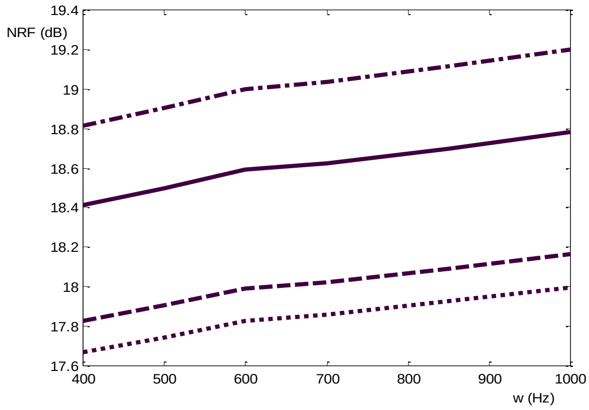

Figure 7: NRF vs. frequency,—— for RC: 200/12, -.-.-. for EX80:200/14, ----for EX80:100/17, and……..for RC: 200/20 DPF unit type in the case of cold conditions, (With no soot layer), and Mach=0.02.

3. Conclusions

The main conclusions can be summarized as follows:

-Wave propagation through the DPF unit seeks of both attenuation and phasing shift, and both attenuation and phase shift damped as shear wave number increase. Both transmission loses and noise reduction factor for the typical filter and other types of DPFs are increasing as frequency increases. Transmission losses at the case of existing soot layer are higher than these with no soot layer. EX80:200/14 DPF type has the best capability of transmission losses, but EX80:100/17 DPF type has the lowest capability to do this, and this appears in all cases and conditions.Transmission losses and NRF have a positive relationship with frequency, and wall thickness. Transmission losses and NRF have a negative relationship with porosity, number of channels per square meter, pressure drop, permeability, and channel width.

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