Design of Reactive Muffler for Study on the Noise Level and Performance of a Two Cylinder Four Stroke 16 H.P Diesel Engine

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KEYWORD:
Wave equation, Separable variable, Muffler, Reactive Muffler, Decibel

ABSTRACT:
A pollutant of concern to the mankind is the exhaust noise in the internal combustion engine. However this noise can be reduced sufficiently by means of a well designed muffler. The suitable design and development will help to reduce the noise level, but at the same time the performance of the engine should not be hampered by the back pressure caused by the muffler.
The authors designed and fabricated a reactive muffler and afterward compared the noise level, Brake thermal efficiency and Brake Specific Fuel Consumptions with the existing muffler and the modified designed and fabricated muffler.

NOMENCLATURES:

BSFC	Brake Specific Fuel Consumption
BP	Brake Power
c	Speed of sound
db	Decibel
f	Frequency of sound wave
L	Length of the muffler
N	Speed of engine
SPL	Sound Pressure Level
t	Time
$u(x,t)$	Pressure Difference
u_0	Initial Sound pressure level
ω	Angular Velocity

INTRODUCTION:
There are five different design criterion of mufflers design. These are Acoustical Criterion, Aero dynamical Criterion, Mechanical Criterion, Geometrical Criterion and Economical Criterion. The acoustical criterion which specifies the minimum noise reduction required from the muffler as a function of frequency. Aero dynamical Criterion specifies the maximum acceptable pressure drop through the muffler at given temperature and mass flow. The Mechanical criterion specifies the materials from which the muffler is fabricated or designed. So that it is durable and requires less maintenance. This is especially important in case of involving high temperature exhaust or corrosive gases or the gaseous flow is carrying solid particles in suspension that might be deposited on the inner surface of the wall of the muffler and reduces the muffler effectiveness. Geometrical Criterion specifies the maximum allowable value and restriction on shape. The Economical Criterion is vital in the market place. A muffler must be inexpensive as possible while designing initial cost as well as operating cost must be considered.

DESIGN OF INLET PIPE:

The diameter of the inlet pipe is taken same as the diameter of the exhaust port of the engine. The length of the inlet pipe is taken as small as possible so that muffler will occupy less space. There is no specific procedure for designing inlet pipe of the muffler. It is designed empirically.

DESIGN OF EXPANSION CHAMBER:

As expansion chamber is of reactive type. It is most effective at low frequencies. i.e. less than 500 c/s and m=10

$$m = \frac{Cross.sectional.area.of.the.expansion.chamber}{cross.sectional.area.of.circular.pipe}$$

i.e. $$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2}$$

where D = Diameter of the expansion chamber

d = diameter of the inlet pipe.

Here the diameter of the inlet pipe = 0.0635. i.e. d=0.0635m

m = 10 (assumed)

$$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2}$$

$$D^2 = md^2$$

$$D = (10)^{1/2} * (0.0635) = 0.20\ m$$

The normal practice is to adopt the length of the chamber 10 to 12 times the diameter of the exhaust pipe.

i.e. l = (10 to 12)d

let us take l = 12d, l = 12* 0.0635=0.762m

l = 0.75m (approximately)

Volume of the expansion chamber $$V_m = \frac{\pi}{4}D^2 * l = 0.785 * (0.2)^2 * 0.75$$

$$V_m = 0.02355\ m^3$$

Transmission Loss of the muffler:

$$TL = 10\log_{10}[1 + \frac{1}{4}(m - \frac{1}{m})^2 \sin^2 kl]$$

$$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2}$$

i.e. $$m = \frac{(0.2)^2}{(0.635)^2} = 9.920019$$

Adopt m =10

K = Sound Wave Number, $k = \frac{2\pi fl}{c}$

$$k = 2\pi f \ / 345 * [295 /(t + 273)]^{1/2}$$

$$k = 2(3.14)(500) / 345 * [295 /(300 + 273)]^{1/2}$$

k= 6.53

As this is reactive type muffler, it is effective up to 500c/s. Therefore f=500c/s is adopted.
Substituting the values of k, l and m in

$$TL = 10\log_{10}[1+\frac{1}{4}(m-\frac{1}{m})^2 \sin^2 kl]$$

we get $TL = 10\log_{10}[1+\frac{1}{4}(10-\frac{1}{10})^2 * \sin^2(6.53)(0.75)]$

$$TL = 13.92\ dB$$

It is stated that commercial mufflers are design and developed empirically to fit particular engine and usually call for specific length of pipes before and after the muffler in order to minimize loss of engine power and minimize the insertion loss in those part of frequency range where the loudness contributions of the source are greatest.

DESIGN OF OUTLET PIPE:

The outlet pipe dimensions are same as that of the inlet pipe. The outlet pipe is also termed as tail pipe. The diameter of the outlet pipe is taken as 0.0635m and length of the outlet pipe is 0.2 m.

MATHEMATICAL MODELING

The one dimensional wave equation is

$$\frac{\delta^2 u}{\delta t^2} = c^2 \frac{\delta^2 u}{\delta x^2} .... \quad ....(1)$$

Using boundary conditions

$$u = 0............at.........x = L.....and...\forall t...............(2)$$

$$u = u_0............at.........t = 0,.....x = 0...............(3)$$

$$\frac{\delta u}{\delta x} = 0.......... \ .... \ at .... \ ..x = 0.......... \ ......(4)$$

$$\frac{\delta u}{\delta t} = 0......... \ at .... t = 0 ....(0 \le x \le L)......... \ ..(5)$$

The solution of can be written in the form

$$u(x,t) = X(x)T(t)......... \ .... \ ....(6)$$

Substituting this values of u(x,t) in (1) we get

$$X'' - \mu X = 0.......... \ .... \ .(7)$$

$$T'' - c^2 \mu T = 0.......... \ .... \ .(8)$$

Using (2) we get $X(L) = 0$

Using (4) we get $X'(0) = 0$

For the solution of equation (7) three cases arises

Case-I

Let $\mu = 0$ then the solution of equation (7) is $X(x) = Ax + B$ and we get A=0 and B=0. So we reject $\mu = 0$

Case-II

let $\mu = \lambda^2 (\lambda \neq 0)$ Then the solution of equation (7) is $X(x) = Ae^{\lambda x} + Be^{-\lambda x}$

we get A=B=0

So we again reject $\mu = \lambda^2 (\lambda \neq 0)$

Case-III

Let $\mu = -\lambda^2 (\lambda \neq 0)$

Then we get $X(x) = A\cos \lambda x + B \sin \lambda x$

By using the conditions $X(L) = 0$, $X'(0) = 0$ we obtain , $A \neq 0$ $B = 0$ and $L\lambda = \frac{1}{2}(2n-1)\pi$ $n = 1,2,3,.........$ ....

Hence non-zero solution of equation (7) becomes

$$X_n(x) = A_n \cos \frac{1}{2L}(2n-1)\pi x$$

Now equation (8) becomes $T'' + \frac{1}{4L^2}(2n-1)^2 \pi^2 c^2 T = 0$

Whose solution is

$$T_n(t) = C_n \cos \frac{1}{2L}(2n-1)\pi ct + D_n \sin \frac{1}{2L}(2n-1)\pi ct$$

The general solution for the equation (1) becomes

$$u(x,t) = \sum_{n=1}^{n=\infty} [E_n \cos \frac{1}{2L}(2n-1)\pi ct + F_n \sin \frac{1}{2L}(2n-1)\pi ct] \cos \frac{1}{2L}(2n-1)\pi x$$ A

pplying boundary condition (3) we obtain $E_n = \frac{4u_0(-1)^{n-1}}{(2n-1)\pi}$

Again applying boundary condition (5) we obtain $F_n = 0$

Therefore the desired solution is

$$u(x,t) = \frac{4u_0}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos \frac{1}{2L}(2n-1)\pi ct . \cos \frac{1}{2L}(2n-1)\pi x$$

i.e

$$u(x,t) = \frac{2u_0}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} [\cos \frac{1}{2L}(2n-1)\pi (ct - x) + \cos \frac{1}{2L}(2n-1)\pi (ct + x)]$$

Therefore $u(x,t) = u_1(ct - x) + u_2(ct + x)$

Where $u_1(ct - x) = \frac{2u_0}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\frac{1}{2L}(2n-1)\pi(ct - x)$

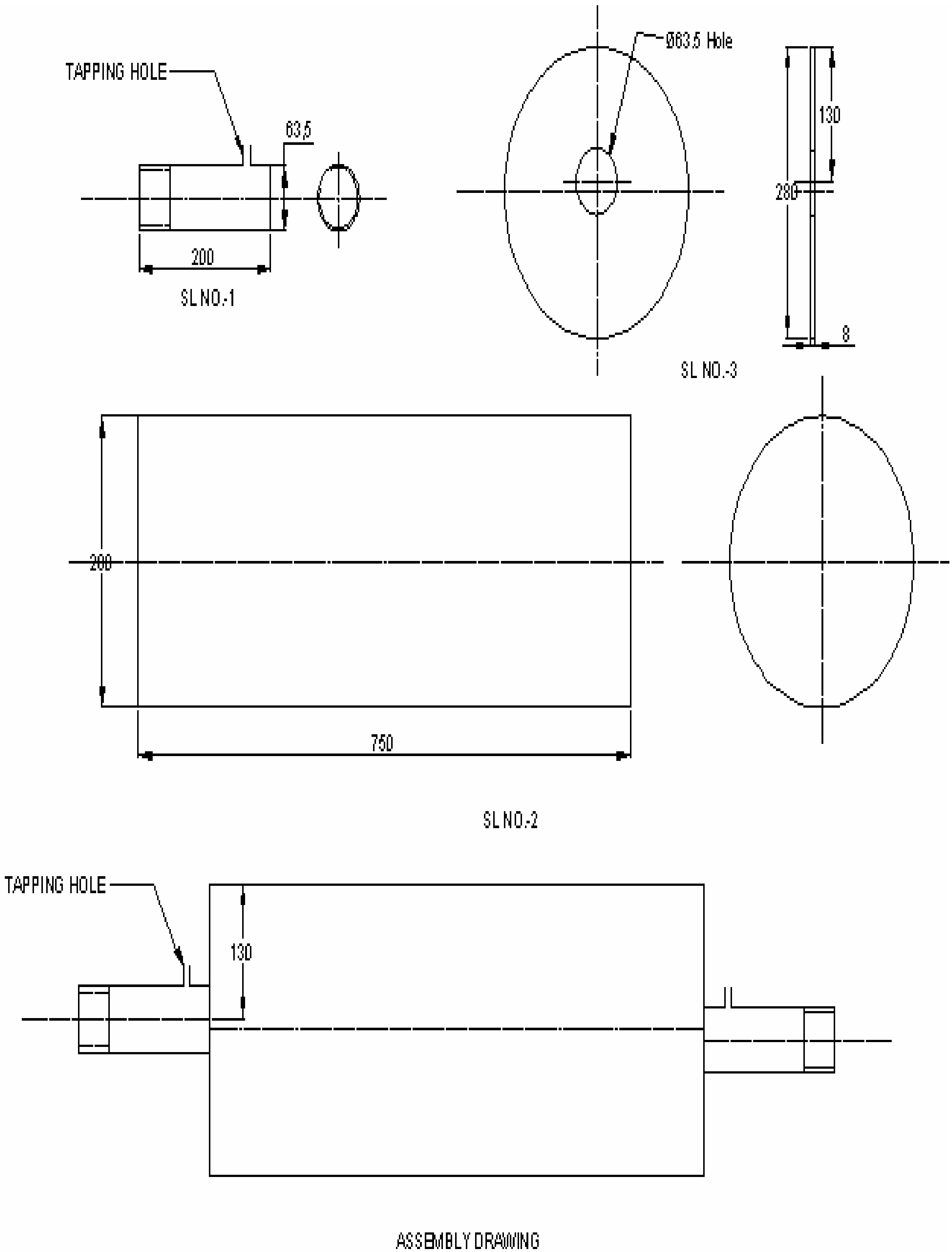
$$u_2(ct + x) = \frac{2u_0}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\frac{1}{2L}(2n-1)\pi(ct + x)]$$

$$u_2(ct + x) = 0$$

For positive going wave

i.e $u(x,t) = u_1(ct - x) = \frac{2u_0}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos\frac{1}{2L}(2n-1)\pi(ct - x)$

DESIGN:



TAPPING HOLE
63.5
200
SL NO.-1
Ø63.5 Hole
130
280
8
SL NO.-3
200
750
SL NO.-2
TAPPING HOLE
130
ASSEMBLY DRAWING

Fig.1

Sl. No.	Name	Quantity	Weight (Kg)	Thickness (mm)
1	**Inlet pipe**	1	0.5	2
2	**Cylindrical drum**	1	3.4	3
3	**Side wall of drum**	2	2.2	3
4	**Exhaust pipe**	1	0.5	2

FABRICATION OF REACTIVE MUFFLER:

Fig. 1 shows the details and assembly drawing of the reactive muffler. Component 1 is a M.S. pipe of 63.5mm φ and 200mm length. The wall thickness of the pipe is about 2mm. Component 2 is the hollow cylinder of 200mm φ and 750mm length. The hollow cylinder was prepared by cutting M.S. Plate of 3mm thickness as per given dimensions. The plate was bend to the truly cylindrical shape with the help of solid cylinder of 200mm φ and 750mm length. The edge of the plate was welded by electric arc welding. Component 3 is the cover plate. The two side cover plates were welded to the hollow cylinder, inlet and outlet pipes are welded to the cover plates as shown in the figure. Thus assembly of the reactive muffler was carried out as shown in the assembly drawing.

EXPERIMENTAL PROCEDURE:

The experimental set up is shown in the following figures.

Fig.2 : Experimental Set up

Fig.3 : Modified Reactive Muffler

The block diagram of the experimental setup is shown in Fig. 4 The set up is self explanatory.

The experiments were conducted in the I. C. Engine Laboratory of College of Engineering & Management Kolaghat, Purba Midnapore with the available facilities. The anechoic is not available in the college; hence all acoustic measurements were taken on relative basis instead of absolute basis. The background noise was measured before starting the experiments. All engines and other machines in the laboratory were shut down during testing of mufflers and also while measuring background noise. This will avoid local disturbances.

The sound level meter was used for measuring sound pressure level. The sound level meter was positioned at a distance of one meter away from the outlet of muffler and at an angle of 45^0. The meter was positioned at the same level that of flow of exhaust gas so that the noise level can be recorded effectively.

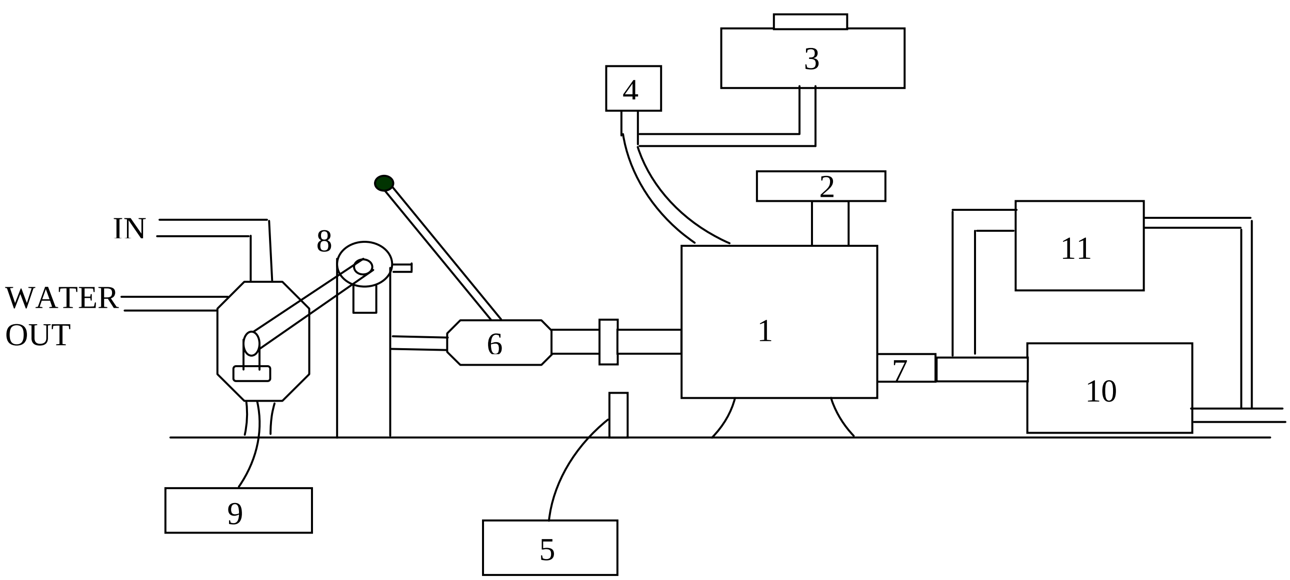
The 4- stroke diesel engine was started. The readings were observed at 1200 rpm, and different torque (loads) no load, 50 Nm, 100 Nm, 150 Nm, 200 Nm. The engine was operated at different load sand fixed speed. The measurement of fuel supply is recorded i.e. time was recorded for consumption of 50 ml of fuel from calibrated burette. The rate of fuel consumptions in Kg/hr was calculated. This data further helped in calculating BP and BSFC.

The sound pressure level was recorded before starting of engine or pump or dynamometer and keeping all the machines and engines of the laboratory in the shut off position. The background noise level was recorded. Room temperature was also recorded. Then sound pressure level was observed at above mentioned speeds and loads. This will helps in getting the signatures of the exhaust noise through the muffler at different speeds and different loads.

The metallic bulb of thermocouple was inserted in the outlet pipe of the muffler and exhaust gas temperature was recorded. The sound pressure level also depends on exhaust gas temperature.

The tube of water filled manometer was attached to inlet pipe and outlet pipe of the muffler. The drop of pressure across the muffler was recorded in mm in water. This data will help in calculating the amount of back pressure exerted on the engine. The experiment was repeated for all types of muffler i.e. reactive, existing and without muffler.

EXPERIMENTAL SETUP:



1.ENGINE 2.AIR FILTER 3.DIESEL TANK
4.DIESEL MEASURING BURRETT 5.SPEED INDICATER
6.CLUTCH 7.EXHAUST PIPE 8.HYDRALIC DYNAMOMETER
9.TORQUE INDICATOR 10.REACTIVE MUFFLER 11.MANOMETER

Fig 4 SCHEMATIC DIAGRAM OF EXPERIMENTAL SET UP

RESULTS AND DISCUSSIONS:

Fig. 5 represents the sound level Vs BP (KW) at 1300 rpm. When sound level is 114.2db by without muffler, at that time we get sound level 94.9 db in existing muffler, 81.3 db in our modified and fabricated muffler, 75.647 db by mathematical modeling. It is interesting to note down the variations between the sound levels percentage variation measured by modified and fabricated muffler & theoretical muffler is 6.95.

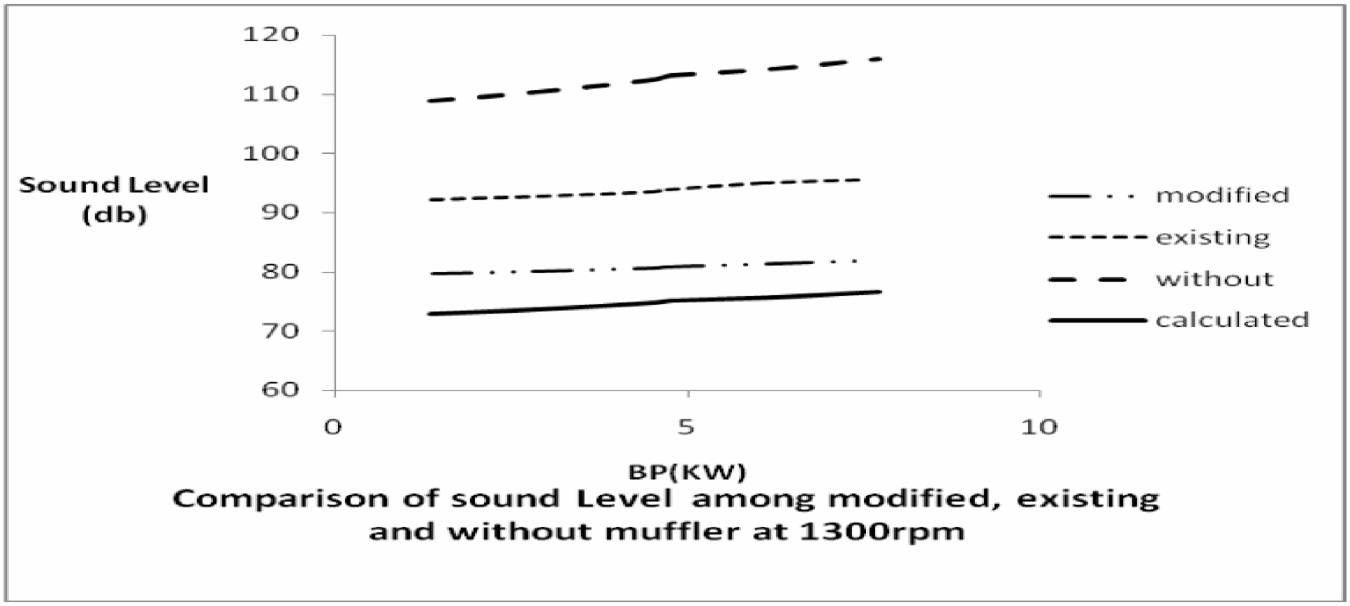


Fig. 5

Fig.6 represents the Comparison of Brake Thermal efficiency among modified, existing and without muffler at 1300 rpm. The maximum Brake Thermal efficiency without muffler, with existing muffler & with modified and fabricated mufflers are 26.3, 24.17 & 25.5 respectively. The Brake Thermal efficiency with modified muffler is little less than the without muffler, because of the higher pressure drop in case of modified muffler in comparison to without and existing mufflers.

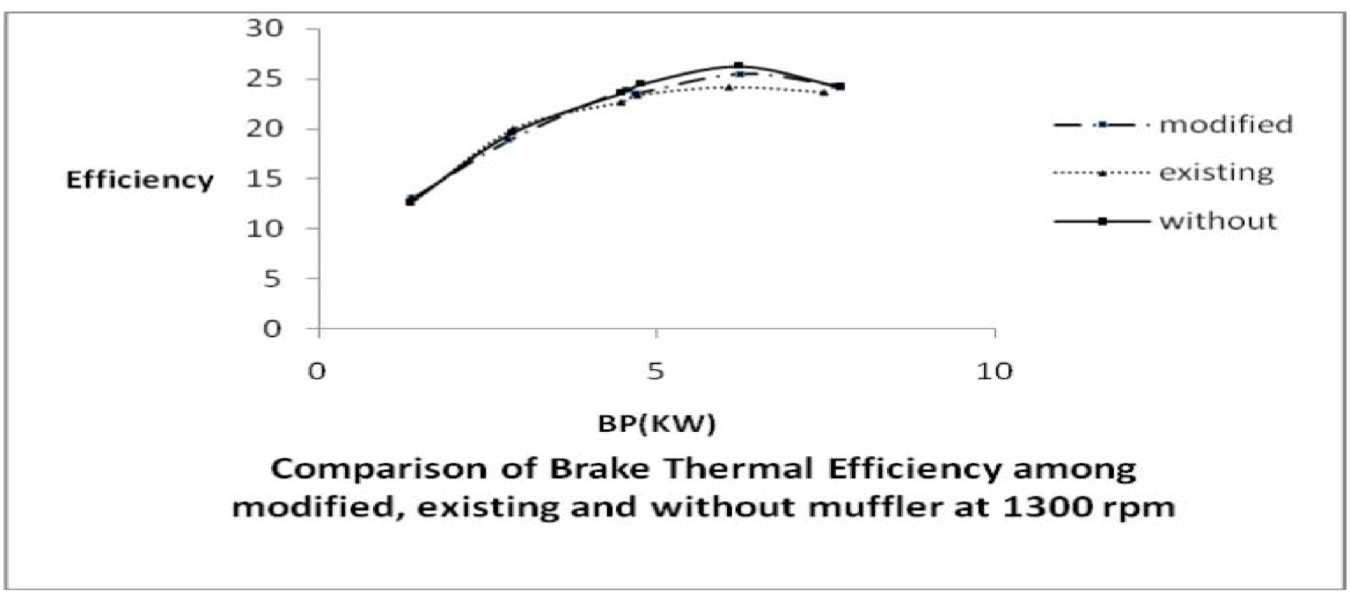


Fig.6

Fig.7 represents the comparison of BSFC among modified, existing and without muffler at 1300 rpm. Here we can see that BSFC is 0.32when it is without muffler. When we use existing muffler BSFC becomes 0.346. For modified and fabricated muffler BSFC is .328.

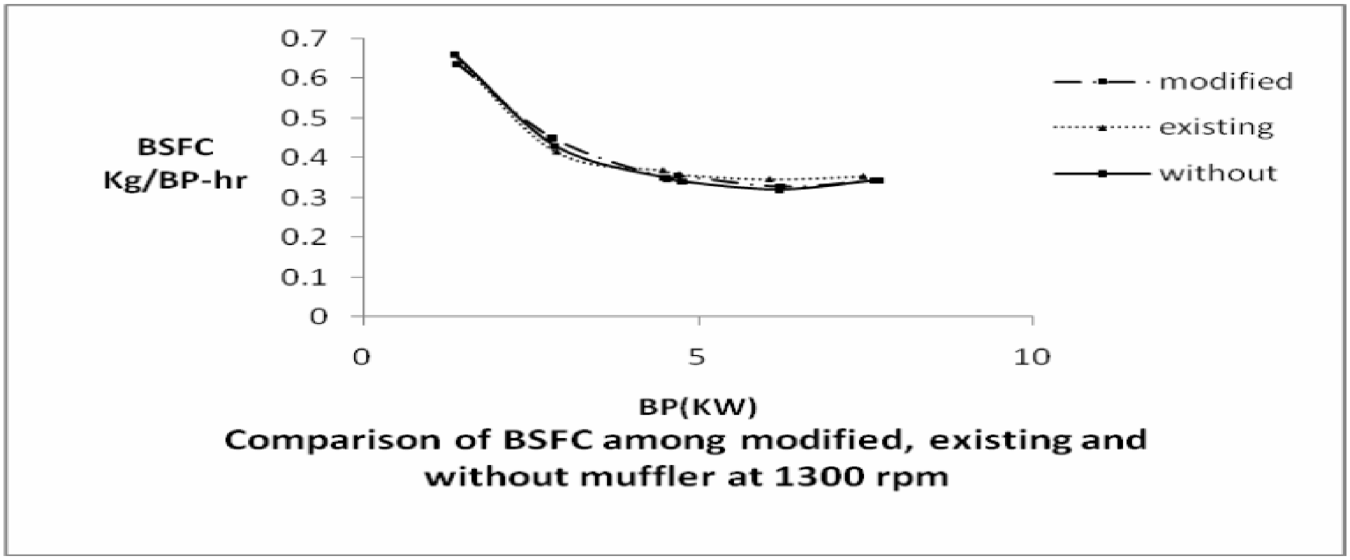


Fig.7

Fig. 8 represents the Drop of pressure at 1300 rpm with modified and existing muffler. It is interesting to note down that the pressure drop for modified fabricated muffler is higher than the existing muffler.

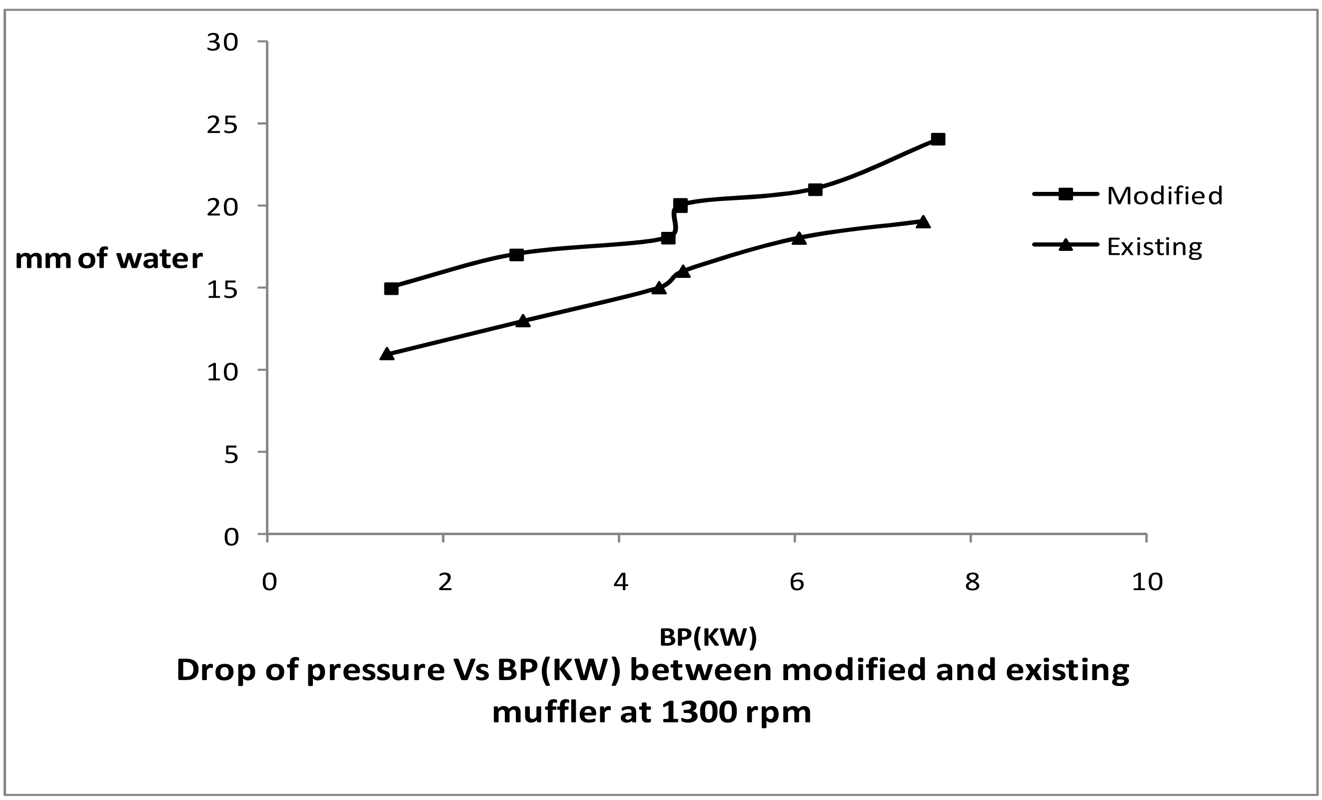


Fig.8

CONCLUSION:

From results and discussions the following conclusions are drawn:

1. Reduction of noise level is around 15db compared to existing muffler.
2. The Brake Thermal Efficiency of engine is higher for modified and fabricated muffler as compared to existing muffler.
3. The Brake Specific Fuel Consumption is low compared to existing muffler.
4. The Fuel Consumption is less compared to existing muffler.

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