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Noise Attenuation Characteristics of Exhaust Mufflers with Medium Size Farm Tractors

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ABSTRACT

Three mufflers viz., muffler A, muffler B and muffler C were evaluated for their noise reduction ability on two tractors of 23 kW pto power. The noise levels of the tractors were measured at operator's ear level at no load under laboratory condition, at no load on tar road during transport mode and during ploughing operation. The spectral analysis (one octave band) of noise levels was carried out in the frequency range from 31.5 to 16000 Hz. The noise levels increased at no load (under laboratory condition and at no load on tar road) at all the frequencies with the increase in engine speed. The highest noise level of the tractors at rated engine speed was observed at the frequency of 1 kHz with muffler A, muffler B, and existing muffler; and at 2 kHz with muffler C at no load under laboratory condition. The exhaust back-pressure increased with increase in engine speed at no load under laboratory condition for all the mufflers. The mounting of muffler B reduced noise levels by 4.1, 5.7 and 5.6 dB (A) on tractor-I and by 1.1, 1.4 and 4.0 dB(A) on tractor-II at 1000, 2000 and 4000 Hz frequencies, respectively as compared to the existing mufflers. It may be concluded that muffler B reduced noise levels considerably on both the tractors in conversational frequencies.

Human comfort is an important aspect associated with proper use of any machine. With the high degree of mechanization of farms along with increasing size and complexity of farm machinery, a safe and comfortable working environment for the operator becomes an important consideration if productivity and customer satisfaction are to be enhanced (Gerke and Hoag, 1981). Agricultural workers experience one of the highest rates of hearing loss among all occupations. This is caused in part by numerous potential sources of loud noise on the farm such as tractors, combines, grinders, choppers, ·ain dryers, and chain saws (Baker, 1993). It has long been recognized that the occupational hazards of tractor driving included deafness and disorders of the spinal column and stomach caused by noise and vibration. Prolonged exposure to excessive noise can cause permanent hearing loss unless noise control measures are taken. Previous investigations concluded that human beings are affected mentally, physically and socially by excessive noise levels (Irwin and Graf, 1979; Roth and Field, 1991; Crocker, 1998).

Research has been conducted on these aspects of tractor design for many years. In addition to affecting the health of the tractor driver, there is evidence that the discomfort of the working environment results in lowering of work output. Sharma and Shyam (1993) reported that vibration levels of different components of most of indigenous tractors did not meet the BIS requirement. However, the noise level of 31per cent of these new tractors met the requirement at operator's ear level.

Mehta *et al.* (1997) conducted a study to measure the noise levels on four tractors viz HMT 3511, HMT 2511, Ford 3600 and MF 1035 at CIAE under laboratory and field conditions. They observed the effect of different types of mufflers on noise levels of tractors. It was observed that the maximum sound pressure levels at operator's ear level on both the tractors at no load were within the recommended limit of 90 dB(A) for 8 h exposure time. The HMT 3511 tractor tested with conventional mufflers contributed considerably to high frequency noise reduction, but was not very effective in reducing low frequency noise. The exhaust back pressure increased with increase in engine speed. The maximum sound pressure versus octave band frequency curves at rated engine speed indicated that sound pressure level was highest at 4000 Hz frequency. It was concluded that the tractor noise was predominant at low and medium frequencies for different mufflers.

Depczynski *et al.* (2005) conducted farm visits on 48 agricultural establishments that produce a range of commodities. Noise levels were measured at the ears of

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operators and bystanders involved in typical activities on farms. The average and peak noise levels were measured for 56 types of machinery or sites of farming activity, totalling 298 separate items and activities. Common identified noise hazards included firearms, tractors without cab, workshop tools, small motors (e.g., chainsaws, augers, and pumps), manual handling of pigs, shearing sheds, older cabbed tractors, and heavy machinery such as harvesters, bulldozers, and cotton module presses.

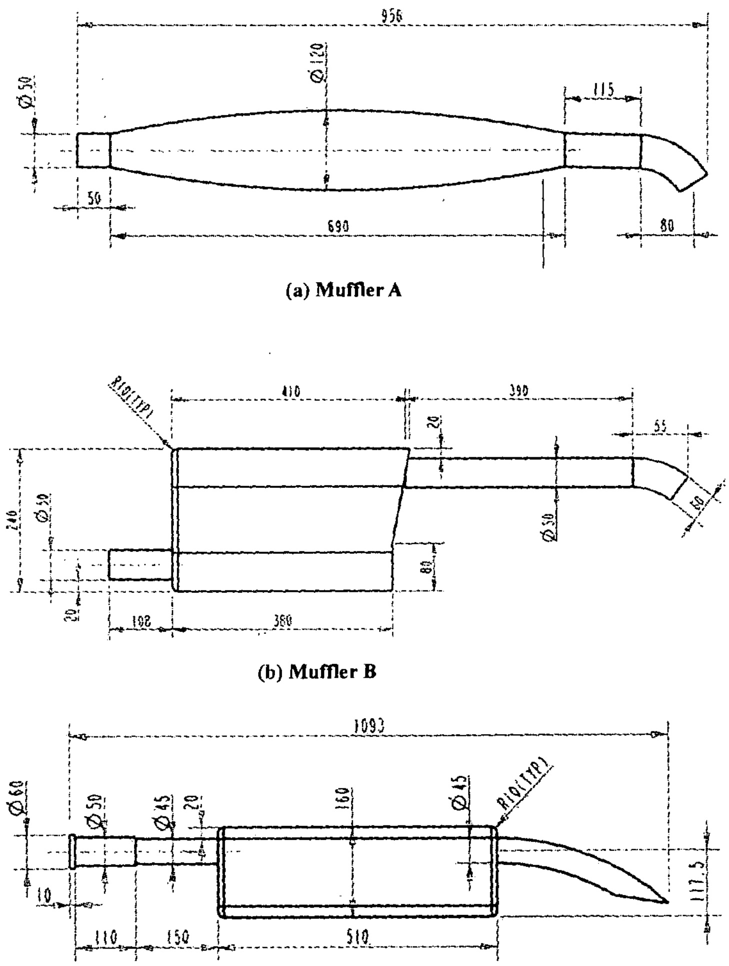
Crocker (1972) investigated tractors and other agricultural equipment and machineries for their emitted noise level and noise production sources. Stangl *et al.* (1973) developed a technique to evaluate potential means of reducing tractor's exhaust noise. They reported that tractor noise typically exceeded conversational limits. Its major source on the tractors without cabs is usually the engine exhaust system.

Noise injury in agriculture is a significant yet often unrecognized problem. Many farmers, farm workers, and family members are exposed to noise levels above recommended levels and have greater hearing loss than their non-farming contemporaries. Tractor operators are subjected to noise and vibration levels that are hazardous to health and deleterious to performance (Simpson and DeShayes, 1969). Even with a muffler in place, exhaust noise usually proves to be the major source of tractor noise (Rowley, 1967). Better noise control features in tractors make their use comfortable for the operator and agricultural workers. Therefore, initial efforts at tractor noise reduction should investigate exhaust muffler improvements. The present paper deals with the noise propagation trends in different makes of mufflers.

MATERIALS AND METHODS

Selection of Tractors and Exhaust Mufflers

Three mufflers viz Muffler A, Muffler B and Muffler C (Fig. 1) of different designs were selected and evaluated on two 23 kW pto power tractors (Tractor I and



(a) Muffler A

(b) Muffler B

(c) Muffler C

Fig. 1: Different designs of mufflers tested on selected tractors

Tractor II). The expansion chambers of these three mufflers were of different designs and shapes. The areas of expansion chamber of muffler A, muffler B and muffler C were 0.59, 0.95 and 0.82 m^2, respectively. The existing muffler on tractor–I had 47 m^2 area of expansion chamber and was of the same shape as that of muffler A. Similarly, the existing muffler on tractor–II had 68 m^2 area of expansion chamber and was of the same shape as that of muffler C. The important specifications of the selected tractors are given in Table 1. Both the tractors had three cylinders, four stroke, direct injection, water-cooled diesel engines.

Instrumentation

The noise level was measured by modular precision sound level meter type 2231 using integrating SLM module Z 7110 (Bruel & Kjaer, Denmark). The 12.5 mm pre-polarized condenser microphone type 4155 was used as a transducer. The octave filter set type 1624 (Bruel & Kjaer, Denmark) confirming the requirements of IS 6964 (1973) was used for frequency analysis of the noise levels. The sound level meter meets the requirements of IS 3931 (1966). The exhaust back-pressure was measured by U-tube manometer (mercury column) at no load under laboratory condition.

Operating Conditions

The sound level meter was calibrated before the start of the tests. The values were measured in A-weighted scale, which were expressed in decibel. The spectral analysis (one octave band) of noise levels was carried out for the frequency range from 31.5 Hz to 16,000 Hz. The wind velocity at the microphone height was less than 5 m/s. The level of background noise was at least 10 dB (A) below the level measured during the test. The test area was a flat and open space, and it was ensured that within at least 20 m of the test tractor, there was no obstacle likely to reflect the significant sound, such as building, a solid fence, etc. The tractors were unballasted and the tyres were not worn more than 50%. The noise level at operator ear level of tractor operator was measured by placing microphone 200±20 mm to the side of the centreline of the seat. The microphone diaphragm faced forward and the centre of the microphone was 790±50 mm above the seat reference point (SRP) and 150±20 mm forward of SRP on tractor seats (IS 11806, 1986).

Test Procedure

The equivalent noise levels (L_{eq}) at operator's ear level were measured on both the tractors with selected mufflers at no load under laboratory condition, at no load of tractor on tar road during transport mode and during ploughing operation with two bottom mould board plough. The noise levels were measured in accordance with the procedure of IS 12180 (Part 1 and 2) [2000].

The exhaust system noise of tractors at no load under laboratory condition was measured by positioning the microphone with windscreen 150 mm beyond the exhaust outlet and 150 mm from the outside diameter of the pipe (measured along a radius directed toward the rear of the tractor) to isolate other noise sources. The microphone diaphragm was perpendicular to a line joining it and the exhaust outlet. The noise level at operator's ear level of tractors was measured at no load on tar road during transport mode on a test track of minimum length of 150 m to ensure that speed of the tractor was stabilized. The measurements were made in each gear with the governor control lever fully open. Forward speed of travel was measured by timing the tractor between marks

Table 1. Important specifications of tractors used in the study

Description	Tractor - I	Tractor - II
Model	1991	1986
Type	Four stroke, direct injection, water cooled, diesel engine	Four stroke, direct injection, water cooled, diesel engine
PTO power, kW	23.0	22.1
Stroke, mm	110	127
No. of cylinders	3	3
Volume of cylinders, cc	2340	2365
Rated speed of engine, rpm	2000	2000
Specific fuel consumption, g/kWh	281	313
Tractor weight, kg	1725	1520

at the beginning and end of each run of 100 m using a digital stop watch. The noise level on tractors during ploughing operation was measured at operator's ear level for a test run of 35 m. All the observations were replicated at least thrice. The three consecutive measurements falling within 3 dB (A) were considered for analysis IS 12180 (Part 1) [2000].

The exhaust back pressure was measured at no load under laboratory condition on two tractors viz. Tractor- I and Tractor – II by mounting three mufflers and existing muffler. The exhaust back pressure was tapped 150 mm above the exhaust manifold of tractors.

RESULTS AND DISCUSSION

Noise Levels At no load under laboratory condition

The measured noise levels at operator ear level on both the tractors with different mufflers are reported in Table 2. It was observed that the noise levels increased with increase in engine speed from 660 to 2410 rpm with different mufflers on both the tractors. On Tractor-I, the noise levels increased from 72.9 to 91.2 dB (A), from 74.6 to 89.1 dB (A), from 73.2 to 93.0 dB (A), and from 74.1 to 93.9 dB (A) with Muffler A, Muffler B, Muffler C, and existing muffler, respectively, with the increase in engine speed from 660 to 2410 rpm at no load under laboratory condition. On Tractor-II, the noise levels increased from 70.8 to 94.5 dB (A), from 70.4 to 95.2 dB (A), from 67.2 to 95.7 dB (A), and from 64.7 to 106.0 dB (A) with Muffler A, Muffler B, Muffler C, and existing muffler respectively, with the increase in engine speed from 660 to 2410 rpm at no load under laboratory condition. The measured noise levels exceeded the recommended limit of 90 dB (A) for 8 h on tractor-II with muffler C and existing muffler at 2000 rpm and above. However, the noise levels on both the tractors with different mufflers exceeded the 90 dB (A) limit at 2200 and 2410 engine rpm. Fig. 2 shows that the measured noise levels on tractor-I are lower as compared to those on tractor-I with different mufflers except with muffler B. This may be due to that the tractor–II is much older and in poor operating condition as compared to tractor–I.

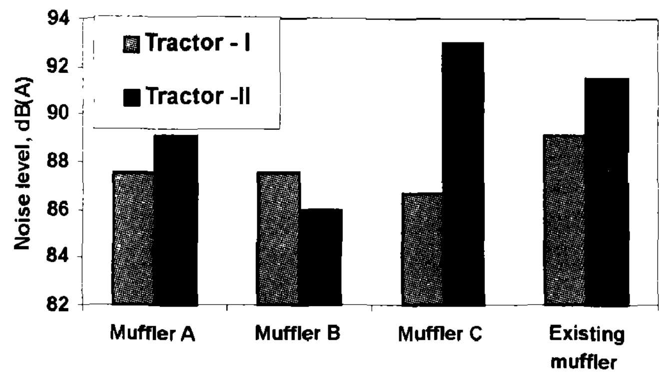


Fig. 2: Noise levels on tractors with different mufflers at no load under laboratory condition

At no load on tar road during transport mode

The measured noise levels at operator ear level on both the tractors at no load during transport mode of tractor with different mufflers are reported in Tables 3 and 4. It was observed that the noise levels on both the tractors increased with increase in forward speed of travel on tar road. The noise level increased from 77.1 to 98.1 dB (A), from 88.5 to 94.0 dB (A), from 74.2 to 95.1 dB (A), and from 76.3 to 99.4 dB (A) with Muffler A, Muffler B, Muffler C and existing muffler, respectively with the increase in forward speed of tractor from 0.36 to 7.69

Table 2. Noise levels at no load on tractors with different mufflers under laboratory condition

Tractor	Muffler	Engine speed, rpm						
		660	990	1320	1650	2000	2200	2410
Tractor - I	Muffler A	72.9	77.3	80.6	85.7	87.5	90.0	91.2
	Muffler B	74.6	79.9	82.7	85.2	87.5	88.9	89.1
	Muffler C	73.2	76.8	81.5	83.9	86.7	90.7	93.0
	Existing muffler	74.1	78.1	82.7	85.7	89.1	91.5	93.9
Tractor - II	Muffler A	70.8	74.5	78.9	84.6	89.1	90.4	94.5
	Muffler B	70.4	75.6	79.1	83.2	86.0	93.7	95.2
	Muffler C	67.2	69.3	73.3	79.8	93.0	93.4	95.7
	Existing muffler	64.7	69.5	75.6	79.8	91.5	95.4	106.0

Table 3. Noise levels in dB (A) at no load on Tractor -I with different mufflers on tar road during transport mode

Mufflers	Forward speed, m/s									
	0.36	0.50	0.69	1.11	1.79	2.08	2.70	3.71	4.54	7.69
Muffler A	77.1	82.3	85.1	87.0	89.0	93.4	94.0	95.2	96.0	98.1
Muffler B	88.5	88.2	88.6	89.4	89.1	88.8	90.3	91.3	92.2	94.0
Muffler C	74.2	74.8	75.0	75.3	82.6	83.8	85.8	88.1	89.4	95.1
Existing muffler	76.3	78.8	82.4	87.2	89.0	93.3	95.7	96.7	98.6	99.4

Table 4. Noise levels in dB (A) at no load on Tractor -II with different mufflers on tar road during transport mode

Muffler	Forward speed, m/s									
	0.37	0.69	0.98	1.64	1.89	2.18	3.03	3.40	4.96	6.71
Muffler A	69.7	70.6	74.0	84.6	89.4	90.0	90.8	92.7	93.1	93.8
Muffler B	62.7	65.6	71.7	80.0	83.5	84.3	86.4	88.4	91.7	93.0
Muffler C	68.1	73.9	77.2	85.2	86.5	88.9	92.9	93.9	95.0	97.6
Existing muffler	64.6	68.8	76.0	82.4	86.7	89.1	93.3	95.7	97.5	98.9

m/s at no load on tar road (Table 3). The measured noise levels exceeded the recommended limit of 90 dB (A) for 8 h at 2.70 m/s forward speed on tractor – I with different mufflers except with muffler C. The noise level increased from 69.7 to 93.8 dB (A), from 62.7 to 93.0 dB (A), from 68.1 to 97.6 dB (A), and from 64.6 to 98.9 dB (A) with Muffler A, Muffler B, Muffler C and existing muffler, respectively, with the increase in forward speed of tractor from 0.37 to 6.71 m/s at no load on tar road as shown in Table 4. It exceeded the recommended limit of 90 dB (A) for 8 h at 3.03 m/s on tractor–II with different mufflers except with muffler B.

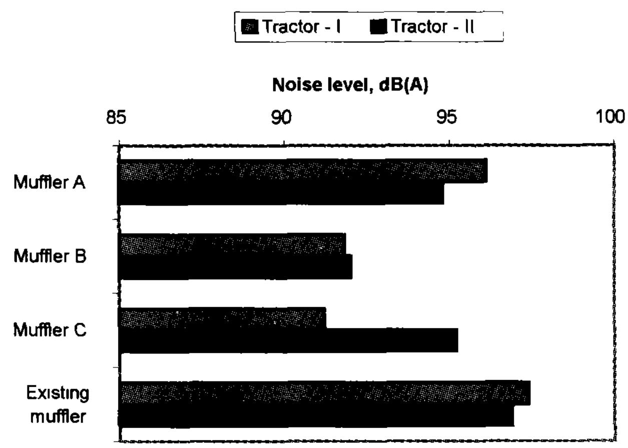


Fig. 3: Noise levels on tractors with different mufflers at rated engine speed during ploughing operation

Ploughing operation

Figure 3 shows that the noise levels at rated engine speed (2000 rpm) on Tractor - I were 96.1, 91.8, 91.2 and 97.4 dB (A) with Muffler A, Muffler B, Muffler C and existing muffler, respectively during ploughing operation with two bottom mould board plough. Similarly, the noise levels at rated engine speed (2000 rpm) on Tractor - II were 94.8, 92.0, 95.2 and 96.9 dB (A) with Muffler A, Muffler B, Muffler C and existing muffler, respectively during ploughing operation. It was observed that the measured noise levels at rated speed on both the tractors with different mufflers exceeded the BIS recommended limit of 90 dB (A) for 8 h. This may be due to heavy load on the tractors during ploughing operation as compared to that during their operations at no load under laboratory condition and on tar road during transport mode of tractors.

Noise Frequency Analysis

Figures 4 and 5 show that the noise levels on both the tractors increased with the increase in frequency up to 1 kHz and then decreased with increase in frequency beyond 1 kHz with Muffler A, Muffler B, and existing muffler. The noise levels with Muffler C increased with the increase in frequency up to 2 kHz and then decreased with increase in frequency beyond 2 kHz. The highest noise levels of 82.1, 83.5 and 84.6 dB (A) was observed at rated engine speed on Tractor-I at no load with Muffler A, Muffler B and existing muffler, respectively at 1 kHz frequency under laboratory condition, whereas the highest noise level of 75.6 dB (A) was observed on tractor-I with Muffler C at 2 kHz frequency (Fig. 4).

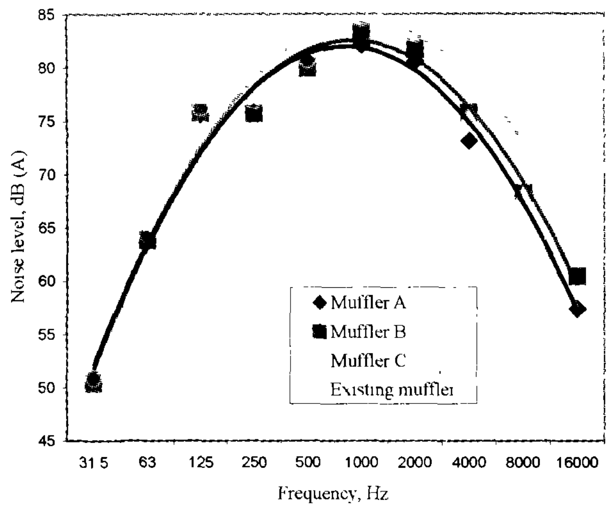


Fig. 4: Spectral analysis of noise levels of tractor–I

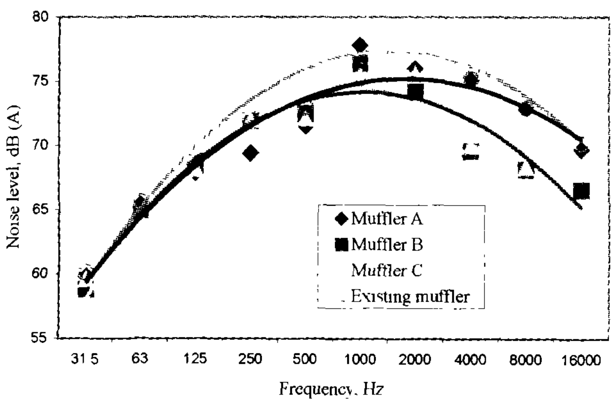


Fig. 5: Spectral analysis of noise levels of tractor -II

The relationship between noise levels at rated engine speed of tractors at no load under laboratory condition and their one octave frequencies for different mufflers was developed by regression analysis.

The regression equations were developed to predict the noise levels on tractor-I with different mufflers for one octave frequencies and are given below with coefficient of correlation.

Muffler A : $y = -1.3496x^2 + 15.395x + 38.06$ ($R^2 = 0.98$)
Muffler B: $y = -1.3205x^2 + 15.388x + 37.72$ ($R^2 = 0.97$)
Muffler C: $y = -1.1011x^2 + 12.705x + 40.52$ ($R^2 = 0.87$)
Existing Muffler : $y = -1.2621x^2 + 15.234x + 38.21$ ($R^2 = 0.97$)

Where,
x = One octave frequency, Hz, and
y = Noise level on tractor -I, dB (A).

Similarly, the highest noise level of 77.8, 76.4 and 80.5 dB (A) was observed on Tractor-II at rated engine speed with Muffler A, Muffler B, and existing muffler, respectively at 1 kHz frequency at no load under laboratory condition, whereas the highest noise levels of 75.6 dB (A) was observed with Muffler C at 2 kHz frequency (Fig. 5).

The regression equations were developed to predict the noise levels on tractor-II with different mufflers for one octave frequencies and are given below with coefficient of correlation.

Muffler A: $y = -0.4659x^2 + 6.355x + 53.523$ ($R^2 = 0.92$)
Muffler B: $y = -0.5814x^2 + 7.057x + 52.742$ ($R^2 = 0.93$)
Muffler C: $y = -0.7864x^2 + 8.819x + 49.987$ ($R^2 = 0.91$)
Existing Muffler: $y = -0.5886x^2 + 7.710x + 52.103$ ($R^2 = 0.91$)

Where,
x = One octave frequency, Hz, and
y = Noise level on tractor -II, dB (A).

The high values of coefficient of correlation indicate that noise levels on tractors at rated engine speed with different mufflers are directly related to their one octave frequencies of measured noise.

Exhaust Back-pressure

Table 5 shows that the exhaust back-pressures on both the tractors with different designs of mufflers increased with increase in engine speed at no load under laboratory condition. The exhaust back-pressure increased from 0.5

Table 5. Exhaust back-pressure on tractors with mufflers at no load under laboratory condition

Muffler	Engine speed, rpm											
	Tractor -I						Tractor -II					
	660	990	1320	1650	2000	2410	600	900	1200	1600	2000	2400
Muffler A	0.5	0.7	2.9	3.7	6.1	6.5	0.4	0.8	1.6	2.2	5.0	5.1
Muffler B	0.7	1.3	1.7	2.3	2.7	3.3	0.1	0.4	0.5	0.6	0.8	0.9
Muffler C	0.1	1.5	1.9	2.4	2.8	3.4	0.7	1.1	1.5	1.9	3.1	4.0
Existing muffler	0.1	0.7	0.9	1.1	1.5	1.9	0.3	0.5	0.8	1.3	2.0	2.2

to 6.5 kPa, from 0.7 to 3.3 kPa, from 0.1 to 3.4 kPa, and from 0.1 to 1.9 kPa with Muffler A, Muffler B, Muffler C and existing muffler, respectively with the increase in engine speed from 660 to 2410 rpm on Tractor-I. The exhaust back-pressure increased from 0.4 to 5.1 kPa, from 0.1 to 0.9 kPa, from 0.7 to 4.0 kPa, and from 0.3 to 2.2 kPa with the Muffler A, Muffler B, Muffler C, and existing muffler, respectively on Tractor-II with the increase in engine speed from 600 to 2400 rpm. The exhaust back-pressure levels at rated engine speed were 6.1, 2.7, 2.8, and 1.5 kPa on Tractor -I and 5.0, 0.8, 3.1, and 2.0 kPa on Tractor-II at no load under laboratory condition. The exhaust back-pressure at rated engine speed on both the tractors with Muffler B was the lowest at no load under laboratory condition. This may be due to that the expansion area of muffler B was the highest (0.95 m^2) among the selected mufflers. It was also found that there was a strong positive relation between noise levels and exhaust back-pressure with engine speed.

Noise Attenuation Characteristics

The reduction in noise levels at rated engine speed of both the tractors with different mufflers as compared to the existing mufflers at one octave frequencies of tractors is given in Table 6. The mean noise reduction was 0.7, 0.8, 0.8, 1.0, 1.0, 4.0, 4.6, 3.6, 3.1 and 5.8 dB (A) on Tractor-I and 0.3, 0.4, 0.6, 1.2, 1.2, 4.2, 3.8, 6.0, 5.8 and 6.2 dB (A) on Tractor-II for the frequencies of 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000 and 16000 Hz, respectively. It indicated that the noise reduction was more at higher frequencies as compared to lower frequencies on both the tractors. It was also observed that there was significant reduction in noise on both the tractors with different mufflers in the frequency range of 1000 – 4000 Hz. This corresponds to the conversational frequencies of human beings. The finding is consistent with conclusions of other investigators (Mehta *et al.*, 1997).

Figure 6 shows that mean noise reduction on tractor – I was higher at lower frequencies (31.5 – 125 Hz) as compared to tractor – II with different mufflers. However, the mean noise reduction on tractor – I was lower at higher frequencies (250 – 16000 Hz) as compared to tractor – I with different mufflers. The mounting of muffler B reduced noise levels by 4.1, 5.7 and 5.6 dB(A) on tractor – I and by 1.1, 1.4 and 4.0 dB (A) on tractor – II at 1000, 2000 and 4000 Hz frequencies. respectively

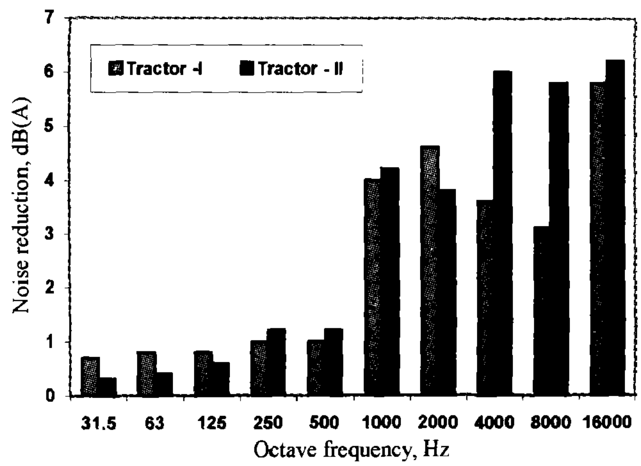


Fig. 6: Relationship between noise frequency and noise reduction for tractors

Table 6. Noise reduction on tractors at rated engine speed with mufflers as compared to existing muffler

Octave frequency, Hz	Noise reduction, dB(A)							
	Tractor -I				Tractor -II			
	Muffler A	Muffler B	Muffler C	Mean	Muffler A	Muffler B	Muffler C	Mean
31.5	0.3	1.3	0.5	0.7	0.1	0.5	0.4	0.3
63	0.2	0.7	1.5	0.8	0.4	0.5	0.2	0.4
125	1.1	0.4	0.8	0.8	0.6	0.4	0.7	0.6
250	2.7	0.2	0.1	1.0	1.1	1.2	1.2	1.2
500	1.5	0.5	0.9	1.0	0.1	. 0.8	2.6	1.2
1000	2.7	4.1	5.1	4.0	2.5	1.1	9.1	4.2
2000	3.9	5.7	4.3	4.6	2.5	1.4	7.5	3.8
4000	0.1	5.6	5.2	3.6	6.7	4.0	7.4	6.0
8000	0.1	4.7	4.5	3.1	5.9	5.7	5.8	5.8
16000	0.5	3.6	13.4	5.8	6.4	3.3	8.9	6.2

as compared to the existing mufflers. Similarly, the mounting of muffler C reduced noise levels by 5.1, 4.3 and 5.2 dB (A) on tractor – I and 9.1, 7.5 and 7.4 dB (A) on tractor – II at 1000, 2000 and 4000 Hz frequencies, respectively as compared to the existing mufflers.

The exhaust back-pressure at rated engine speed on both the tractors with Muffler B was the lowest and reduced noise levels considerably in conversational frequencies at no load under laboratory condition. However, the muffler C reduced noise levels considerably in conversational frequencies at no load under laboratory condition on tractor – II. But, the exhaust back-pressure at rated engine speed on the tractor increased considerably as compared to existing muffler affecting the performance of the tractor. Therefore, it may be concluded that muffler B reduced noise levels considerably on both the tractors in conversational frequencies.

CONCLUSIONS

i. The noises levels and exhaust back-pressures on both the tractors increased with increase in engine speed under different operating conditions.

ii. The noise levels at operator's ear level exceeded the recommended limit of 90 dB(A) for 8 h at 2.70 m/s forward speed on tractor-I (except with muffler C) and 3.03 m/s forward speed on tractor-II (except with muffler B) on tar road during transport mode and at different operating conditions during ploughing operation.

iii. There was significant noise reduction with both the tractors with different mufflers in the frequency range of 1000 – 4000 Hz. This corresponds to the conversational frequencies of human beings.

iv. The exhaust back-pressure at rated engine speed on both the tractors with Muffler B was the lowest and reduced noise levels considerably in conversational frequencies at no load under laboratory condition. Therefore, the Muffler B was found to be the best for noise reduction on tractors.

REFERENCES

Baker D E. 1993. Noise: The invisible hazard. Department of Agricultural Engineering, University of Missouri-Columbia, http://www.cdc.gov/niosh.

Crocker M J. 1972. Noise sources, noise measurements and noise reduction. ASAE Paper, 72, 812.

Crocker M J. 1998. Handbook of Acoustics. John Wiley and Sons, New York.

Depczynski J; Franklin R C; Challinor K; Williams W; Fragar L J. 2005. Farm noise emissions during common agricultural activities. J. Agric. Safety and Health, 11(3), 325-334.

Gerke F G; Hoag D L. 1981. Tractor vibration at the operator's station. Trans. American Soc. Agric. Engrs, 24 (2), 1131-1134.

Irwin J D; Graf E R. 1979. Industrial Noise and Vibration Control. 1st Edn. Prentice-Hall, Inc, London.

IS 3931. 1966. Sound level meters for the measurement of noise emitted by motor vehicles. Bureau of Indian Standards, New Delhi.

IS 6964. 1973. Octave, half-octave and third octave band filters for analysis of sound and vibrations. Bureau of Indian Standards, New Delhi.

IS 11806. 1986. Method for determination of seat reference point of agricultural tractors. Bureau of Indian Standards, New Delhi.

IS 12180 (Part 1&2). 2000. Tractors and machinery for agriculture and forestry – noise measurement – method of test. Part 1: Noise at the operator's position – survey method. Part-2: Noise emitted when in motion. Bureau of Indian Standards, New Delhi.

Mehta C R; Shyam M; Sharma P K. 1997. Studies on noise and vibration levels of different tractors. Final Project Report, CIAE, Bhopal.

Roth O L; Field L H. 1991. Introduction to Agricultural Engineering. 2nd Edn, Can Nostrand Reinhold, New York

Rowley D W. 1967. Control of farm tractor intake and exhaust noise. Sound and Vibration, 1(3), 15-23.

Sharma P K; Shyam M. 1993. Noise and vibration levels of indigenous tractor – a status report. Paper presented at XXVIII convention of ISAE held at CIAE, Bhopal.

Simpson E W Jr; Deshayes I L. 1969. Tractors produce ear damaging noise. J. Environmental Health, 31(4), 347-350.

Stangl G A; Porterfield J G; Lowery R L. 1973. Tractor exhaust noise evaluation technique. Trans. ASAE, 16 (4), 601–605.