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Energy Procedia 75 (2015) 893 – 899
Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Acoustic analysis of a single cylinder diesel engine using biodiesel fuel blends

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Abstract

Fuel type has a direct effect on the quality of IC engine's combustion phenomenon. One of the most important quality parameters that can be fluctuated by fuel type is engine noise. The purpose of this study is to analyze the noise parameter of a diesel engine using B0, B5 (5% vol., biodiesel and 95% vol., diesel blends), B10, B15, B20, B25 and B30 biodiesel–diesel blends. This study was carried out at stationary position and at three positions such driver's left ear position (Drivers Left Ear Position-DLEP), 1.5 meter (1.5 meter Away From Exhaust-MAFE) and 7.5 meters (7.5 meter Away From Exhaust-MAFE) away from exhaust at 6 engine speeds (1200, 1400, 1600, 1800, 2000 & 2200 RPM). The results proved that the lowest and highest Sound Pressure Level (SPL) of power tiller takes place at B10, and B30 respectively. The SPL increased by 7.8 dB for increasing engine speed from 1200 to 2200 RPM. The test results showed that the average SPL at DLEP was 4.3 dB higher than 7.5 MAFE position. The dominant frequency of engine noise was315Hz that exhaust structure is the source of it. In this frequency SPL of B10 was, 23%lower than thefuelB30 (a mixture of 30percentbiodiesel and70percentdieselfuel, respectively). The slightest and strongest sound by using theB10, B30 fuel mixture was produced respectively.

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Keywords: biodiesel; frequency analysis; sound pressure level; diesel engine noise

1. Introduction

There are several sources of noise in an industrial and agriculture environment. Machines with rotating or reciprocating engines are sound-producing sources. As the SPL of machines has a direct impact on the biological and psychological systems of operator and those around him, so the sound of machine is a very important criterion in choosing a machine. Also, the audio signal can be analyzed to discover how well

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doi:10.1016/j.egypro.2015.07.217

machines operate. Diesel engines complex noise SPL and sound frequency content both strongly depend on fuel combustion [1-6], which produces the so-called combustion noise. Actually, the unpleasant sound signature of diesel engines is due to the harsh and irregular self-ignition of the fuel. Therefore, being able to extract combustion noise from the overall noise would be of prime interest. This would allow engineers to relate the sound quality back to the combustion parameters [7]. The residual noise, produced by various sources, is referred to as mechanical noise [8-11]. Since diesel engine noise radiation is associated with the operators' and pedestrians' discomfort, attention to it is getting more and more. The main sources of noise generation in a diesel engine are exhaust system, mechanical processes such as valve train and combustion that prevails over the two other [12, 13]. In the present work, experimental tests were conducted on a single cylinder diesel engine in order to investigate the combustion noise radiation during stationary state for various diesel and biodiesel fuel blends. The experimental test matrix included seven different fuels, namely neat diesel fuel and six blends of diesel fuel with either bio-diesel.

2. Materials and Methods

The engine used in the current study is an ASHTAD DF120-RA70 that is a single cylinder 4 stroke water cooling diesel engine and its nominal power is 7.5 hp at 2200 rpm. The experiment has been done at three positions (Left ear of operator, 1.5 and 7.5 meter away from exhaust) based on ISO-5131 and SAE-J1174 standards [14]. For engine speed measurement the detector Lurton 2364 was utilized that its Measurement accuracy is 0.001 rpm. To obtain highest accuracy, contact mode of detector was used. The engine noise was measured by HT157 sound level meter and digitalized and saved with Sound View software. HT157 uses allow impedance, capacitor Microphone with a unidirectional pattern that its size, Sensitivity and frequency range is1/2", 50 mV/Pa and 10 Hz to 20 kHz with a flat extrusion respectively.

Choosing the combination of fuel was carried out according to experiments that have been done before to determine engine operation parameters. According to this, the experiment matrix (table 1) has been derived. The experiment set up and environment is shown in figure 1.

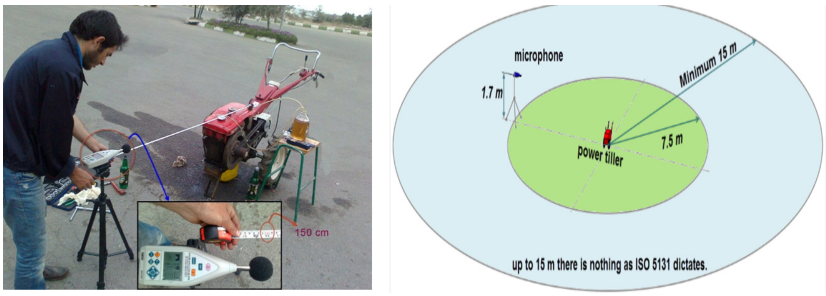


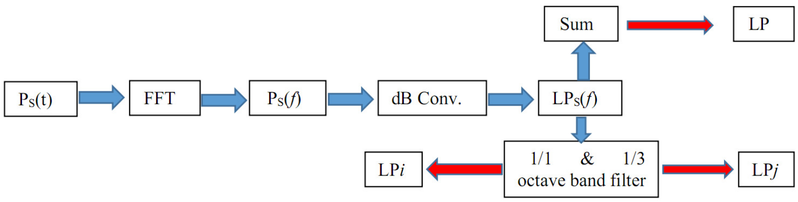
Fig. 1. *Left*: experiment set up, *right*: dimension of experiment track.

Table 1. experiment matrix

	Variable level	1	2	3	4	5	6	7
Variables	Fuel Type	B00	B05	B10	B15	B20	B25	B30
	Engine Speed (RPM)	1200	1400	1600	1800	2000	2200	---
	Microphone Position	*DLEP	**1.5 MAFE	***7.5 MAFE	---	---	---	---

* Drivers Left Ear Position, **1.5 Meter Away From Exhaust and 7.5 Meter Away From Exhaust

It should be mentioned that air/ fuel ration have not been changed, but fuel mixture changed. The test was conducted with four replications for each treatment. The overall analysis chart is shown in Table1. In each treatment at least 10 seconds sound signal recorded, and in the early stages of analysis, the signals were sampled as long as 2 second. The test was conducted in a factorial experiment with randomized complete block design. Statistical analysis has been done using PASW Statistics 18 and Microsoft Excel 2010 software's. For frequency analysis a FORTRA 95 code was derived. Analysis process is shown in the flowchart:



$P_S(t)$ is the sound pressure signal at the time domain that transferred to the frequency domain ($P_S(f)$) with FFT function. At the second stage using equation 1, the pressure of sound converted to a logarithmic scale dB, that its result is $LP_S(f)$. For statistical analysis, using equation 2, the overall SPL (LP) calculated. LP is calculated for each weight A and Z.

$$LP = 20 \log \frac{p}{p_0} \quad (1)$$

$$LP_{total} = 10 \text{Log} \sum_{i=1}^{n} \left(\frac{p}{p_0}\right)_i^2 = 10 \text{Log} \sum_{i=1}^{n} 10^{LP_i/10} \quad (2)$$

That LP is overall SPL (db), p local sound pressure (N/m2),p0reference pressure (N/m2) and i is octave frequency band number. For frequency analysis, it has been carried out by two type analysis; narrow band frequency analysis and wide band frequency that has been done for distinct frequencies. For frequency analysis, narrow band utilized up to 100 Hz ($P_S(f)$) and for upper frequencies wide band applied. For this purpose 1/1 and 1/3 octave band filters applied and the 1/3 octave (LP_j) band discussed.

3. Results and discussions

According to statistical survey it made clear that highest and lowest SPL of tractor engine is for B30 and B10 respectively. In weight Z and 1% error there is no significant difference between B00, B05, B10 and B15 Fuels. Using A-Weighted signals that is connected with human ear frequency response, there is no significant difference between different fuels at 1% error level. But at 5% error level, significant differences between generated noises are observed. B30 and B25 fuels at 5% error generates the loudest overall sound with no significant difference. The two fuels B10 and B20 also have lowest SPL with no significant difference at 5% error level. However to choosing the right fuel according to noise level, there is 5 choices: B00, B05, B10, B15 and B20 that in A-Weighted signal and 5% error level haven't significant differences. Figure 2 shows the statistical analysis result and significance of differences at 5% error level. between group 'a' and 'b' there is approximately 0.8 dB difference which shows the sound pressure of group 'a' is 101% greater than group 'b'.

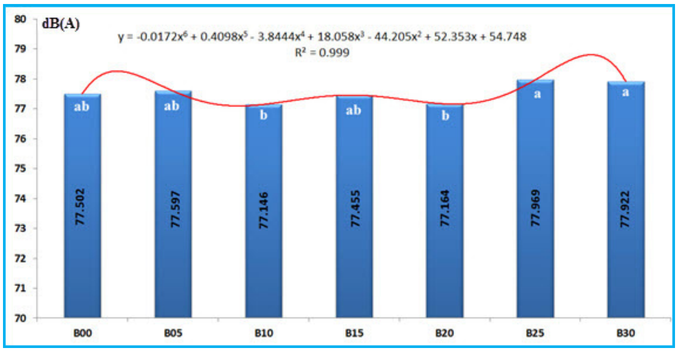


Fig. 2. Statistical analysis result at A-Weighted signal with 5% error level for different fuel combination

The experiment has been done for 6 engine speeds (1200, 1400, 1600, 1800, 2000 and 2200 RPM) and three positions (DLEP, 1.5 MAFE and 7.5 MAFE) that just the speed 1800 RPM and position DLEP presented. In Fig. 3 the spectrum of narrow band frequency are shown. At frequencies higher than 100Hz because of spectrum curve compaction, it is impossible to detect hotspots. According to engine speed firing frequency calculated (1800/120=15 Hz). Obviously, the higher modes of this basic frequency with a weakened power will be observed. In Figure 3 the first peak point (1) shows this basic firing frequency. In this point the pure diesel's (B00) SPL is 5 dB louder than the other biodiesel blends SPL that can be due to combustion knock. As it visible the other blends have a same power at this point that it's logical. The next major peak point (2) located at 30 Hz frequency. this peak generated by two sources; the first source is the firing frequencies second mode and the second source comes from all members of the engine, such as piston, valves and crankshaft that their movement cycle in each round of crankshaft accomplishes.

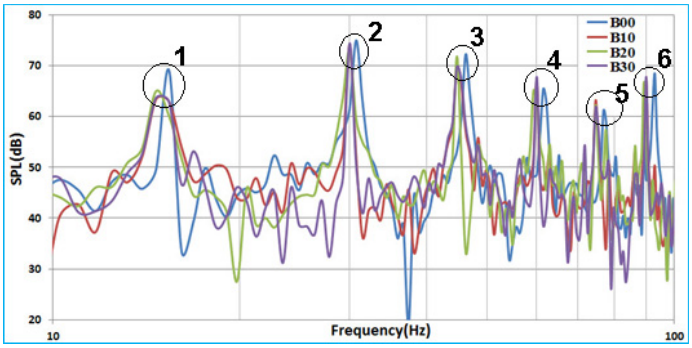


Fig. 3. Narrow band spectrum for 4 fuel at speed 1800 RPM and drivers left ear position

The most important noise in this point seems to be the valve collision to its seat. So the sound pressure level of this frequency is vector summation of combustion noise and engine dynamics. Given that the peak noise level for different fuels are the same, so the impact of combustion on this peak is ignorable so the dynamic of engine such as valve collision can be assumed the major source of noise in this frequency. The 3th peak point couldn't have dynamical source and as its SPL is stronger than first peak point, it should to have a 3th source that its identification is very important. The 4th peak points Frequency is 60 Hz. The 5th peak point's frequency is 75 Hz that can be ignored because its dB is more than 5 dB less than the highest peak point. The 6th point that has 90 Hz frequency, is not a basic one but maid of 3 basic said signals. According to expressed content about the first 6 peak points, with fuel type replacement which affects combustion quality, the SPL didn't change that proves the first 6 point are not affected by combustion process. It should be noted that 15 Hz frequency is firing frequency not firing (combustion) quality As figures 2 and 3 illustrates, in narrow band spectrum, frequencies higher than 100 Hz is such compressed that its data is not debatable so for frequencies higher than 100 Hz, 1/3 octave band filter applied that is geometric mean of an upper and lower bound of frequency domain. For peak point's upper than 100 Hz narrow band frequency is not proper so 1/3 octave band is used. Figure 4 indicates whole peak points that the first 4 explained. The next peak point's frequency that is the most important and effective one is 315 Hz. Peak points between 250 up to 500 Hz is rooted to exhaust structure. This peak point shows all frequencies between 282 and 355 Hz. However, the peak frequencies main source is exhaust structure but the higher modes of told 3 basic frequencies are effective. Fuel diversity is appeared significantly in this peak and difference between maximum (B15) and minimum(B10) SPL is 1.83 dB that is a significant difference. In more accurate expression SPL of B15 is 23% higher than B10 SPL. This gross differences in SPL rooted in combustion and exhaust resonance. Here is two possibility that why B15's SPL is higher than B10's SPL; B15 has a complete combustion that results higher temperature and pressure in out let gas and the second possibility is supposed that this blend has a more knock full combustion. Maximum combustion pressure of B15 is higher than B10. So its combustion is more complete than B10 but by this data's it's not impossible to prove knock status. Exhaust structure is such that its natural frequency is inside this range therefore if the frequency of outlet gas is in this range, resonance will be occurring and such powerful peak will appear. Short peaks from 1 kHz up to 4 kHz have a root in combustion but SPL in range from 1 kHz up to 2.5 kHz is more robust.

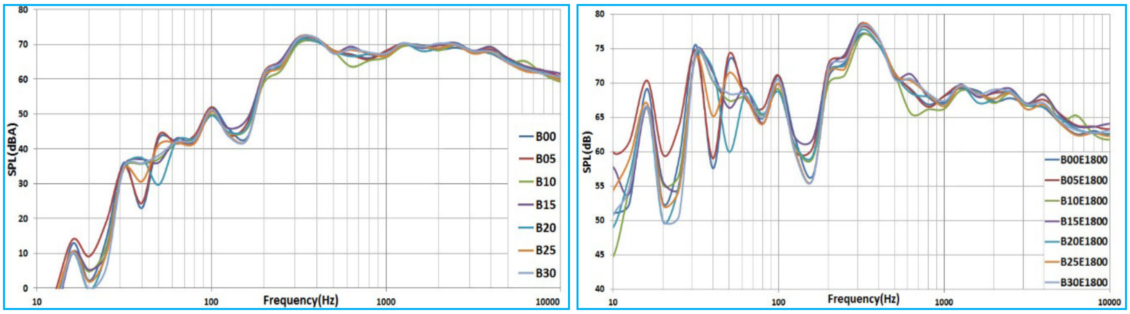


Fig. 4. Right: 1/3 octave spectrum for all blends of fuel at DLEP and engine speed 1800 RPM, Left: A-Weighted 1/3 octave spectrum for all blends of fuel at DLEP and engine speed 1800 RPM

4. Conclusions

B10 has minimum sound pressure level (SPL) but its difference with B00 (DIESEL FUEL), B05 and B15 is not significant in 1% error level. Regarding to NOISH standard the operator can work with machine for 8 hours. In DLPE position the most overcome frequency is 315 Hz for all blends that resulted from exhaust and combustion. B10 has a minimum SPL at this peak point significantly lower than other blends. For the used engine at this experiment, by optimizing muffler design it's possible to reduce SPL of engine in this frequency peak point. By applying A-Weighted filter that matches with human hearing system, frequencies between 300 and 3000 Hz are the effective range. Combustion and exhaust (muffler) design are the source of this range.

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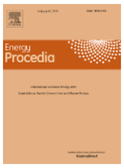

Biography

Dr. Gholamhassan Najafi is assistant professor in Mechanics of biosystem engineering department, Tarbiat Modares University, Tehran, Iran. He is expert in the fields of internal combustion engines and renewable energies.