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Combustion Estimation by Cylinder Vibration Analysis on A Supercharged IDI Diesel Engine - A Comparative Study with A New Fuel as Total Replacement

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Abstract— In addition to the performance evaluation of the IDI engine with alternate fuel like waste cooking oil biodiesel, an attempt was made to evaluate the engine performance indirectly by measuring engine cylinder vibrations. The excitation for which is regarded as the very combustion itself in both the chambers. Especially the time waves recorded expressed ample evidence for the suitability in replacing the conventional fuel i.e. diesel fuel. Time waves are recorded in three directions forming two on the cylinder head and one on the foundation of the engine. The recordings are presented at full load on the engine with different fuels combinations. The investigation revealed that waste cooking oil with 6% hydrated methanol proved efficient booth in the wise of combustion propensity and torque conversion.

Keywords—Waste cooking oil biodiesel (WCOBD); Vibrations; Time waves; Hydrated Methanol; Torque conversion.

I. INTRODUCTION

Diesel engines are recognized for the high level source of vibrations and sound because of the heterogeneity of combustion. In the case of open combustion chamber, the cylinder vibration is further more than the IDI engine for the same power to weight ratio. It is an established fact that the divided combustion chamber produces lesser high frequency vibration due to Helmholtz resonance principle and that is the specific reason the IDI engine is being selected for experimentation. Research on fault diagnosis of internal combustion engines is popular due their contribution to the industrial sector and condition monitoring and fault diagnosis is a valuable technique to ensure that the diesel engine stays in good order [1]. Literature in the field of vibration analysis reveals that; Vibration analysis is a difficult task due to the multiple sources of unstable and stable frequency excitations [3]. To minimize the noise levels during the operation of diesel engines, intake and exhaust silencers have been developed [2]. Some other methods like wavelet packet technique can carry out multi resolution analysis to lower the noise and to heighten signal-to-noise ratio (SNR). By this the vibroacoustic signatures can be effectively extracted from vibration responses [4]. In general diesel engine diagnostic techniques are usually developed at specific engine working conditions and on an individual engine. However, diesel engines work under different ambient conditions and load, and the dynamic features vary from engine to engine. It is desirable that a diagnostic technique can provide acceptable accuracy of diagnostic results while being insensitive to the variation of engine working conditions and engine-to-engine differences [5]. Vibration monitoring is a major technique for mechanical fault diagnosis. The vibration parameters to be measured include displacement, velocity, acceleration, and stress. However, accelerometers are deemed popular transducers for vibration analysis because of their accuracy, light weight, good temperature resistance, and wide frequency response [6]. DC-11 accelerometer piezoelectric pickup was used to measure the IDI engine vibration signatures at three strategic positions on the cylinder head and this was investigated by authors [7-8]. It was found that vibration signatures measured on cylinder head and in the piston slap direction helps in analyzing the performance of the engine in an indirect way. The vibration signatures always vary with diesel engine combustion depending on the load on the engine and the type of engine. In this paper experimental findings of IDI diesel engine vibration signatures are reported. Waste cooking oil biodiesel (WCOBD) was chosen as an alternative fuel with variable percentages of hydrated methanol as an additive in the span from 2% to 8% with an increment of 2%.

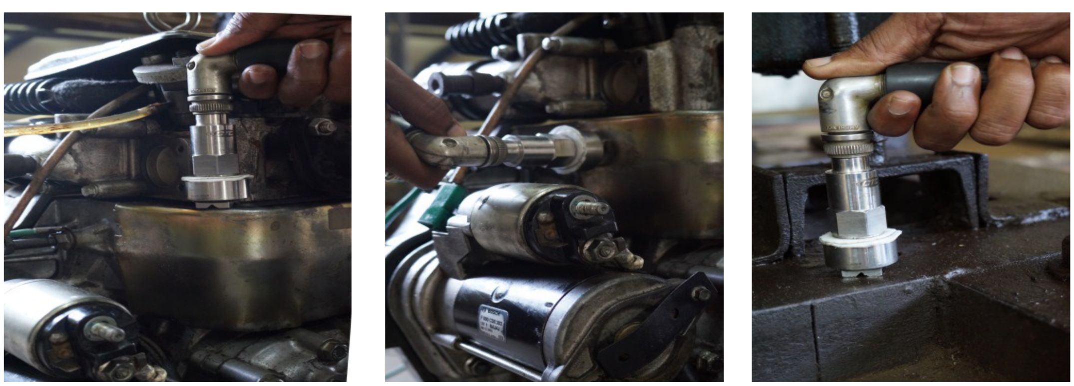
II. MATERIALS & METHODS

A. Materials:

Keeping above said reasons in mind, experimentation was conducted on a supercharged IDI diesel engine. With Neat diesel fuel (low sulphur) as the reference fuel, it was tested waste cooking oil biodiesel and also the fuel combos with different additive percentages are tried in this experimentation. Different percentages of additive i.e. hydrated methanol were injected into the combustion chamber at the suction end with an electronically controlled secondary fuel injector. DC-11 vibration analyzer was used to measure the vibration signatures.

B. Method:

Low cost feed stock of waste cooking oil biodiesel (WCOBD) was used as an alternative fuel to replace conventional fuel. Indirect injection (IDI) diesel engine (IDI) was supercharged with a 350 watt air blower. Tests were conducted at five discreet loading conditions i.e. in the span from no-load to full load (2.92kW) by maintaining a fixed rpm of 1500. All the parameters of vibration were taken when the engine is in thermal equilibrium condition. Vibration signatures are measured at three strategic positions i.e. vertically on the cylinder head, in radial direction and on the engine foundation as shown in the **Fig. 1 (a, b, c).** Diesel was taken as a reference fuel and Neat WCOBD and different percentages of hydrated methanol (2% to 8%) were used as an additive with the biodiesel. DC-11 vibration analyzer which gives the spectral data in the form of time waves was analyzed at full load. The technical specifications of IDI engine and of vibration analyzer are presented in the **Table. 1&2** respectively. Each time wave recorded makes an average of 4000 samples and presented in the shown form.



a. Vertical on cylinder head ***b. Piston slap*** ***c. Foundation***

Figure 1. (a, b, c) Vibrations measured at three strategic positions

Table 1. IDI Engine specification

S.No	Specification	Factor
1	Bore (mm)	86
2	Stroke (mm)	77
3	Compression Ratio	24:1
4	Stroke Volume (cm^3)	447.3
5	Max Torque (Nm) at 2200 rpm	18.7
6	Injection Pressure (bar)	142 to 148

Table 2. Vibration analyzer specifications

S.No	Specification	Factor
1	Frequency range	1-20000 Hz
2	Input signal range	100mV
3	Gain	Auto, 0-54dB in 6dB Steps
4	Frequency span	1-2000 Hz in 1 Hz resolution
5	Frequency resolution	1600 lines
6	Signal to noise ratio	Greater than 70dB
7	Linear averages	1-256

III. RESULTS & DISCUSSIONS

A. Vibrations measured in vertical direction on the cylinder head:

Figures from 2 to 7 represent the vibration signatures measured on the cylinder head at maximum load. It can be observed that there are three peaks that represent pumping of air into the pre combustion chamber, burning in pre chamber, and of the fuel combustion in the main combustion chamber. It can be ascertained from the **Fig.2**, the density of the spectrum is more for diesel. This may be due to the high heat value of diesel fuel and more heterogeneity in combustion. For other combination fuels the density of the spectrum is comparatively lesser, where as 6% hydrated methanol in WCOBD exhibits even better time wave with efficient heat to torque conversion and also there is a judicial sharing of combustion in main and pre combustion chamber as shown in **Fig.6**. The time wave is smoother with better harmonic combustion. It can also be observed that the high frequency combustion amplitude in the neighborhood of 12800 Hz is below 10 dB in case of 6% additive in WCOBD. For the other combo fuels the amplitude exceed above 10 dB. This is an indication of lesser higher frequency burning which obviously eliminates piston shock and improves torque conversion since the burning follows suit of the piston movement in vertical direction.

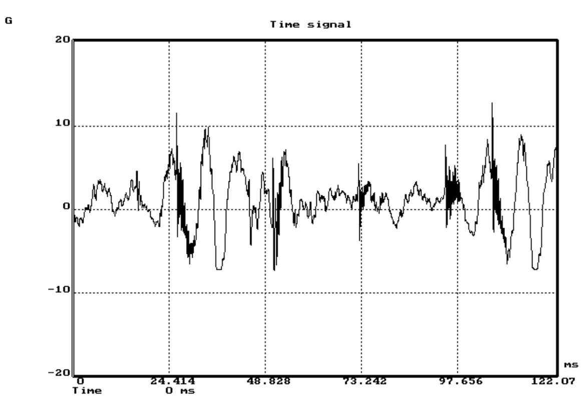


Fig.2 Diesel

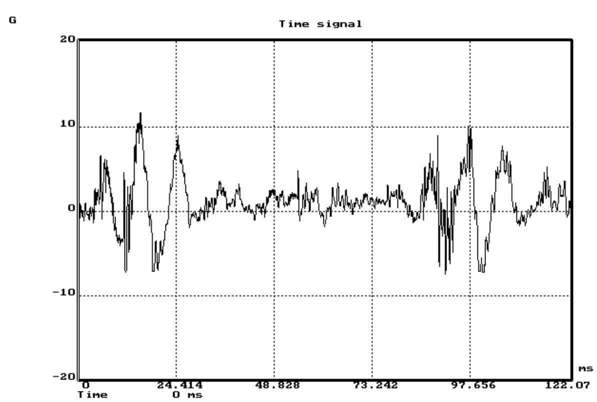


Fig.3 WCOBD

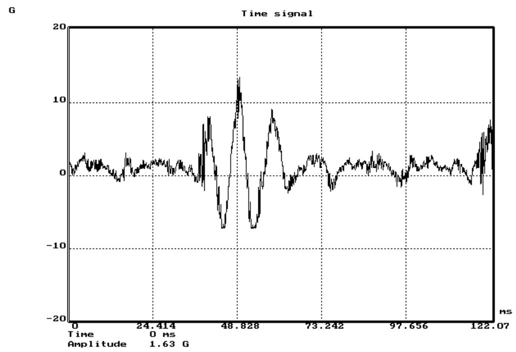


Figure 4. WCOBD+2% Methanol

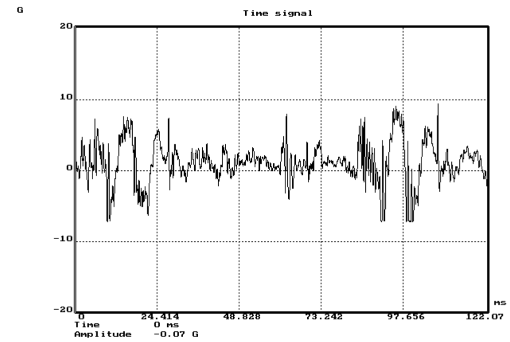


Figure 5. WCOBD+4% Methanol

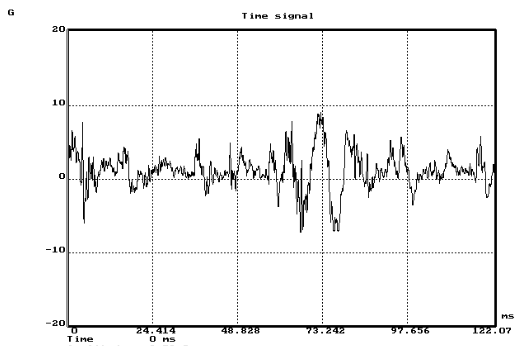


Figure 6. WCOBD+6% Methanol

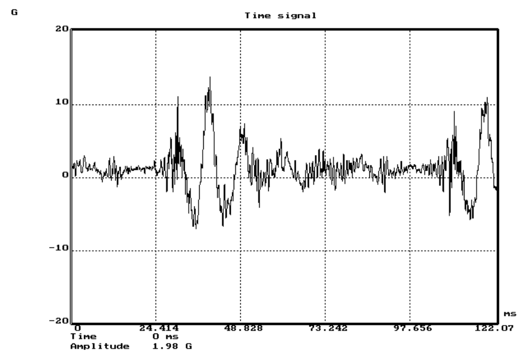


Figure 7. WCOBD+8% Methanol

B. Vibrations measured in radial direction

Vibrations in piston slap direction provide potential information about the torque conversion aspects and about the impression of the thrust in the piston axis direction. It is also to be noted that for the engine chosen, the diameter of the bore is greater than the stroke length of the cylinder **(Table.1)**. **Figures from 8 to 13** represent the time waves recorded in the piston slap direction when the engine is operated at full load. In the case of diesel fuel the plots reveal maximum piston slap which is the disturbing phenomena since the excess slap damages the engine body, piston rings and excess wear in the direction of slap leading to ovality of the cylinder bore. This aspect of excess piston slap disturbs the bearings at the gudgeon pin and at the crank end also. 6% additive in WCOBD maintains low piston slap vibration compared all the other fuel combinations as shown in **Fig.12**.

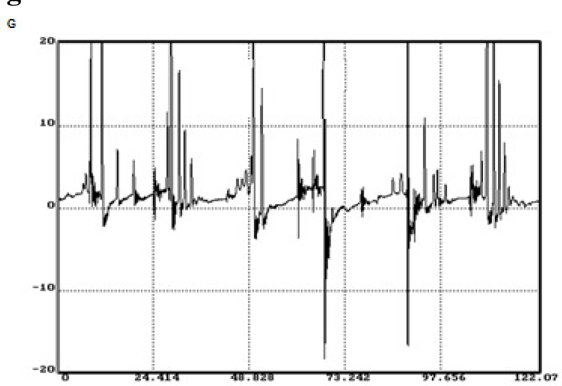


Figure 8. Diesel

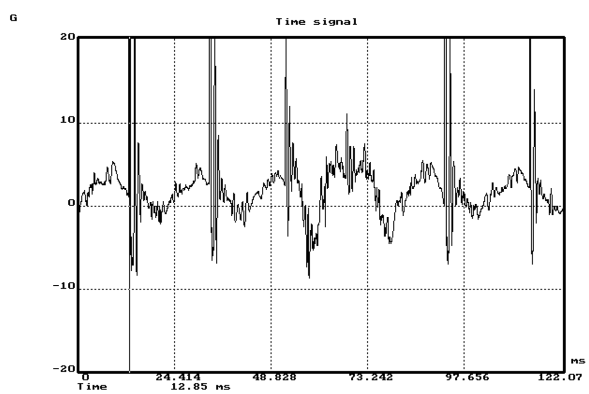


Figure 9. WCOBD

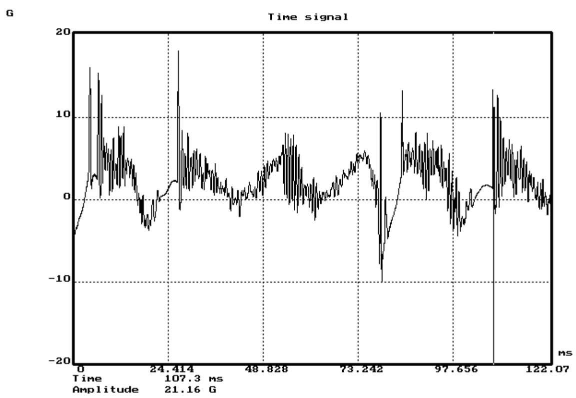


Figure 10.WCOBD+2% Methanol

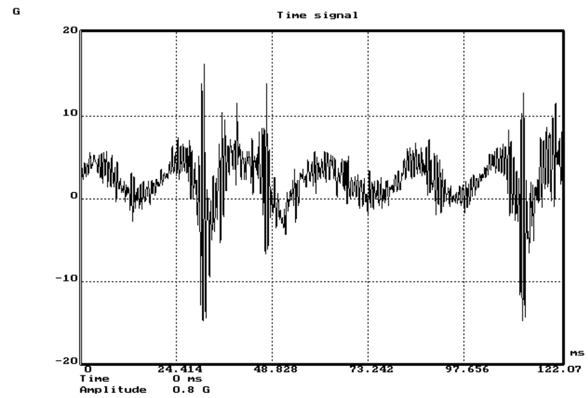


Figure 11. WCOBD+4% Methanol

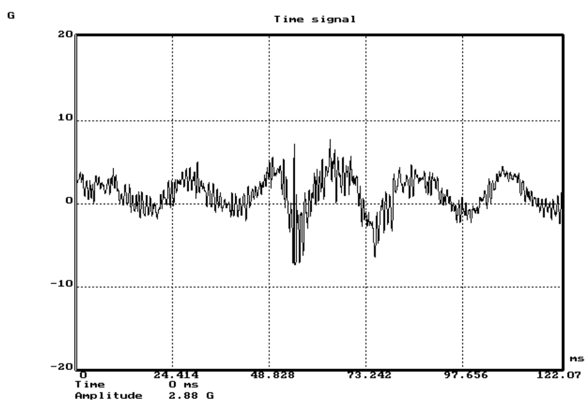


Figure 12. WCOBD+6% Methanol

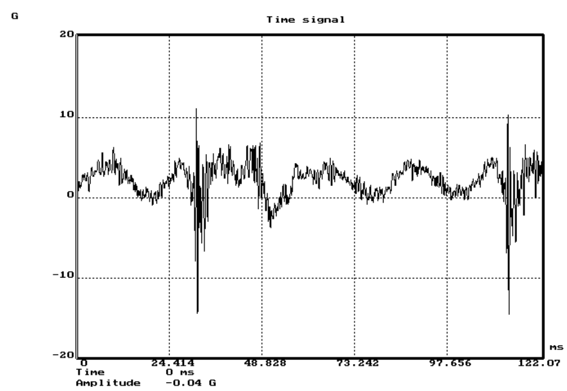


Figure 13. WCOBD+8% Methanol

C. Vibrations measured on engine foundation:

From the **Figures 14 to 19** represent the vibration recorded in the vertical direction on the foundation of the engine. These vibration plots are complementary when we consider the vibration on the foundation and in the piston slap direction which is reduced by approximately by ratio of 10:1 for the new combo of the fuel introduced. This obviously gives an indirect indication that the torque conversion has increased multifold in the case of the new fuel and the endurance of the engine increases because of drastic reduction in the piston slap thrust in radial direction.

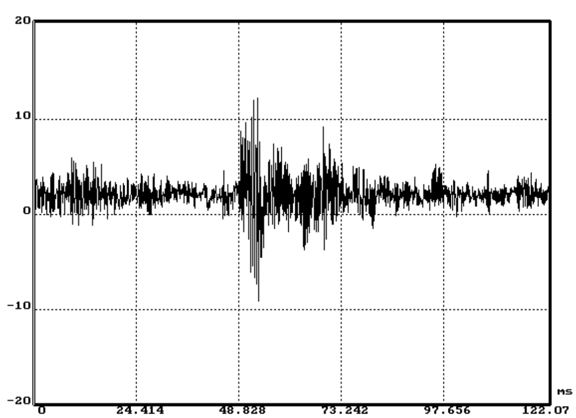


Figure 14. Diesel

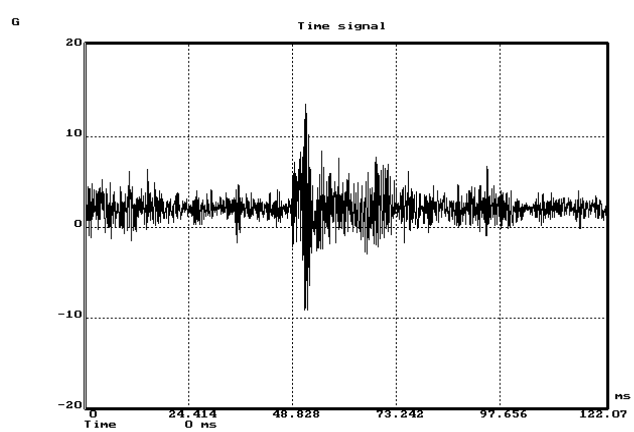


Figure 15. WCOBD

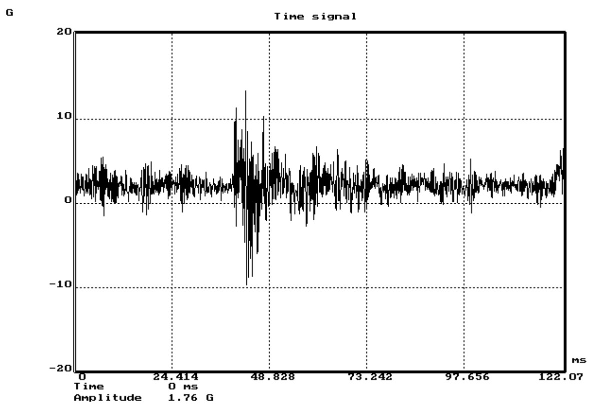


Figure 16. WCOBD+2% Methanol

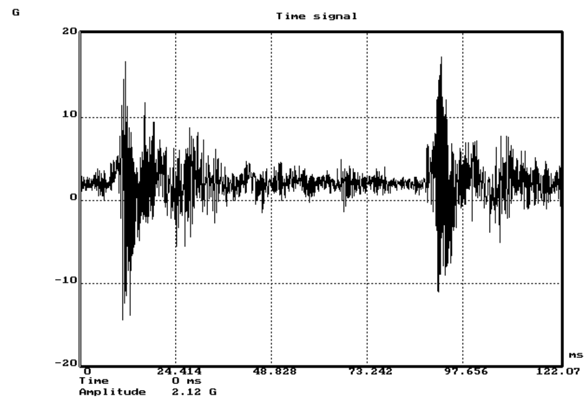


Figure 17. WCOBD+4% Methanol

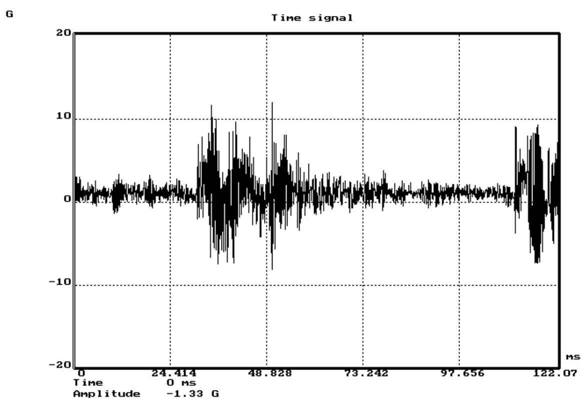


Figure 18. WCOBD+6% Methanol

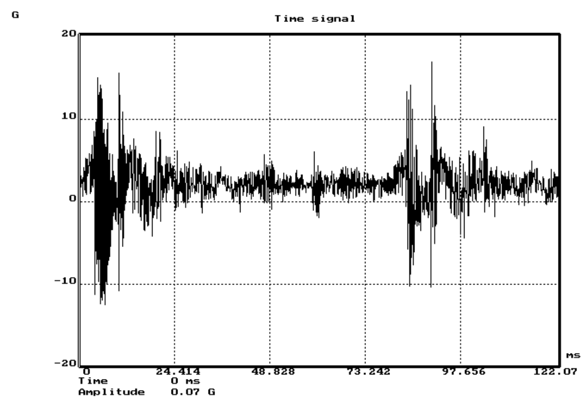


Figure 19. WCOBD+8% Methanol

IV. CONCLUSIONS

In this experimentation, IDI engine was chosen in lieu of the open combustion chamber engine since the later engine is comparatively silent engine and runs efficiently with any alternate fuel. Experiments with diesel fuel (reference fuel), WCOBD and WCOBD with different percentages of hydrated methanol as an additive were tested. The conclusions are as follow:

- The time waves recorded on the cylinder head in vertical direction are analyzed and found that 6% methanol with biodiesel proved efficient and deserving candidate for replacement.
- It can be observed that the vibration in the piston slap direction is comparatively lesser for the above said fuel leading to the reliability of the engine without damaging engine components.
- The configuration of the time wave indicates more harmonic frequency release with smoother combustion with the new combo fuel.
- Finally, the torque conversion aspect is many folds better than the diesel fuel as it is evident from the time wave recorded in the piston slap direction.

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