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Combustion Analysis Of A Diesel Engine Operating With Performance Improvement Additives

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ABSTRACT : *The following is a report on the Combustion Analysis of Diesel Engine with performance improvement additives. Experiments are conducted with pure Diesel, Acetone mixed with diesel and Naphthalene balls mixed in Diesel. During the experiments, Pressure values are noted at each crank angle of the crankshaft using pressure sensors mounted inside the engine cylinder. Heat Release Graph, Work done per cycle, Ignition Delay values are calculated for all the three cases and then plotted. Finally, suggestions are made on which fuel is best and what modifications should be made to make full utilization of the fuel and the engine.*
Keywords *– additives, combustion analysis, diesel engine, heat released, performance*

I. INTRODUCTION

Internal combustion engines produce mechanical power from the chemical energy contained in the fuel. The energy is released by oxidizing the fuel, which is basically the burning of fuel inside the combustion chamber in the engine. The burning of the fuel and the release of high-temperature & pressure gases and work transfer between the gases and mechanical components of the engine provide the desired output.
There are two types of Internal Combustion Engines:
Spark Ignited Engines (Otto or Petrol Engines) and Compressed Ignited Engines (Diesel Engines)
Diesel Engines are compressed ignited engines where air alone is introduced in the cylinder and the engines use this heat of compression of air to ignite the fuel and burn it. Before the combustion process is about to start, a fuel injector is used to inject the fuel in the combustion chamber. By changing the amount of fuel injected in every cycle, load control can be achieved. If more power output is required, more fuel is injected and lesser fuel for low power. At a particular engine speed, the air flow is basically the same. Diesel engines today are used in wide variety of industries such as automotive, submarines, trucks, power generation etc.

II. COMBUSTION IN DIESEL ENGINES

The compression ratio used for diesel engines lie in the range of 12 to 24, much higher than that of Spark-Ignited engines. The compression ratio employed also depends on whether the engine is turbocharged, supercharged or naturally aspirated. Air at around atmospheric pressure is induced in the cylinder and is then compressed in compression stroke to reach a pressure of 4 MPa and temperature of around 800K. At about 15-20 degrees before the Top Dead Centre (TDC), the fuel injection begins. When the liquid fuel comes in contact with hot compressed air, the fuel evaporates and mixes with air. The air inside the combustion chamber is well above the ignition temperature of the fuel which atomizes the fuel in small drops. The ignition of air-fuel mixture begins after a small delay period and thus the combustion process starts. The flame spreads rapidly through the mixture and the evaporation proceeds. After the expansion stroke, the exhaust process takes place where most of the burnt gases are driven out of the combustion chamber. The cycle starts again after the exhaust stroke.

III. PRESENT WORK

Generally additives are used with diesel fuel to improve the performance of the engine and to reduce its emissions. Many such additives are commonly employed in the diesel engines such as dimethyl ether, naphthalene, acetone, camphor, benzyl alcohol, toluene, xylene etc [1-6]. The purpose of the present work is to calculate the combustion parameters like the ignition delay, heat released, work done per cycle etc by conducting the experiments in a diesel engine run by mixing diesel with additives naphthalene and acetone and compare the relative performance of the engine with these additives.

IV. EXPERIMENTS WITH DIESEL

For the experiments, the setup used is a two cylinder, four stroke, water cooled Diesel engine. The engine is connected to the Brake -Rope type Dynamometer and a load sensor. A Pressure sensor is mounted on the top of cylinder to detect the pressure. Output shaft of the engine is coupled to crank angle sensor which is used for determining the RPM of the output shaft and used for detecting crank angles at different points. Using both Pressure Sensor and Crank Angle Sensor, pressure values can be determined at different crank angles to get the Pressure-Theta graph. The Rope Brake Dynamometer along with the Brake Drum, which is coupled to the engine shaft are used to vary the load in the experiment. By varying the rope tension on the brake drum, the load can be increased or decreased. Cooling water arrangement is used to cool the brake drum during application of load.

A real time data acquisition is done by interfacing the setup with a computer using the inbuilt software with the experimental setup. The software is capable of tabulating the sample readings according to the different inputs received from the various sensors incorporated in the engine setup such as load sensor, pressure sensor, crank angle sensor, fuel sensor etc. The software is also capable of storing data, printing data and preparing spread sheet in Excel.

The Specifications of the engine are as follows:

Engine	:	Two cylinder, 4 stroke, vertical, water Cooled.
H.P	:	14 HP
Bore diameter	:	87.5 mm
Stroke length	:	110 mm
Brand	:	Kirloskar

For the experiment the engine was made to run at 1500 RPM and made to stabilize. Then, the load was set to 0 kg and Pressure-Theta and Pressure-Volume graph of the engine were taken in the Excel sheet. Then, the load was changed to different values till the rated load is achieved. The pressure-theta and pressure-volume graph were also observed for the various loads.

V. CALCULATION OF HEAT RELEASED

The heat released during the combustion was calculated using the following relation [7]

$$\frac{dQn}{dt} = \frac{\gamma}{\gamma - 1} P \frac{dV}{dt} + \frac{1}{\gamma - 1} V \frac{dP}{dt} \qquad (1)$$

Where,

dQ_n/dt is the heat released
dV/dt is the change in volume per unit time
dp/dt is the change in pressure per unit time
γ is the ratio of specific heats

The change in pressure and volume is calculated for every one crank degree change. Then, pressure and volume values are substituted during the entire combustion duration (i.e. 30 degrees before TDC) till the peak pressure is attained (i.e. 3 degrees after TDC) and summated. The summated value is then multiplied by the no. of cycles per second (i.e. no. of times fuel is injected per second in the combustion chamber) which gives the heat released.

The pressure and theta values are taken from the pressure – theta graph. Once the pressure and theta values are known, the volume at particular theta can be calculated. Pressure and crank angle sensors are present in the diesel engine setup. The sensors provide pressure values for every degree rotation of crankshaft. Volume sensors are also present and together with pressure values, they provide the Pressure – volume graph. A typical pressure theta graph (Fig1) and the heat release graph (Fig2) are shown below for the engine running with pure diesel and at a load of 20kg.

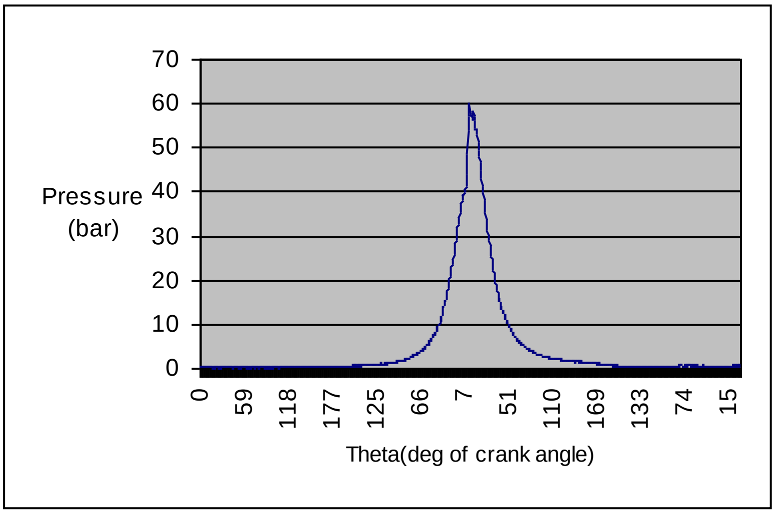

Fig 1 Variation of cylinder pressure at different crank angles.

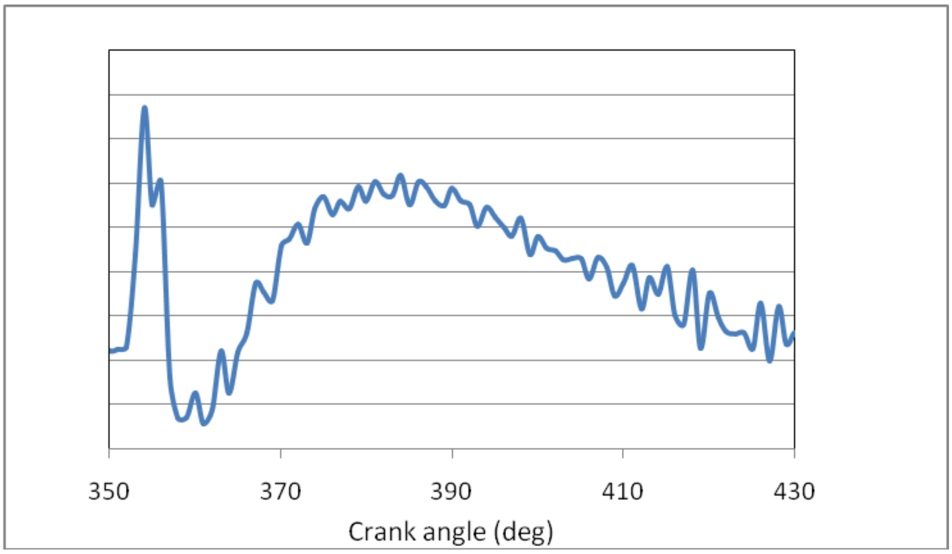

Fig. 2 Heat released at different crank angles.

VI. CALCULATIONS OF WORKDONE

The work done is calculated by calculating the area under P-V (Pressure-Volume) graph. The P-V values were obtained experimentally. The work done is positive for suction and expansion stroke whereas negative for compression and exhaust stroke. The values were then summated.
The work done per cycle is calculated using the relation [7]

$$W = \int_{V_i}^{V_f} PdV \qquad (2)$$

Where V_i is the initial vc the final volume. Pressure – Volume graph is obtained experimentally.

VII. IGNITION DELAY

Ignition delay is the time difference between the start of fuel injection into the cylinder and when the fuel actually starts to burn.
Ignition delay is calculated using the following relation [7]

$$\tau_{id}(CA) = (0.36 + 0.22Sp)\exp[EA(\frac{1}{RT} - \frac{1}{17190})(\frac{21.2}{P-12.4})^{0.63}] \qquad (3)$$

Where,

P is the pressure at the end of compression stroke at TDC (bars)
T is the temperature of the charge at TDC (Kelvin)
S_p is the mean piston speed of the engine (meter per second)

R is the universal gas constant (8.314 J/mol.K)
E_A is the apparent activation energy (joules per mole) and is given by[7]

$$E_A = \frac{618840}{CN + 25} \qquad (4)$$

CN is the Cetane number of the fuel.
The above relation gives the ignition delay in degrees rotation of the crankshaft and can be converted into milliseconds using the speed of the engine.

VIII. EXPERIMENTS WITH ADDITIVES

For the experiment with acetone, around 25 ml. of Acetone (CH_3-CO-CH_3) was mixed with three liters of Diesel and the engine was run at different loads. Naphthalene, with chemical formula $C_{10}H_8$, is the second additive that was used for the experiment. Naphthalene consists of fused pair of Benzene rings and is white crystalline solid. For the experiment, two mothballs were mixed in three liters of Diesel and then engine was operated at four different loads as in previous case.

IX. COMPARISON OF VARIABLES FOR DIFFERENT FUELS

Comparison of heat released

The first quantity that will be compared is the Heat Released Graph for 100% Diesel, Acetone added in Diesel and Naphthalene balls added in Diesel for the various loads. In Fig3 the Horizontal axis (X-axis) represents the Crank Angle in Degrees and the vertical axis is the Heat Released which is in a relative unit (bar-cc / theta) for all the three cases. The plot assumes the following shape. From the Comparison of Heat Release Graph, it was found out that the peak pressure obtained in the case of Acetone and Naphthalene Balls is much higher than 100% Diesel.

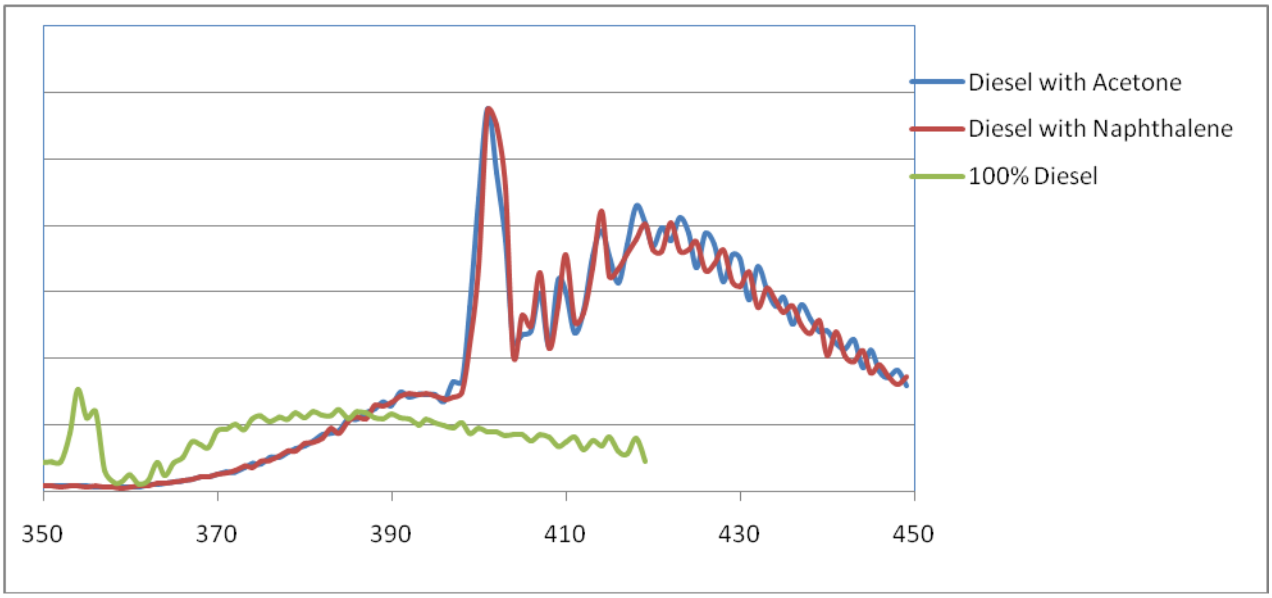

Fig3 Comparison of heat released at different crank angles

Comparison of Work Done

The work done per cycle in kJ is compared at all the four loads in tabular form (Table 1). As expected, the work done by the engine increases as the load increases.

Load	Work Done		
	100% Diesel	Acetone in Diesel	Naphthalene in Diesel
0 Kgs.	0.1023 KJ	0.162 kJ	0.179 kJ
10 Kgs.	0.1225 kJ	0.294 kJ	0.286 kJ
20 Kgs.	0.1394 kJ	0.365 kJ	0.3318 kJ
30 Kgs.	0.2061 kJ	0.417 kJ	0.388 kJ

Table 1: Comparison of Work Done

From the table 1, it is evident that work performed by the engine increases when the engine runs with additives as compared to 100% Diesel run. The expected trend of increasing work with increasing load is also seen.

Comparison of Ignition Delay

The Ignition delay is compared for all the four values of load on the engine similar to the work done (Table 2). As discussed earlier, the ignition delay is the time lag/delay between the time when the fuel is injected into the cylinder and when the actual combustion of fuel starts taking place. From the values it can be observed, 100% Diesel has the least Ignition Delay values when compared to other two. It is owing to the high Cetane Number (approximately 45) of Diesel. Naphthalene, owing to its very low Cetane Number (around 10) has high ignition lag period as expected.

Load	Ignition Delay (milli-seconds)		
	100% Diesel	Acetone in Diesel	Naphthalene in Diesel
0 Kgs.	1.588	7.35	7.43
10 Kgs.	1.4787	7.21	7.28
20 Kgs.	1.413	7.1	7.12
30 Kgs.	1.3688	6.993	6.993

Table 2: Comparison of Ignition Delay

Comparison of Brake thermal efficiency with engine Brake Power

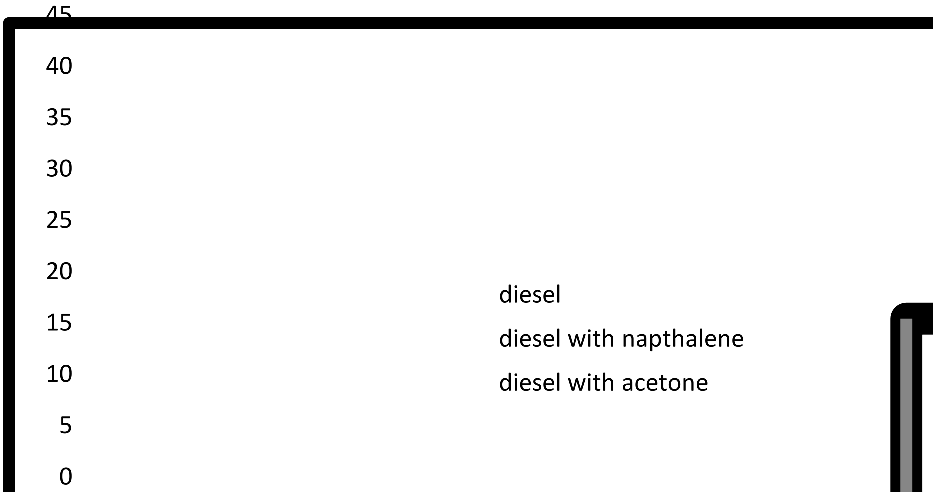

Fig 4: Variation of Break thermal eff. (%) with BP

Figure 4 shows the variation of brake thermal efficiency with the engine brake power output. From the graph it can be seen that with the increase in BP the three curves tend to follow the expected trend ie. an increasing trend. It can also be seen that the efficiency is higher for the engine with the additives compared to the base engine operation with diesel alone. This further validates our calculation of higher work output for the engine operated with the additives.

X. RESULTS AND CONCLUSIONS

Firstly, a number of experiments were conducted in the laboratory with 100% Diesel to determine the ignition delay, heat released, work done and efficiencies.

Next, after the Diesel experiment, additives like Acetone and Naphthalene Balls were added to the Diesel and the experiments were conducted. From the data obtained from the experiments, it was found out that the peak pressure obtained was attained quite a few degrees after the Top Dead Center or during the expansion stroke both in the case of the Acetone and the Naphthalene Balls. The Heat Release graph, Work done and Ignition Delay was calculated for all the three fuels and compared.

Ignition delay was found at four loads and the results were tabulated. From the table 2 it can be concluded that with increasing loads the delay period tends to decrease at same engine speed and it can also be observed that 100% Diesel has the least Ignition Delay values when compared to other two.

From the Comparison of Heat Release Graph, it was found out that the peak pressure obtained in the case of Acetone and Naphthalene Balls is much higher than 100% Diesel. Therefore, by advancing the ignition timing of the fuel, and using these additives, high heat release can be obtained in the engine. Also, the work performed by the engines in case of additives per cycle is much higher when compared to 100% Diesel. So, these additives can actually increase the work performed by the engine per cycle and heat release and thus the efficiency by employing certain Ignition advancing techniques.

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