PERFORMANCE CHARACTERISTICS AND ENERGY ANALYSIS OF A 4-STROKE SINGLE CYLINDER DIESEL ENGINE USING DIESEL AND DIESEL-KEROSENE BLENDS

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Abstract

The energy has become the essential part of human life which leads to a global challenge for sustainable development. As the conventional fuels are depleting in a very fast manner and hence it becomes important to make some methods either by switching towards alternative fuels or using advanced technologies which will reduce the losses in the existing system. Though a lot of work has been done on the performance and emission analysis of compression ignition engine using diesel and diesel-kerosene blends, still there are some important issues which need to be resolved. In this article, energy analysis of a single cylinder 5 HP water cooled diesel engine has been performed. Based on the analysis, a comparison has been shown through the graphs for diesel and diesel-kerosene blends. At various load condition, the engine performance has been analysed. The percentage energy consumption in every part of the engine at different loads for each blend is shown. When pure diesel is used, the characteristic curve for each performance parameter is smooth. Whereas, energy loses in the case of diesel-kerosene blends through exhaust gases and as unaccounted losses maintain this smooth trend till 20% kerosene level. As the kerosene increases beyond 20%, the exhaust gases and unaccounted losses do not maintain this smooth trend. As engine load is increased, all the fuel blends show a lower value of brake specific fuel consumption (BSFC). At maximum brake power, the value of BSFC is highest for pure diesel and the graph is almost overlapping for the other blends. As the engine load is increased, the brake thermal efficiency (BTE) also increases. When the engine is at no load condition, the BTE shows the lowest value and the highest being at K40. Heat release rate (HRR) increases with higher engine load. Higher the engine load, lower the air-fuel ratio and more is the Heat Release Rate. It can be seen from the graph that at maximum load condition pure diesel has the highest HRR whereas K40 blend has the lowest value of HRR.

Keywords: Diesel Engine, Diesel, Kerosene, Combustion, Energy, Performance analysis.

Nomenclature:

\[ IP \quad \text{Indicated Power} \]
\[ BP/FP \quad \text{Brake Power/Friction Power} \]
\[ ITE \quad \text{Indicated Thermal Efficiency} \]
\[ m_a \quad \text{mass flow rate of air} \]
\[ m_f \quad \text{mass flow rate of fuel} \]
\[ A/F \quad \text{Air fuel ratio} \]

Symbols

\[ T \quad \text{Torque} \]
\[ H \quad \text{Heat/Energy} \]
\[ \eta \quad \text{Efficiency} \]

Subscripts

\[ w \quad \text{Water} \]
\[ bp \quad \text{Brake power} \]
Introduction

Energy is one of the essential parts of day to day activities of one’s life. Energy creation is not possible and hence fuels play an essential role in the efficient conversion of energy from one form to another. If fuel becomes scarce, energy will become a major cause of concern. Increasing energy crisis is a cause of major concern in the present world. Several researches are thus, being conducted to find out alternatives which can provide cheaper and better energy source. Kerosene is a widely used fuel to power jet engines and rocket engines and even for household purposes. Sometimes, it is also used for small outboard motors and bikes. Energy released when kerosene is combusted is similar in value to that of diesel fuel. The lower calorific value is 43.1 MJ/kg and higher calorific value is 46.2 MJ/kg. Pure kerosene is not used since the vaporization of pure kerosene is not that easy as it can withstand high temperatures. Blending of kerosene with diesel can provide many benefits. Kerosene can change the cold weather handling temperatures of diesel fuel. 10% kerosene can lower the temperature by 5°C. The blend also produces cleaner emissions. BSFC and fuel conversion efficiency are the parameters used to investigate the engine performance [1].

The various literature talks about many changes and improvements that is being tried and tested to use kerosene and check its benefits. Chen et al. [2] in 2017 experimentally proved that RP3 could be used in single cylinder CI engine for all loads in place of diesel. RP3 gave higher 2nd stage MHRR and reduced soot emissions at loads of around 0.8MPa. NO_x emissions had little difference whereas the amount of CO and THC increased by 12-24% and 11-50% respectively at low loads. As compared to diesel, RP3 gave higher indicated thermal efficiency and the fuel consumption also reduced. Tay et al. [3] in 2017 used numerical investigation on the results of changing injection timing and diverse pilot blends on combustion in an engine running on kerosene-diesel/ammonia dual fuel. With the change in pilot fuel from diesel to kerosene, the principal peak heat-release increased with a progressing SOI. In addition, as SOI progresses, a secondary peak heat-release occurs because of the fuel remaining around the crevice regionand the cylinder liner undergoing combustion. The chief advantage of progressive SOI is that ammonia undergoes complete combustion. Tay et al. [4] in 2016 developed a greatly compact and consists interaction mechanism of kerosene-diesel consisting of only 48 species and 150+ reactions, using a PSD approach to simulate diesel engine. The kerosene sub-mechanism was used for CVCC justification. Observations showed that the simulations of AHRRs, FLOLs and ignition delays are similar to that from experimental data. However, the sub-mechanism of kerosene was not aimed to replicate the emissions due to actual kerosene, although the heat released and ignition delay time is matched accurately enough. Finally, it can be established that the mechanism is robust and condensed adequately to be used for simulations of diesel engines.

Tay et al. [5] in 2016 developed a dependable kerosene–diesel reaction mechanism with chief emphasis on sub-mechanism of kerosene. With experiments related to Jet-A/JP-8 shock tube, the ignition delay periods of the sub-mechanism of kerosene were confirmed and decent compliance was seen between experiment results and predictions. In addition, persistent volume combustion authentications were also executed. The sub-mechanism is capable of predicting the ignition delay periods of JP-8 in a CVCC well for a vast series of engine-like environments. Furthermore, the reaction mechanism was capable of calculating the combustion characteristics, along with soot formation developments and oxidation trends of kerosene as well as diesel, as under actual engine settings. Aydin et al. [6] in 20, observed that to counter the negatives of the biodiesel-diesel fuel blends, biodiesel can be blended with a low viscosity liquid that is kerosene. K10, K25 and K50 were tested under constant load condition in a 4 cylinder diesel engine and it was seen that NO_x emissions reduced while HC emissions increased. Finally, it was concluded that biodiesel and kerosene blends with higher proportion of biodiesel can be a good alternative to diesel. Patra et al. [7] in 2015 conducted an experiment by blending 5% and 10% ethanol with kerosene based on flame features and combustor performance. Snapshots of the flame at high speed were examined to determine changes in brightness, standard deviation of brightness and rate of flicker occurrence of the flames. The wall temperatures of combustor and the changes in temperature and concentrations of
certain species in the exit gas were detailed. It was seen that blends with 5% kerosene reduced the values of luminosity, brightness and standard deviation of brightness due to lesser soot, significantly but increasing the proportion to 10% decreased these values very slightly. Whilst the flame flickers frequency remains almost same. Due to decrease of heat flux of radiation from the blended fuel flame of lesser luminosity, the peak combustor wall temperature decreases by approximately 11.5% and 4%, respectively, for 5% and 10% blending. Due to ethanol having a lower heating value, the temperature of exit gas using the blended fuel is lowered. The fuel combustion is better with ethanol blending which can be verified by lower CO concentration in exhaust. Ameer et al. [8] in 2015 conducted an experiment using various blends of mustard oil on a four stroke single cylinder CI engine at different loads. Mustard oil has lower values of heating hence when used alone it reduces the power output of the engine. It was observed that due to high viscosity, mustard oil is not used directly but is mixed with kerosene in certain proportions. M20 and M30 have been found as the best suitable mixture for diesel engines.

In 2015, Patil et al. [9] investigated experimentally the effect on performance characteristics on usage of blends of DEE along with kerosene and diesel. It was seen that brake thermal efficiency improves with rising percentage of DEE in diesel. With increasing amount of DEE in the blend, the smoke decreased but higher blends gave out more smoke when observed at full load. Considering other gases, amount of NO and CO emitted was reduced sharply whereas amount of HC increased at full load. Prachi et al. [10] have conducted experimental analysis on a diesel engine for diesel and diesel-biodiesel blends and they have concluded that blending of 20% biodiesel in diesel gives best performance of the engine. It was also concluded that heat release rate increased as engine load increased. It was observed that a large amount of energy wasted through the exhaust of engine. Exhaust gas taken away more energy when blends are burned as compare to pure diesel. Engine with fuel blend of 5% kerosene gave highest BTE at lower loads [11]. Bayındır et al. found that fuel consumption and bsfc were slightly increased when kerosene-diesel blends are used as compare to pure diesel [12]. Further, the authors have suggested analyzing the system performance based on second law of thermodynamics to check the scope of improvement in the existing system.

Material and Properties

Kerosene

Table 1. Certain important properties of kerosene

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Net Calorific Value</td>
<td>43 MJ/kg</td>
</tr>
<tr>
<td>2</td>
<td>Density</td>
<td>810 kg/m³</td>
</tr>
<tr>
<td>3</td>
<td>Specific Gravity</td>
<td>0.81</td>
</tr>
<tr>
<td>4</td>
<td>Kinematic Viscosity</td>
<td>2.71 X 10⁻⁶ m²/sec</td>
</tr>
</tbody>
</table>

Diesel

Table 2. Certain important properties of kerosene diesel

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Net Calorific Value</td>
<td>42.6 MJ/kg</td>
</tr>
<tr>
<td>2</td>
<td>Density</td>
<td>825.6 kg/m³</td>
</tr>
<tr>
<td>3</td>
<td>Specific Gravity</td>
<td>0.826</td>
</tr>
<tr>
<td>4</td>
<td>Kinematic Viscosity</td>
<td>4.0 X 10⁻⁶ m²/sec</td>
</tr>
</tbody>
</table>

Diesel- Kerosene Blends

Four grades of diesel and kerosene blends have been prepared. K10, K20, K30, K40 are the four blends that have been considered for the experiment. K10 means that 10ml kerosene is blended with 90 ml diesel to form a complete of 100ml blend. On the similar
grounds, K20, K30 and K40 were prepared. These blends are shown in the

![Image of Diesel-biodiesel blends, B10, B20, B30 and B40 fuel sample]

**Figure 1.** Photograph of Diesel-biodiesel blends, B10, B20, B30 and B40 fuel sample

**Experimental Setup**

An experimental setup consisting of upright 4-stroke single cylinder diesel engine (water cooled) attached on a rigid frame was used. The exhaust is characterized with a counter flow heat exchanger type calorimeter to estimate the exhaust gas mass flow rate. For load application on the engine, a brake type dynamometer is used. Mass flow which is required for combustion rate is calculated with the help of an orifice meter, which is attached to the air supply line. The working fluid in the calorimeter and the cooling system is water. A burette attached to the fuel tank measures the fuel mass flow rate. A line diagram of this setup is as shown in Fig 2.

![Line diagram for Engine with Brake Dynamometer]

**Figure 2.** Line diagram for Engine with Brake Dynamometer

Table 3. Specifications of the Diesel Engine used in the experiment
EXPERIMENTAL TEST PROCEDURE

The experimentations were completed by use of diesel and kerosene blends at varying loading conditions. Along with unadulterated diesel, four other blends were prepared for the experiments i.e. K10, K20, K30 and K40 (40% kerosene and 60% diesel by volume). For assessment of the engine performance, some significant engine parameters such as rate of air flow, engine speed, fuel consumption, temperatures of inlet and outlet of water cooling system and calorimeter were noted. After recording the observations, the main engine performance parameters like brake power, brake thermal efficiency and specific fuel consumption, among others, were determined. Further, for each case of the blends, heat balance sheet was prepared based on the energy analysis. Primarily, the engine was operated for at least thirty minutes to achieve steady state conditions and the readings for zero load condition were collected. Similarly, a set of statistics was also lodged for other loads by using all various fuels, which includes pure diesel, K10, K20, K30 and K40. By means of K10, K20, K30 and K40 fuel blends in the engine, performance characteristics were examined and then they were equated with that of the engine working on pure diesel. In addition to performance examination, a discrete heat balance sheet was prepared to confirm the position of maximum energy loss. This was prepared by the energy analysis of the existing system.

FORMULATION AND ENERGY ANALYSIS

Using equation (4.1) brake power of the engine at certain loading was calculated. A brake dynamometer is attached with the engine to measure the tension (T) in the spring balance and subsequently brake power is calculated.

\[ BP = \frac{1}{60} \times \frac{1000T}{F} \text{ kW} \]  
(4.1)

Brake thermal efficiency (%); \( \eta_{brh} = \frac{BP + 100}{mf + NCV} \)  
(4.2)

For total heat content in the fuel, net calorific value (NCV) of the fuel is considered.
Friction Power: Friction power has been calculated using William’s line. A plot between the fuel consumption and brake power (kW) has been made which shows a straight line and this line is extended towards the negative side till it touches x-axis. The value of power on the negative axis where the fuel consumption becomes zero is friction power.

Brake Specific fuel consumption (kg/kW-hr); 

\[ BSFC = \frac{mf}{BP} \]  

(4.3)

Heat Balance Sheet: Applying first law of thermodynamics, a heat balance sheet has been created for each fuel blend. All values in terms of power have been transformed to their equivalent energy values, to ensure that energy units are available for each component. For the energy unit, it was considered that the engine was running for an hour and the energy released by the fuel is taken as the total energy input to the system. Subsequently, HRR and energy exchange by other components like heat equivalent of BP, heat carried away by cooling water and exhaust gases, radiation, and unaccounted losses were also calculated. Heat equivalent to brake power: 

\[ H_{bp} = BP \times 3600 \]

Similarly, all the power units were converted into corresponding energy units.

\[ H_{un.} = H_{fuel} - (H_{bp} + H_w + H_{ex}) \]

Results and Discussions

Detailed computation and calculations have been made to calculate the engine parameters, based on the experiments conducted. The various performance parameters that are considered in the present analysis are brake power, friction power, indicated power, brake thermal efficiency, BSFC and heat release rate. Consequently, a detailed energy analysis for the same engine has been performed to check the possibility of saving energy and to identify the possible improvements that can be done in the available setup. The energy analysis was completed using the first law of thermodynamics and numerous graphs have been plotted to get a better understanding of the system. Equation (4.1) has been used to calculate brake power under various load conditions. For each blend, William’s line has been plotted to compute friction power. The graphs mentioned below show the percentage energy consumption at different loads. The loads applied to the engine during experiments are 0% (no load), 20%, 40% and 60%.

Fig 4: Energy consumption for pure diesel K0

Fig 5: % Energy consumption for pure diesel K0

With increasing load increases the heat release rate of the engine. With the engine load, the brake power also increases. When the engine runs on pure diesel, a smooth curve can be seen for every parameter but those for energy losses are not smooth. It is very fluctuating as shown in figure 6,8,10 and 12.
Fig 5, 7, 9, 11 show the percentage energy consumption in each part of the engine at varying loads. Maximum energy was observed when the brake power was zero. As temperature increases, the energy lost also increases. In the current experiment, radiation losses are not considered. The engine is run with pure diesel and then the following blends of the mixture - K10, K20, K30, K40. After the experiment with one particular blend, the engine is cooled down to the natural temperature. All the graphs shown below have energy called as ordinate and load has abscissa.
Brake Thermal Efficiency

From Fig. 14, a similar nature is seen for the plot of BTE with respect to the engine load. With a rise in engine load, the BTE also rises. When the engine is at no load, the BTE is the lowest, the highest being at K40.

Fig 14: % BTE for all blends at varying loads

Fig 15: Brake Power for all blends at varying loads

Fig 15 shows that Brake Power increases with the increase in engine load. Fig 16 illustrates the graphs for A/F ratio with respect to load for each blend has. At no load condition, maximum A/F ratio has been observed for all the blends. At higher engine loads, all the curves in the graph almost coincide except the one with pure diesel, and hence engine requires almost same fuel-air mixture.

Fig 16: A/F ratio for all blends at varying loads

Fig 17: BSFC for all blends at varying BP
Brake Specific Fuel Consumption

The variation of BSFC and brake power for each blend has been shown in Fig. 17. A uniform trend has been observed for all the blends. As the brake power increases BSFC decreases. At maximum brake power, the value of BSFC is highest for pure diesel and the graph is almost overlapping for the other blends. This value depends on the viscosity, density and chemical composition of the fuel.

Heat Release Rate

The heating value if fuel and the fuel-air mixing determine the heat release rate. HRR increases with an increase in the engine load since higher the load, lower the air-fuel ratio and more is the Heat Release Rate. It is clear from the graph that pure diesel has the highest HRR where as K40 blend has the lowest value of HRR, at maximum load condition.

The graph in Fig. 19 shows the energy lost in exhaust gases when the engine is run at varying loads, using different blends. When the engine is at no load condition, a lot of energy is wasted in exhaust. Around 40% of the fuel energy is rejected in the environment as exhaust. For most of the blends, the heat rejected in exhaust is lesser at full load as compared to the no load condition.

Conclusions

In this paper, energy analysis of a single cylinder 5 HP water cooled diesel engine has been performed. Energy analysis for each of the blends, such as K0 (pure diesel), K10, K20, K30 and K40 fuels, have been done. Based on the analysis, a comparison has been shown in the graphs for kerosene and diesel-kerosene blends. At various loading conditions, the performance of the engine has been evaluated and percentage energy consumption in each component of the engine for each blends are presented. A detailed heat balance sheet for the engine has been drawn for each blend. The major conclusions based on the experimental results are summarized as follows:

- The brake thermal efficiency increases as the engine load increases. When the engine is at no load condition, the BTE shows the lowest value and the highest being at K40.
- At higher engine load, all the fuel blends show a lower value of BSFC. At maximum brake power, the value of BSFC is highest for pure diesel and the graph is almost overlapping for the other blends.
- Heat release rate increases with an increase in the engine load. Higher the engine load, lower the air-fuel ratio and more the Heat Release Rate. It can be seen from the graph that at maximum load condition pure diesel has the highest HRR whereas K40 blend has the lowest value of HRR.

From the present analysis, one can conclude that the high-temperature exhaust gases will have enough energy content to utilize. Exhaust gases are at a temperature of 100°C and thus has high energy content. From the second law of thermodynamics, it is
known that the higher the temperature at which the energy is available, higher is the quality. Hence, the high-temperature exhaust gases will have higher exergy content. The present work can thus be extended to do a detailed exergy analysis.

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