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Research Article

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The Impact of Variable Parameters on the Performance of a Dual Fuel Engine

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Abstract The diesel engine gives high thermal efficiency and brake power with less fuel consumption compared to a similar gasoline engine. However, the resulting exhaust pollutants are significant and affect the environment and public health. In this study, the performance of a single-cylinder combustion engine is evaluated by adding liquefied petroleum gas to diesel fuel at different volumetric rates .The thermal efficiency is increased by increasing the proportion of diesel fuel at low loads, and reduced by increasing the load. For the stable operation of a dual-fuel engine, an appropriate amount of diesel fuel must be maintained. As the engine operated at lower amount of diesel, the engine operated irregularly and may failed to operate. The fuel consumption of dual-fuel engines is greater than that of diesel fuel only. When the engine was operated close to total load, the fuel consumption of a dual engine specific fuel consumption approached to its value when operating with diesel fuel only.

Keywords LPG, dual engine, delay period, thermal efficiency

Introduction

The world benefits from diesel engines in operating a variety of transport vehicles such as small cars, buses, Lorries, construction equipment, trains, and ships [1]. It is also used in the production of electric power through generators whose generation capacity reaches several megawatts [2]. The impact of pollutants emitted from these engines on the environment has become known to all [3]. Pollutants from the diesel engine contribute to air pollution [4], increased global warming [5], and climate change around the world [6]. Therefore, Europe and the United States have started to set many legislations to reduce emissions and are strictly enforced, forcing manufacturers of these engines to create many alternatives to reduce the pollutants emitted from these engines [7].

Dual fuel engines are defined as engines that can operate on two different types of fuel, one gas and the other is liquid fuel, or one of the two fuels separately [8, 9].

Several factors contributed to the use of this type of engines:

1. Gas fuel is available at cheaper prices than liquid fuel, compared with the thermal value generated by both [10, 11].
2. The conventional liquid fuels are close to be depleted in the near future [12].
3. The cleanness burning of duel fuel reduces the environmental pollution as the emission emitted from the gas engines are less than liquid fuel [13, 14].
4. The operating life of the engine extended more due to lower lubrication dilution that reduces the corrosion between the engine's parts surfaces [15, 16].
5. The easy transport of liquefied gases economically because of the major developments in the construction of reservoirs [17].

6. The simplicity of equipment to convert a compression ignition engine into a dual-fuel engine, and the possibility of changing the engine's function from one type to another automatically at compulsory conditions [18].

Gaseous fuels such as natural gas (NG) and liquefied petroleum gas (LPG) require high compression ratios to obtain an efficient combustion process for its high self-ignition temperature [19]. This high compression ratio is not available in spark ignition engines [20]. Many types of gaseous fuels can be used in dual-fuel engines, such as natural gas, liquefied petroleum gas, hydrogen, liquefied petroleum gas and gasoline [21].

The thermal value of gaseous fuel used in a dual fuel engine shall not be less than 2430 kJ/m^3 [22]. Several factors affect the combustion nature of dual fuel engines:

1. Diesel fuel: Diesel fuel is used to help start ignition and is usually injected several degrees before the top center point (before the end of compression stroke) [23, 24]. If the amount of the entered fuel is large, the amounts of heat released and transferred to the mixture will also is large, resulting in rapid combustion accompanied by a sharp increase in the maximum pressure of the cylinder [25].This combustion makes the engine in conditions close to that of knock conditions [26]. But, if the amount of diesel fuel is low, the engine brake power will be decreased as a result of the incomplete ignition of the whole mixture, and a part of unburnt fuel will exit with exhaust gas [27].

   Most studies have confirmed that the best power can be obtained from a dual fuel engine when the diesel fuel is about 7 to 15% of total thermal energy entering the engine at full load [28, 29].
2. The effect of injection timing: The early timing of injection increases the delay of ignition, causing higher maximum pressure value, which increases the probability of knock condition [30].While the delayed timing of injection reduces the delay of ignition, resulting in combustion after the upper dead center in many degrees, which reduces the maximum pressure of the cylinder, thus reducing the output power of the engine [31, 32].
3. The effect of the cetane number: The decrease in the cetane number than its natural value weakens the dual fuel engine performance [33]. Although the impact of the cetane number is little in the nature and quality of combustion of dual fuel engines compared to the octane number of gaseous fuel [34].
4. The effect of the temperature of the mixture entering the engine: The increase of the temperature of the mixture entering the cylinder at high loads caused the low output power of the engine [35]. As well as its increase at low loads requires the engine operation at the lean side [36].The low temperature of the mixture at partial loads of the engine running with a rich mixture improves the thermal efficiency, while this efficiency decreases in the case of a lean mixture for lack of complete combustion, and the exit of the amount of the fuel with the exhaust gas [37].
5. Effect of the type of used gas: The effect of the type of fuel gas used in dual fuel engines mainly depends on the limits of ignition and resistance to knock [38]. These characteristics vary depending on the components of the gas, and rely heavily on the extraction sites [39].

Duel fuel engines can run in liquid and gaseous fuels, the added fuels to diesel may be liquids as ethanol [40, 41], methanol [42, 43], and biodiesel [44, 45]. Gaseous fuel is highly efficient when working on the rich side of the mixture, rather than on the weak side [46]. Most of which have high knock resistance [47]. The equivalent ratio of the dual fuel engine depends mainly on the amount of diesel fuel needed to ignite the mixture in the combustion chamber [48]. High engine power can be obtained when working with a lean mixture, because it has a relatively long delay period and a slow combustion rate [49]. These characteristics lead the combustion to happen near the maximum pressure position of the top dead center, which increases the combustion efficiency [50]. Working with the rich mixture will causes a quick and sudden burning accompanied by a sharp rise in the maximum pressure of the cylinder, causing knock condition [51, 52].

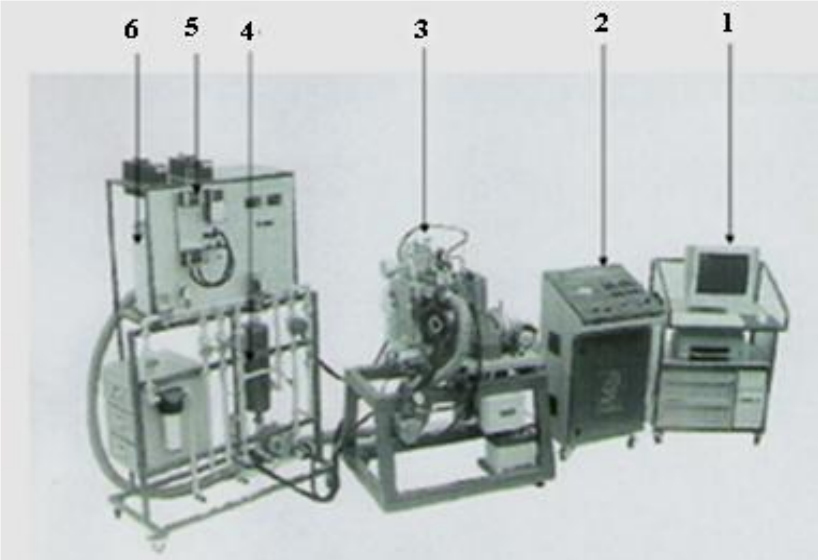
This paper aims to evaluate the benefit of using duel fuel (consists of LPG and Diesel) in a single cylinder diesel engine. A comparison will be made between dual fuel operation and neat fuel operation.

Experimental Setup

The experiments were carried out using a single-cylinder, four-stroke internal combustion engine with a variable compression ratio type (GR0306/000/ 037A, Prodit Company, Italy). The engine is connected to a hydraulic dynamometer, which is used to measure the torque projected on the engine. The air supplied to the engine is measured by an orifice plate. The air processing system is composed of: air intake pipe, damping chamber, and differential power switch. The exhaust gas temperature measured using thermocouples type K, installed at the beginning of the exhaust pipe.

LPG feeding system:

The system used to supply the engine with LPG composed from the following parts: fuel tank, fuel filter, electromagnetic valve, liquefied petroleum gas evaporator, gaseous fuel flow meter, damping box, gas feeder and flame retardant. Fig. 1 shows the engine used in experiments with all its accessories.



1. Computer and its accessories 2. Control panel 3. The engine 4. Engine's cooling unit 5. The engine's fuel unit 6. The air supply system

Figure 1: The system used in experiments

The following equation used to calculate the engine variables [53]:

1. Brake power (bp):
2. Bp=Wb*N/34

As, W_b– the subjected load in N

N- engine speed in revaluation by second (rps)

3. The equivalence ration (Ø)

$Ø= (A/F)_{stoichiometric}/ (A/F)_{actual}$

4. The specific fuel consumption

$bsfc=m^o{}_f* 3600/bp$

As, $m^o{}_f$– fuel consumption rate (LPG+diesel)

5. Volumetric efficiency

$\eta_{vol}= (m_a)_{act}/ (m_a)_{theo.} *100$

As, $(m_a)_{act}$- The practical air mass flowing into the engine

$(m_a)_{Theo.}$- The theoretical air mass flowing into the engine

Results and Discussion

The performance of a dual fuel engine is an indication of the degree to which it succeeds in achieving the required functions. The degree of success is measured by several factors. The factors that are highlighted in the research are the specific fuel consumption, the amount of diesel fuel entering the engine, and the mean effective pressure of different operational conditions.

The relationship of these factors with the cylinder maximum pressure, the delay period of flame, and thermal efficiency are as follows:

1. The specific fuel consumption

Figure 2 shows the relationship between the specific fuel consumption and the thermal energy ratio of diesel fuel to the total energy entering the engine. When the engine operated at low loads (3.08 bar), the largest specific fuel consumption occurred at the lowest rate of diesel fuel due to lean mixture strength and low combustion efficiency. After this point the specific fuel consumption starts to reduce as the diesel fuel share in the mixture increased. As the amount of diesel fuel increased the thermal energy transferred to the gas fuel was increased, thus reducing the amount of non-burning fuel that comes out with the exhaust gas.

The specific fuel consumption returned to increase once again when the engine is powered only by diesel fuel, because diesel engines generally have higher fuel consumption at low loads. This phenomenon was due to the lean equivalence ratio and the diesel fuel failed to combust completely.

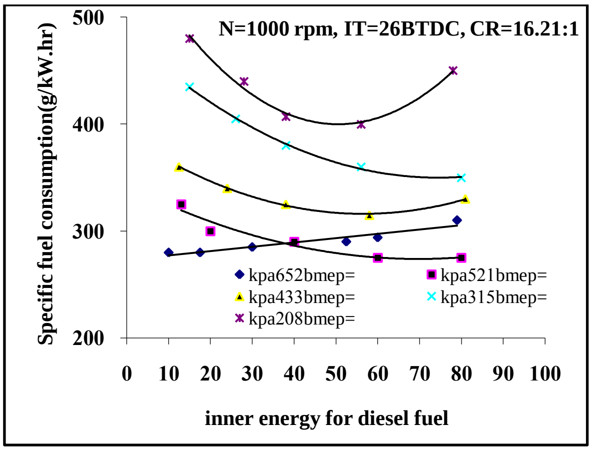


Figure 2: The relation between specific fuel consumption and the diesel thermal energy rate to the total energy of the engine

At medium loads, the maximum specific fuel consumption also occurs at the lowest ratio of diesel fuel, and continues to decrease with the increase of this percentage until it reaches the minimum value when the engine run only by diesel fuel. Increasing the load at low concentration of gas in the mixture led to an increase in the entered air quantity. The increase of air quantity resulted in higher burning efficiency of the engine, resulting in higher combustion efficiency. At high loads, the minimum specific fuel consumption is occurred at the lowest proportion of diesel fuel due to the higher combustion efficiency and the lower the amount of fuel that is not burned. The maximum specific fuel consumption occurred when diesel fuel was used alone. In this case, there is no time period for completely burning the fuel, which led to exit some of this fuel in the exhaust gas. This condition led to a qualitative increase in fuel consumption.

2. Brake thermal efficiency and diesel fuel quantity

Fig. 3 shows the relationship between the brake thermal efficiency and the thermal energy ratio of diesel fuel to the total energy entering the engine. All curves start from the ignition failure point due to insufficient diesel fuel for a stable combustion process.

The engine operation at part loads can be achieved by reducing the diesel fuel percentage at fixed load that led to reduce the brake thermal efficiency. This impact appeared obviously at low loads. The increase in diesel fuel percentage from 15.7 to 100% and from 11.1 to 100% for loads (3.08 and 5.33 bars) led to increases the efficiency by 17 and 10%, respectively. When the engine was run at a load close to the maximum load of 7.52

bar, it was observed that the thermal efficiency of a dual fuel engine was equal to the working state with diesel fuel only. The dual fuel engine can burn greater amounts of gas that fills the combustion chamber, due to the formation of many fronts of flame cornels in the combustion chamber, resulting in efficient combustion. Thus, the engine will run in higher output power. When the fuel is liquid, the diesel drops cannot occupy the entire combustion chamber, resulting in the quantities of unburned fuel existed with the exhaust gas. The curves manifested that increasing the load led to increased brake thermal efficiency for the same mass, because increasing the load led to improved combustion efficiency.

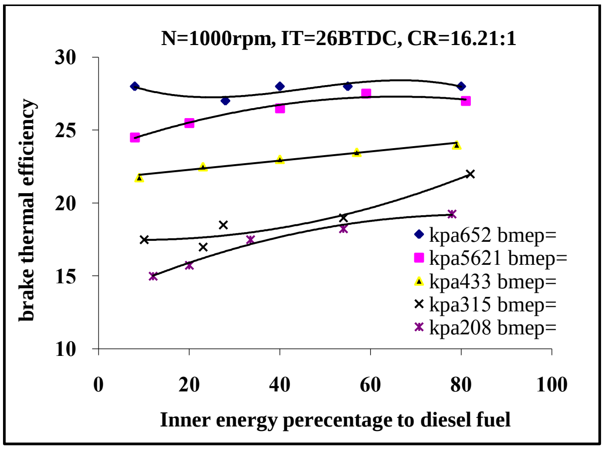


Figure 3: The relationship between brake thermal efficiency and the thermal energy ratio of diesel fuel to total energy entering the engine

Fig. 4 shows the relationship between brake thermal efficiency and the brake mean effective pressure when the engine is powered by diesel fuel only, and when it was supplied by the lowest proportion of the thermal energy of diesel fuel to the total energy of the engine.

The minimum ratio of diesel fuel required for the operation of a dual fuel engine stable at fixed speed, injection timing, compression ratio and various loads was at 18.2 to 19.3% of the thermal energy entering the engine are specified.

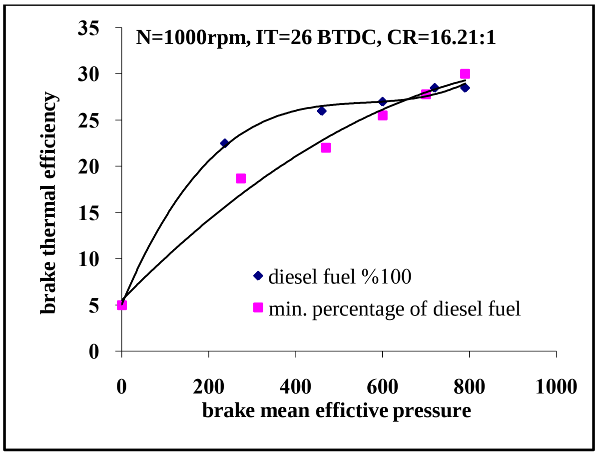


Figure 4: The relationship between brake thermal efficiency and mean effective pressure

Fig. 5 declares the relationship between the thermal energy consumed by the engine and the ratio of the thermal energy of diesel fuel to total energy. The reduction in the thermal energy consumed by the engine due to the increased combustion efficiency in high diesel fuel rates occurred because of the reduction in quantity of unburned fuel. At the low fuel consumption of diesel fuel, the fuel does not completely burn, which increased the amount of fuel needed by the engine to maintain the speed required.

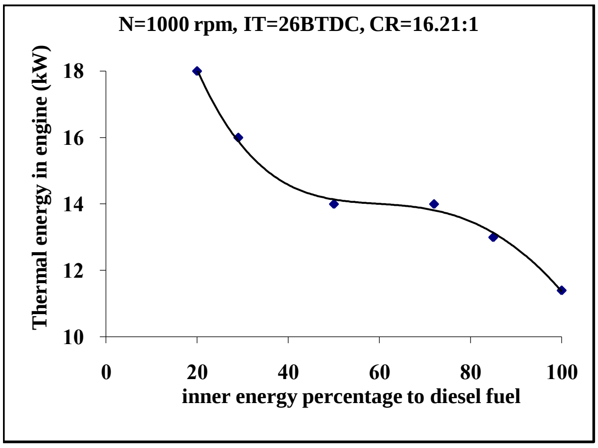


Figure 5: The relationship between the thermal energy consumed by the engine and the ratio of the thermal energy of diesel fuel to total energy

Maximum cylinder pressure

From the observed pressure values of the test groups in Fig. 6 for different percentages of the thermal energy of diesel fuel to the total engine power; the lower maximum pressure value was observed at partial loads in the case of engine operation at low rates of diesel fuel. The maximum pressure value of the cylinder was low, and increase by increasing the proportion of diesel fuel to reach its highest value.

At medium loads, the reduction in the amount of gaseous fuel in the mixture causes an increase in the amount of air inside the cylinder, and the high proportion of diesel fuel led to an increase in the amount of heat released and transferred to the gas fuel, which increased the efficiency of combustion.

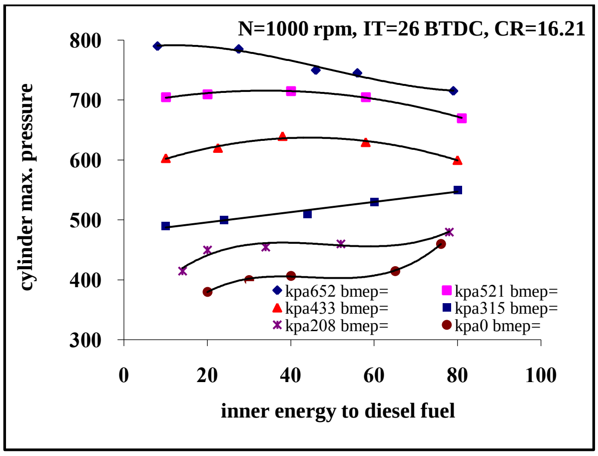


Figure 6: The recorded pressure values for the set of tests for variable rates of the thermal energy of diesel fuel to the total energy of the engine

When the load is close to the maximum value, the highest value of pressure inside the cylinder occurred when the engine was run at the lowest proportion of diesel fuel. The maximum load value started to decrease gradually with the increase in the proportion of diesel fuel. This happened because of the reduction in the delay period and the lack of time enough to prepare the largest amount of fuel ready to combust. The mixing nature at the high fuel gas ratios in a dual fuel engine at high loads is much better than the mixing nature of a diesel engine only. This led to better spread and distribution of flame and rapid and efficient combustion. If the maximum pressure value of the engine decreased, the operation can be switched to be only with diesel fuel.

Flammable delay period

The ignition delay period is measured in terms of crank angle degrees from the pressure curves. This period represents the period from the start of the fuel injection in crank angle degree at which the pressure curve is separated from the pressure curve of the air when the combustion is obtained if the engine is run at fixed speed.

Fig. 7 shows the relationship between the degree at which the ignition starts at the injection timing at 26° before top dead center (BTDC), to different proportions of the thermal energy of the diesel fuel to the total energy of the engine and with different loads. The increase in the amount of gas in the mixture led to a decrease in the amount of air arriving to the engine as a result of the volume it occupied rather than the air. In addition to the length of the chemical delay of the mixture was due to the lack of oxygen in large quantities.

The delay period is affected by the pressure and temperature of the mixture during the compression stroke. As increasing the engine load causes an increase in the cylinder contents temperature, and then the period will decrease.

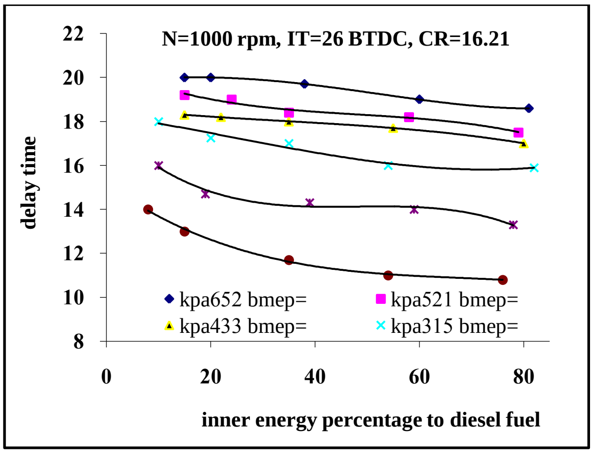


Figure 7: The relationship between the degree at which ignition starts and fixed injection timing of 26°BTDC, with different loads

Conclusions

This article investigated the use of dual fuel to operate a single cylinder diesel engine without any modification on the engine except for the LPG feeding system. The conclusions obtained from this study are:

1. The increase in the proportion of diesel fuel in low loads reduced the specific fuel consumption, until it reaches the lowest value in the proportions of 40 to 60% of diesel fuel, then it raised again.
2. The highest specific fuel consumption is achieved in medium loads at the lowest ratio of diesel fuel.
3. At loads close to the maximum load, the least specific fuel consumption was occurred when the diesel fuel proportion was at its lowest value.
4. The thermal efficiency of a dual fuel engine in high loads is greater than its value when working with partial loads.
5. The increase in the proportion of diesel fuel in low loads led to higher thermal efficiency gradually progressive, and more clearly than when the engine works with medium loads.
6. When the engine was loaded close to the maximum load, the thermal efficiency of the dual engine is approximately equal to its value when operating with diesel fuel only.
7. The ignition delay period was increased at low rates of diesel fuel in the mixture, and decreased several degrees with increasing diesel fraction. Increasing engine load caused a decrease in the ignition delay period.

8. The maximum cylinder pressure occurred at low loads when the engine ran with diesel fuel only. While the maximum value when the engine works in medium loads occurred at rates between 40 to 60% of diesel fuel. At loads neat the full load, the maximum pressure inside the cylinder occurred at the lowest proportion of diesel fuel.

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