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Effect on ignition delay period of a dual fuel diesel engine by hydrogen and producer gas

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Abstract

This ignition delay of a dual fuel diesel engine analyzed experimentally the effect of hydrogen, producer gas and combination of producer gas and hydrogen paper are presenting in this paper. The experiments were conducted on a 4-cylinder turbo-charged and intercooled 62.5 kW gen-set diesel engine running at constant speed of 1500 RPM. The experiments were conducted with different quantity of hydrogen and producer gas as a secondary fuel with diesel as pilot fuel at wide variety of load conditions. It was pragmatic that, when only 30% of hydrogen is used as secondary fuel ignition delay increased by 2^0*CA at lower load condition. Furthermore, by 50% of hydrogen substitution maximum reduction in ignition delay was observed at 80% load condition. By 50% producer gas substitution the ignition delay is increased by* 6^0*CA at 80% load condition. In mixed fuel mode (*$PG+H_2$*), it was found that of all the different mixture combinations verified, the ignition delay are more than pure diesel operation but better as compared to producer gas alone.However, mixture combination of* $PG:H_2=(60:40)$ *is found to be the most suitable one at which ignition delay is in good comparison to that of pure diesel operation.Further, it is experiential that the ignition delay of dual fuel engine depends not only on the type of gaseous fuels and their concentrations but also on charge temperature, pressure and oxygen concentration.*

Keywords: *Dual fuel engine, Alternative fuels, Hydrogen, Producer gas, Ignition delay.*

1. Introduction

In the century, it is believed that crude oil and petroleum products will become very scare and costly. Day-to-day, fuel economy of engines is getting improved and will continue to improve. However, enormous increase in number of vehicle has started dictating the demand for fuel. Gasoline and diesel will become scare and most costly in the near future. With increased use and the depletion of fossil fuels, alternative fuel technology will become more common in the coming decades.

Another reason motivating the development of alternative fuels for the IC engine is the concern over the emission problem of gasoline and diesel engines.

A third reason for alternate fuel development is the fact that a large percentage of crude oil must be imported from other countries which control the larger oil fields.

Hydrogen is thought to be the most possible alternative fuel for vehicle because of its clean, high efficiency and reproducibility characteristics. It requires smaller ignition energy, has a wider fire range and faster burning speed in contrast with gasoline and diesel. Among the other gaseous fuels, producer gas derived from biomass gasification is a better alternative as an environment friendly fuel. This fuel gas, in addition to being CO_2 neutral, generates lesser quantity of undesirable emissions [4]. In the current background of the petroleum fuel, biomass gasification identifies for better utilization of the biomass resources available in huge quantity by thermo chemically converting in to producer gas.

In dual fuel engine the combustion process is quiet different than C.I. and S. I. engines. The ignition delay in a diesel engine is defined as the time onwards between the injection of first droplet in to the combustion chamber and the first sign of combustion [1]. Further, it can also be defined as the angle between the time of injection and the time at which 1% of mass fraction is burned. Hence in a dual fuel diesel engine, it becomes important to determine the start of injection and start of combustion to estimate ignition delay period. The beginning of injection of pilot diesel fuel usually defined as the immediate when the injector needle lifted a specified distance from its seat [2]. The initiation of combustion is defined as the crank angle at which the heat release rate becomes zero and then becomes positive. In this paper, the point at which the heat release rate is zero was measured as the initiation of combustion. Fig.1 presents the graph of net heat release rate vs. crank angle for the engine run on diesel only.

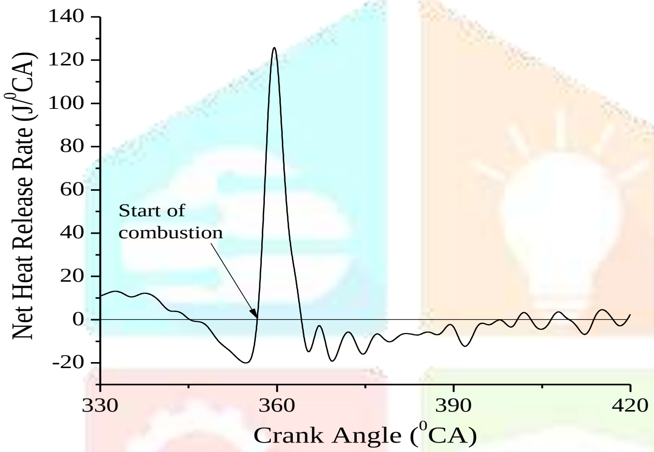

Fig. 1 Net heat release rate (J/^{o}CA) vs. Crank angle (^{o}CA)

The foreword of gaseous fuel with the intake air produces variation in the physical and transport properties of the mixture, such as specific heat ratio and to a lesser amount the heat transfer parameters. Also, changes in the intake partial pressure of oxygen due to air displacement by the gaseous fuel, changes in the pre-ignition reaction activity and its associated heat release and the effect of residual gas can bring about significant changes to the pre-ignition processes of the pilot and hence the length of the delay period [3, 4].

Lata et al. [5] correlated the experimental results for ignition delay with the relationships laid down by other researchers for diesel and dual fuel engine. It was found that the ignition delay of dual fuel engine depends not only on the type of gaseous fuels and their concentrations but also on charge temperature, pressure and oxygen concentration. Nwafor et al. [6] investigated that the dual fuel operation running on natural gas shows longer ignition delay and lower burning rates. Neilson et al. [7] experimentally investigated the effect of gaseous fuels such as hydrogen, carbon monoxide, or methane on the ignition delay period in dual fuel diesel engines by using n-heptane or cetane as pilot fuels. Helium was introduced to increase compression temperature of the gaseous-air mixture whereas, nitrogen to remove the influence of specific heats and changes in oxygen concentration. It was noticed that the ignition delay period influenced mostly by cylinder charge temperature, pilot fuel quantity and flow of combustible gas. Samuel et al. [8] argued that in a dual fuel diesel engine, the pre-ignition and combustion processes are getting affected due to the presence of some methane in the surrounding air of n-heptane droplets. Moreover, increasing the concentration of methane reduced ignition delay and time to attain maximum heat release rate.

Gunea et al. [9] investigated that to ignite the gaseous fuel-air mixture, the smaller quantity of pilot fuel with higher cetane number is sufficient. Further, the result of cetane number of diesel on the ignition delay period in dual fuel engine run on pure methane, propane and mixture of methane and low heating value gases like nitrogen and carbon dioxide with different pilot fuel quantities was also observed. The variation in ignition delay period due to increased gaseous fuel adding together depends on the quantity and quality of the pilot fuel. Liu and Karim [10] observed that the use of gaseous fuels like methane, propane, ethylene, hydrogen and diluents in the diesel engine affect physical and chemical processes during the ignition delay period.

Banapurmathet al.[11, 12] investigated that the honge oil-producer gas, honge oil methyl ester-producer gas and diesel-producer gas dual fuel operation shows longer ignition delay than pure diesel operation. It was also observed that the combustion duration during dual fuel mode operations was higher compared to single fuel mode of operations. Singh et al. [13] observed that producer gas could be used in CI engine without any modification. However, it cannot replace fossil diesel completely because of its poor ignition delay.

Hernandez et al. [14] used CHEMKIN software along with GRIMech. chemical reaction mechanism to compare the results of auto-ignition delay time for various composition of producer gas at different values of pressure, temperature and equivalence ratio with those obtained for iso-octane and methane. He showed that producer gas has potential to reduce knock tendency in S.I. engine. Martinez et al. [15] reviewed that at a constant cylinder pressure of 20 bar, the auto-ignition delay period for producer gas was much longer than that for gasoline in the low temperature range. While, at high temperature range the ignition delay period significantly shortens. Moreover, for pressure increased to 50 bar the auto-ignition delay period for producer gas remains just slightly shorter than that for gasoline in the high temperature range. Selim et al. [16] examined the effects of pilot fuel quantity of a dual fuel engine and observed that the ignition delay period of the pilot diesel fuel increases, when the pilot fuel mass increases beyond a certain amount.

2. Experimentation

The experimental setup used in the present paper is same as in reference [5] and has been illustrated here in brief for the sake of clarity. A diesel engine test setup, model Ashok Leyland ALUWO4CT, turbocharged with inter-cooler and gen-set was developed to carry experimental investigation. A schematic layout of the diesel engine test setup used during the experiments is shown in Fig. 2 [5].

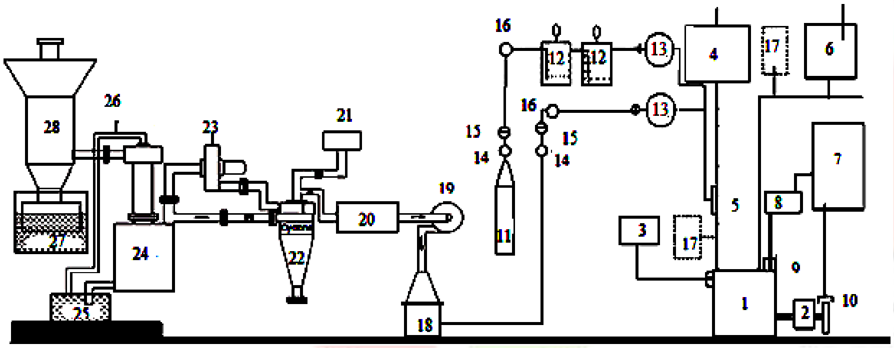

Fig. 2 Experimental set-up

Experiments were carried out for different gas-air ratios at various load conditions. The piezoelectric pressure transducer and a charge amplifier in the range of 0-250 bars were used to measure in-cylinder pressure. The pressure data were further transferred to data acquisition system for analysis. A Kistler made crank angle encoder with an accuracy of $1^0$was used for angle measurement. After 15 minutes of engine operation on stabilized conditions, the pressure data were obtained for an average of 100 cycles. The experiments were conducted for five times to ensure repeatability [1].

The experiments were conducted on the diesel engine setup under the following Cases [2].

(i) Case I : Engine runs on neat diesel only.
(ii) Case II: Engine runs on diesel as pilot fuel and hydrogen (H_2) as secondary fuel.
(iii) Case III: Engine runs on diesel as pilot fuel and producer gas (PG) as secondary fuel.
(iv) Case IV: Engine runs on diesel as pilot fuel and a mixture of producer gas and hydrogen ($PG + H_2$) as secondary fuel.

3. Results and discussions

The experimental results for injection pressure of 260 bar and injection timing of 16^0 before top dead center at rated speed of 1500 rpm are presented for the Cases II, III, and IV at various load conditions. The mixture of producer gas (PG) and hydrogen (H_2) was varied in the following proportions in each combination (M): (PG-90% + H_2-10%), (PG-80% + H_2-20%), (PG-70% + H_2-30%), (PG-60% + H_2-40%).

3.1 Ignition Delay

Fig. 3 exhibits the ignition delay for the Cases I and II at 13%, 40% and 80% load conditions. It is observed that at light load conditions for Case II, the ignition delay period initially increases up to 30% of gaseous fuel substitution as compare to pure diesel operation (Case I). Further increase in gaseous fuel substitution decreases the ignition delay period. At 13% and 40% load condition, the ignition delay for 30% and 50% of hydrogen substitution is 13.5 ^{0}CA, 11.5 ^{0}CA and 11 ^{0}CA, 10 ^{0}CA respectively as compared to 11 ^{0}CA and 9 ^{0}CA of Case I operation. The ignition delay of pilot diesel fuel initially increases may be due to drop in partial pressure of oxygen by the addition of the gaseous fuel. Besides, higher overall specific heat of the charge and less ignition sources responsible for the reduction in temperature of the gaseous fuel-air mixture at top dead center position may also increases the ignition delay. Further, since small amount of gaseous fuel are present at light load conditions, the mixture formed is lean. Thus, the rate of pre-ignition energy release becomes low and hence charge temperature as well as ignition characteristics cannot improve considerably.

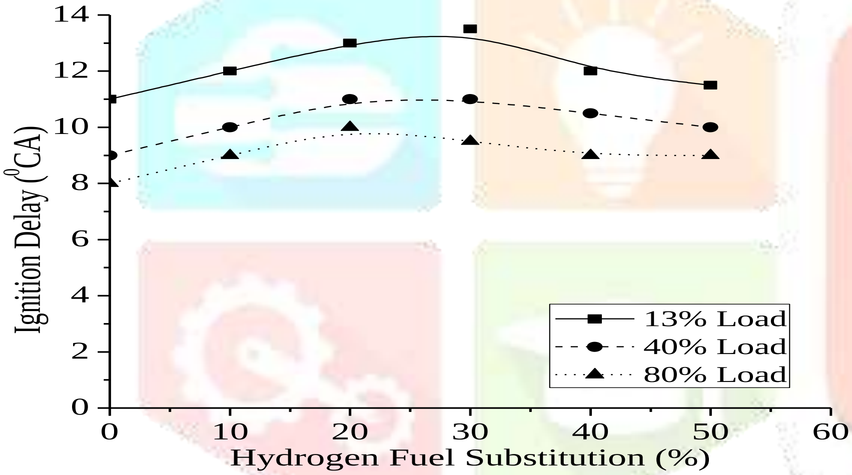

Fig. 3 Ignition delay (^{0}CA) vs. hydrogen substitution (%).

At 80% load condition (Fig. 3), the 30% and 50% hydrogen substitution shows ignition delay of 9.5 ^{0}CA and 9 ^{0}CA respectively as compared to 8 ^{0}CA of Case I operation. As the vapor pressure of pilot diesel fuel increases exponentially with the increase in temperature, the heat transfer to the diesel droplet increases, and evaporation attained at fast rate. As a result, small time is required to form a stoichiometric mixture and hence ignition delay is small [11]. Further, for higher concentration of the gaseous fuel mixture at high load condition, the propagation of flame from various ignition centers of the pilot fuel is fast and consumes the largest part of the cylinder gaseous fuel-air mixture resulted in higher residual gas temperature. Hence, ignition delay period reduces [18].

As shown in Fig.4 compared with conventional diesel engine, the experimental data indicate that the ignition delay of the Case III becomes longer at different load conditions. The ignition delay decreases with the increase in engine load. However for increased substitution of producer gas, ignition delay increases. The length of ignition delay is more at low load condition whereas, at higher load condition it is comparatively low. The ignition delay at 30% and 50% of producer gas substitutions are found to be 16 ^{0}CA and 18 ^{0}CA, 14 ^{0}CA and 16 ^{0}CA, 12 ^{0}CA and 14 ^{0}CA respectively at 13%, 40% and 80% load conditions as compared to 11 ^{0}CA, 9 ^{0}CA and 8 ^{0}CA of Case I operation. At light load conditions, the temperature of mixture at the end of compression process is lower with the increased concentration of producer gas substitution. As a result, the ignition delay of the dual fuel engine increases remarkably. Further, as the substitution of gaseous fuel increases, the ignition delay of pilot diesel fuel increases due to reduction in partial pressure of oxygen by the addition of the gaseous fuel. The associated change in the charge temperature during compression, pre-ignition energy release, external heat transfer to the surroundings and the contribution of residual gases appears to be the main factors responsible for the length of the ignition delay of the engine.

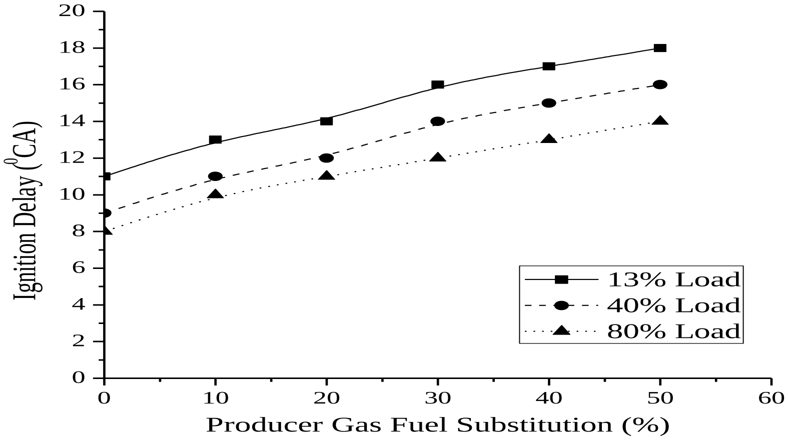

Fig. 4 Ignition delay (^{0}CA) vs. producer gas substitution (%).

The ignition delay of dual fuel engine decreases with the increase of engine load. However, it increases for increased concentration of producer gas in the mixture of producer gas-hydrogen. At light load conditions, as the mixture is lean, low rate of pre-ignition energy release and residual gas effects does not allow the charge temperature as well as ignition characteristics to improve considerably. The residual gases influence the temperature of the cylinder surfaces by causing variation in the temperature of the gaseous fuel-air mixture at the beginning of compression process. While the kinetic effect of residual gases can largely affect the performance of the engine which may cause an increase in the pre-ignition reaction activity of the gaseous fuel-air mixture.

The ignition delay period reduced at higher load condition for higher concentration of the mixed gaseous fuel. This may be due to the use of a large amount of cylinder gaseous fuel-air mixture by the flame initiated from the various ignition centers of the pilot fuel propagates at a faster rate which results in higher residual gas temperature [18].

As shown in Fig. 5 at 80% load condition, compared with other mixture combination of producer gas-hydrogen used, mixture combination 60:40 substituted in the range of 30%-70%, gives small ignition delay. During this, the gaseous fuel produces significant amount of energy and species, which help in ignition processes of the pilot diesel fuel and hence the ignition delay period is small. Fig. 11 compares the graphs of ignition delay versus gaseous fuel substitution for Cases I, II, III and Case IV (60:40) at 13% and 80% load conditions. It is evident from the figure that the ignition delay during the use of mixture combination of producer gas: hydrogen is much smaller than that of producer gas alone.

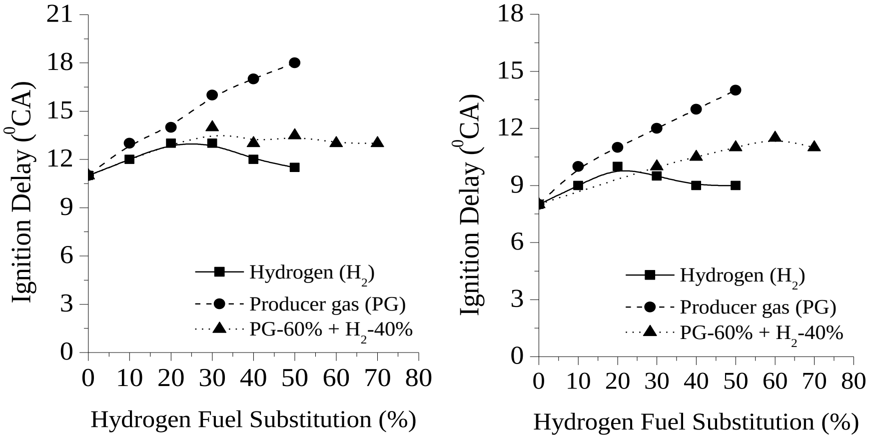

Fig.5 Ignition delay (^{0}CA) vs. Gaseous fuel substitution.

4. Conclusions

Based on experimental investigation for the combustion duration and ignition delay of dual fuel diesel engine presented in this paper, following conclusions may be drawn:

1. The ignition delay at light load conditions in Case II increases with the increase in percentage of hydrogen up to 30% and onward decreases as compared to pure diesel operation. The maximum increment at 13% load condition and for 30% of hydrogen substitution is 2 ^{0}CA.
2. At higher load condition in Case II, the ignition delay decrease at higher substitution of hydrogen may be due to higher temperature at the time of injection.
3. The ignition delay in Case III is longer compared to case I at all load conditions. It increases with the increase in producer gas substitution and reduces with the increase in load. The length of the ignition delay is more at 13% load condition for 50% of producer gas substitution i.e. 7 ^{0}CA.
4. The mixture combination of producer gas: hydrogen = 60:40 gives lesser combustion duration and ignition delay as compared to producer gas alone.
5. The ignition delay in dual fuel diesel engine depends on the type of gaseous fuels and their concentration in the cylinder charge.
6. The ignition delay depends on charge temperature, pressure and oxygen concentration.

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