Examination of the dual-fuel engine performance using low Btu gaseous fuels

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SUMMARY

The effects of changes in the cetane number of liquid pilot fuels on the ignition delay period in dual fuel engines were investigated experimentally. Different pilot fuel quantities were employed with methane and low heating value gaseous fuel mixtures over a wide range of engine loads. The operation with low heating value gas fuel mixtures represented by different mixtures of methane and nitrogen (or methane and carbon dioxide) simulating the behavior of a fuel gas containing significant amount of diluents, shows increase in the ignition delay.

1. INTRODUCTION

The dual fuel engine is a diesel engine that operates on gaseous fuels while maintaining some liquid fuel injection to provide a deliberate source for ignition. Such a system attempts usually to minimize the use of the diesel fuel by its replacement with various gaseous fuels and their mixtures while maintaining satisfactory engine performance. There are some problems associated with the conversion of a conventional diesel engine to dual fuel operation. At light load, the dual fuel engine tends to exhibit inferior fuel utilization and power production efficiencies with higher unburned gaseous fuel and carbon monoxide emissions, relative to the corresponding diesel performance. Operation at light load is also associated with a greater degree of cyclic variations in performance parameters, such as peak cylinder pressure, torque, and ignition delay, which have narrowed the effective working range for dual fuel applications in the past. These trends arise mainly as a result of the poor flame propagation characteristics within the very lean gaseous fuel – air mixtures and originating from the various ignition centers of the pilot.

Much research effort had been expended towards providing effective measures for the further improvement of dual fuel operation at light load [1-3]. The effects of changes in the initial charge temperature, oxygen and diluents concentrations, pilot liquid fuel quantity and its injection characteristics on the ignition delay period, when a range of different gaseous fuels admitted with the intake air, were investigated [4-6]. These studies showed that changes in the mean charge temperature and pressures at the end of compression resulting from the variations in the physical properties of the charge, preignition energy release, external heat transfer and residual gas effects are major factors that control the extent of variation in the ignition delay period, cyclic variations and exhaust emissions of dual fuel engines at light load.

An objective of this work was to determine whether through the use of a pilot liquid fuel having a high cetane number, smaller pilot quantities can be employed effectively when operating on gaseous fuels, particularly natural gas. Moreover, whether dual fuel engine performance at light load then can be improved further when operating low heating value gas mixtures, which usually display longer ignition delay periods than those observed with methane [6-7].

2. EXPERIMENTAL SETUP

The test engine used was a single cylinder, water cooled, direct injection, normally aspirated, four stroke diesel engine 108 mm bore, 152 mm stroke and a 14.2 compression ratio. The gaseous fuels employed were fumigated into the intake air at a point in the engine manifold just outside the cylinder. The engine was coupled directly to an electric dynamometer, which permitted the engine to operate under partial motoring conditions representing negative brake output. Four different commercial and three other prepared diesel fuels were used, having different cetane numbers. The specification of these diesel fuels are given in Table 1. Various pilot quantities were employed with commercials methane Natural Gas and a low heating value gas made up of a mixture of methane and nitrogen or carbon dioxide. For any set of operating conditions, the pilot fuel was kept constant while the amount of the main gaseous fuel was gradually increased. The ignition delay period was established from pressure-time records obtained using a water-cooled piezoelectric transducer. The injection timing was established using an electric inductance transducer. The average values obtained form several consecutive cycles were used. Throughout these tests, the injection timing was kept constant and the engine was operated at 1000 rev/min, under normally aspirated conditions.

3. RESULTS & DISCUSSIONS

The variations in the length of the ignition delay in compression ignition engines have a profound and controlling effect on the subsequent combustion process and hence on almost every feature of engine performance. With constant injection timing the crank angle at ignition was used to represent the ignition delay variations.

The engine was operated in the dual fuel engine mode on commercial methane having an average methane concentration of more than 96% by volume. Two different pilot amounts of commercial CN 41.5 and CN 58 diesel fuels were initially employed. One of the pilots was 0.2 kg/h and the other pilot related to the minimum one could be used (for the CN 41.5 this minimum was 0.14 kg/h and for the CN 58 the minimum was 0.11 kg/h). It can be seen from Fig. 1 and Fig. 2 that, for pilot quantity of 0.20 kg/h, as the amount of gaseous fuel is increased under dual fuel operation, producing a higher total equivalence ratio, the ignition delay increases markedly to reach a maximum value. The delay begins to decrease later on with the continued addition of the gaseous fuel. For the case of minimum pilot, the ignition delay decreases markedly all the time. These changes in the delay period depend very strongly on the pilot quantity being used, as shown in Fig.2 and Fig.3. Larger pilots tend to display smaller changes to the delay while relatively small pilots bring about a large extension to the ignition delay. With a continued decrease in the pilot fuel size, the ignition delay period increases to such an extent that regular ignition cannot be maintained below a certain level of pilot quantity.

The extent of the ignition delay depends also on the type of gaseous fuel used. The operation with low heating value gas fuel mixtures represented by different mixtures of methane and nitrogen (or methane and carbon dioxide), simulating the behavior of a fuel gas containing significant amounts of diluents, shows increases in the ignition delay that tends to be related to the concentration of the nitrogen admitted (Fig.4). This increase in the delay is a reflection of the corresponding reduction in the partial pressure of oxygen in the intake charge, the associated reduced reaction activity and the corresponding changes in the effective temperature level during combustion. Similar mixtures that contained carbon dioxide instead of nitrogen, as shown in Fig. 5 produced yet a greater increase in the delay largely due to the further lowering of the mean temperature and pressure. This effect can be seen better when three different conditions of gas fuel mixtures (CH_4; 35% CH_4 & 65% N_2; and 35% CH_4 & 65% CO_2) plotted in the same graph as shown in Fig. 6. Generally, it was observed that for a given inert gas concentration and pilot quantity, lower power outputs and cycle pressures are produced with CO_2 than with N_2 addition.

An increase in the cetane number of the pilot fuel when operating the engine on low heating value gas fuel mixtures, represented by 35% CH_4 and 65% N_2 by volume, decreases the ignition delay significantly, while maintaining its characteristic variations with the increased admission of the gaseous fuel, as shown in Fig. 7. The decrease is relatively less marked when operating with this large pilot liquid fuel quantity when a high cetane number fuel is employed. It can also be seen that the employment of relatively lower pilot quantity can increase significantly the ignition delay as shown in Fig. 8.

It can be seen that the employment of a relatively high cetane number pilot fuel with nitrogen-methane fuel gas mixture can reduce significantly the ignition delay at light load to values comparable to those obtained with methane operation when pilots of a regular commercial diesel fuel (CN 41.5) are used. Similarly, the use of high cetane number pilots also enhanced dual fuel operation with nitrogen – methane fuel gas mixtures. Relatively smaller pilots as low as 0.15 kg/h can be also employed satisfactorily.

The change in the length of the ignition delay depends not only on the chemical interactions between the fuel jet vapor and the surrounding gaseous fuel-air mixture but also on the characteristics of the pilot fuel injection, atomization, vaporization, and mixing processes within the cylinder charge. For a heavy fuel with high viscosity, the extension to the physical part of the delay may be a controlling factor. This was the case when using the commercial diesel fuel III with nominal cetane number of 53 having relatively inferior physical properties compared to the other commercial diesel fuels. It was found that with such a fuel the use of small pilot quantities could not maintain satisfactory engine operation as it led to late ignition and erratic engine load and speed fluctuations.

The limits of nitrogen and carbon dioxide admissions were obtained by keeping the pilot and gas (methane) quantity employed constant during the test. By adding the amount of nitrogen or carbon dioxide in the methane and changing the load to adjust the speed of the motor at 1000 rpm. Fig. 9 & 10 are the result of the limits tests for the nitrogen and carbon dioxide admissions for two different cetane number, pilot quantities, and equivalence ratios. As it can be seen from Fig. 9, the ignition delay increases gradually by adding the inert gasses (i.e. nitrogen or carbon dioxide) to certain points, but later on it increases sharply to the limit point when the satisfactory engine operation will be impossible. In this figure the effect of cetane number and equivalence ratio on the limit curves have been shown. The effect of pilot quantity on the limits curves has been shown in Fig. 10. All of these curves show that at lower percentage of carbon dioxide the limiting point occurs compare to nitrogen addition. In these tests the constant equivalence ratio was assumed, although there were small variations of this quantity mainly due to the changes of the volumetric efficiency of engine when the percentage of nitrogen or carbon dioxide admissions were varied.

4. CONCLUSIONS

- The ignition delay in gas-fueled diesel engines of the dual fuel type depends strongly on both the quantity and quality of the pilot fuel used.
- Dual fuel engine performance is improved with the employment of high cetane number pilots. Their use permits the employment of smaller pilot quantities and can improve engine operations on low heating value gaseous fuel mixtures compared to operation with common diesel fuels having a relatively low cetane number.
- The limiting point of inert gas (N_2 or CO_2) admission is strongly dependent on quality and quantity of pilot diesel fuel and total equivalence ratio. For carbon dioxide, this limiting point (compare to nitrogen) occurs at lower percentage of introducing these inert gases.

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Table 1. Diesel Fuel Specifications

Diesel Fuel	Description	CN	Density (Mg/m3)	Lower Heating Value (MJ/kg)	Higher Heating Value (MJ/kg)
# 1	Commercial Diesel Fuel I	41.5	0.834	42.051	44.673
# 2	Commercial Diesel Fuel II	46.5	0.824	43.413	46.035
# 3	Commercial Diesel Fuel III	53.0	0.883	41.550	44.172
# 4	Commercial Diesel Fuel IV	58.0	0.830	42.960	45.582
# 5	50% # 1+ 50% # 4	49.7	0.832	42.505	45.128
# 6	Cetane	100.	0.774	43.957	47.260
# 7	Heptamethylnonane	15.0	0.793	42.907	47.260
# 8	80% # 4 + 20% # 6	66.3	0.819	43.159	45.918
# 9	80% # 1 + 20% # 7	36.2	0.826	42.222	45.190

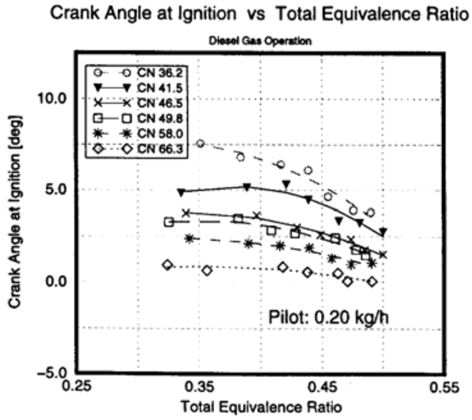

Fig.1. Variations of the point of Ignition versus equivalence ratio (Φ) for diesel gas operation when using wide range of cetane number fuels at 1000 rpm.

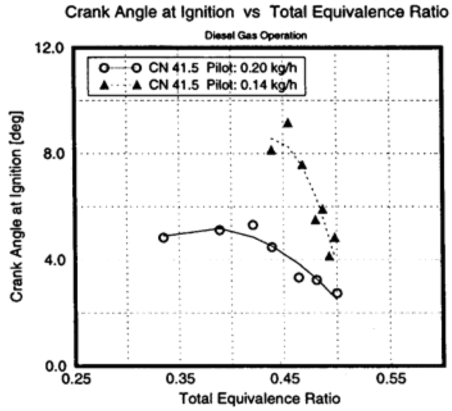

Fig.2. Variations of the point of ignition versus total equivalence ratio for different fixed pilot quantities when operating on a CN 41.5 fuel with methane at 1000 rpm.

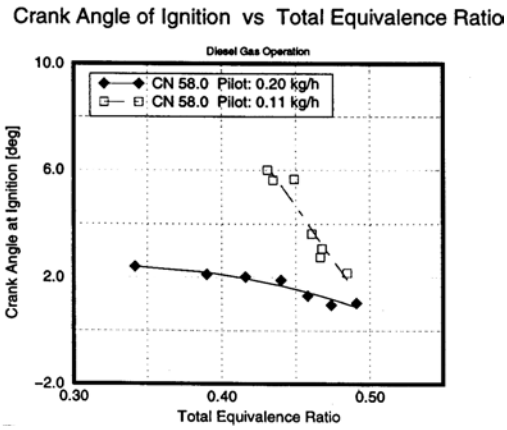

Fig.3. Variations of the point of ignition vs. (Φ) for different fixed pilot quantities when operating on CN 58 diesel fuel with methane at 1000 rpm.

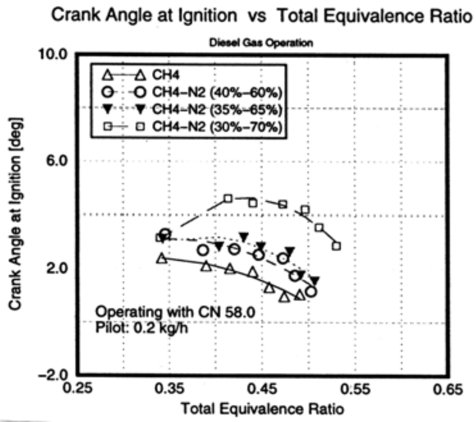

Fig.4. Variations of the point of ignition vs. (Φ) at 1000 rpm when using nitrogen introduced for 0.2 kg/h pilot and CN 58 diesel fuel.

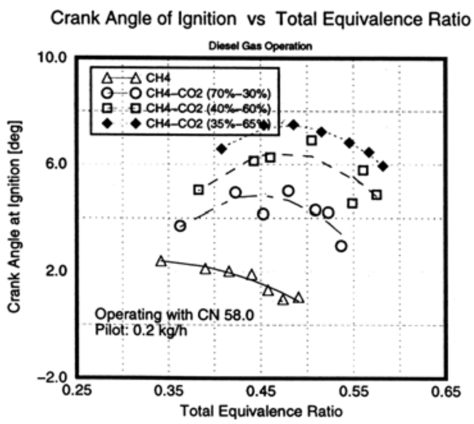

Fig.5. Variations of the point of ignition vs. (Φ) at 1000 rpm when using different % of CO2 introduced for 0.2 kg/h pilot and CN 58 diesel fuel.

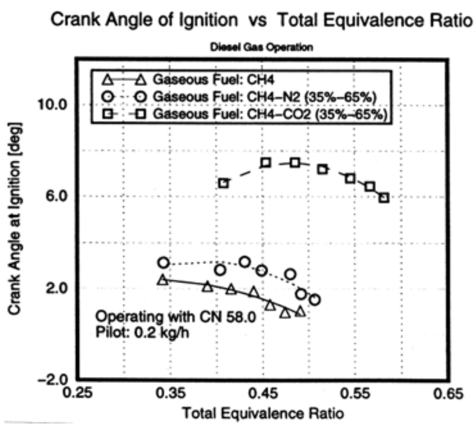

Fig.6. Variations of the point of ignition vs. (Φ) at 1000 rpm when operating with CN 58 and 0.2 kg/h pilot quality for different gas fuel mixture.

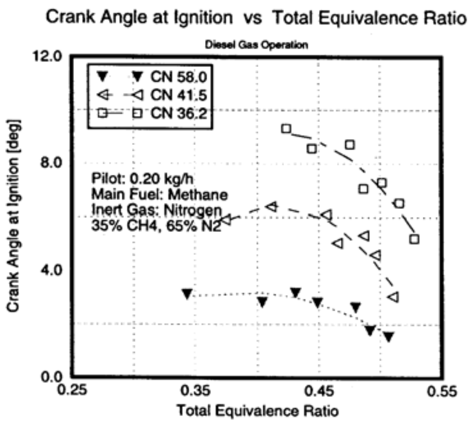

Fig.7.Variations of the point of ignition vs. (Φ) at 1000 rpm when using different cetane number fuels with 35% CH4 & 65% N2 for 0.2 kg/h pilot quantity.

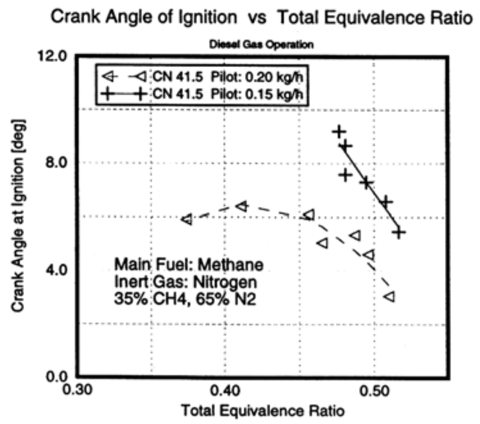

Fig.8. Variations of the point of ignition vs. (Φ) at 1000 rpm when operating with CN 41.5 for two different pilot quantities, 35% CH4 & 65% N2 gas fuel mixtures.

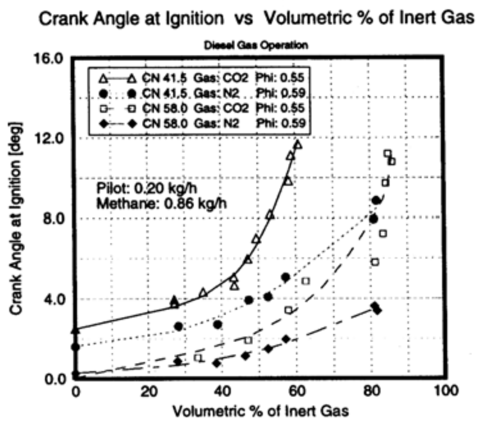

Fig.9. Variations of the point of ignition vs. volumetric percentage of inert gases for diesel gas operation with 0.2 kg/h pilot quality and 0.86 kg/h methane at 1000 rpm.

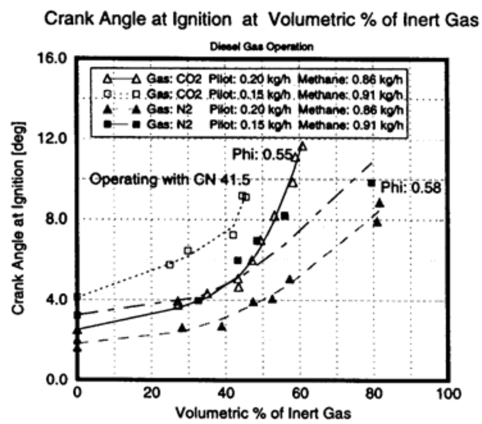

Fig.10. Variations of the point of ignition vs. volumetric percentage of the inert gases for diesel gas operation using CN 41.5 diesel fuel at 1000 rpm.

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