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Experimental analysis of homogeneous compression ignition with premixed compression ignition in a diesel engine

Sendilvelan S*
Department of Mechanical Engineering, Dr.MGR Educational and Research Institute,
Chennai- 600 095, India,
***Corresponding author: E-Mail: sendilvelan.mech@drmgrdu.ac.in, Phone: 9003262740**

ABSTRACT

The objective is to help in creating better environment, free of gas emissions and to initiate a new combustion technology that would substantially reduce harmful emissions, that is damaging the environment and also to improve the overall performance of an internal combustion engine. Factors required at the time of designing a new combustion process would be higher compression ratio, lean homogeneous air fuel mixture and complete combustion and early combustion, which would suggest Homogeneous Compression Ignition (HCI). In this work, it is analyzed experimentally the performance and emission values of Homogeneous Compression Ignition with Premixed Compression Ignition (PCI) mode using Secondary Injection using a combustion initiator. Experiments were conducted in a modified single cylinder water-cooled diesel engine, where in it was observed that there is a substantial reduction in emission level of carbon monoxide (CO) and hydro carbon (HC) with same power output of a conventional diesel engine.

KEY WORDS: Diesel Engine, Homogeneous Compression Ignition, Premixed Compression Ignition, Specific Fuel Consumption.

1. INTRODUCTION

To minimize the emission, spark ignition and compression ignition engine combustion can be coupled to obtain a lean burning hybrid combustion mode known as homogeneous compression ignition in which the combustion takes place spontaneously and homogenously (Allen, J, 2002). In homogeneous compression ignition combustion properly mixed fuel and air are compressed to the ignition point which is controlled by the combustion initiator. This reaction releases chemical energy and converted into work and heat (Christensen, 1997). Stratified compression ignition depends on temperature and density increase due to compression, but combustion takes place at the boundary of fuel-air mixing to initiate combustion (Fuerhapter, 2004).

Homogeneous compression ignition occurs at various levels at a time which makes the fuel/air mixture burn almost at the same time. Since not initiator available for combustion, the process is challenging one to control. With the use of microprocessors and proper understanding of the ignition process, Homogeneous compression ignition can be controlled to control the emission. (Jiang, 2005)

Obtaining very lean homogenous mixture is hard, it becomes difficult to sustain Homogeneous compression ignition mode over the operating range of varying speeds and loads, to effectively over the operating range a modified form of homogenous compression ignition mode combustion known as Premixed Compression Ignition-Direct Injection (PCI-DI) can be used (Prabhahar, 2012). The major advantage of PCI-DI mode combustion over that of Homogeneous compression ignition mode combustion is that, after achieving homogenous charge PCI-DI mode combustion employs a pilot injection is used as initiator and establishing an effective control over the combustion in variable load and speed. Although all the inherit characteristics of homogeneous compression ignition mode combustion cannot be obtained in this mode of combustion, it still performs better than the conventional mode of combustion (Prabhahar, 2012).

2. MATERIALS AND METHODS

Methods for Achieving HCI Mode: Homogeneous compression ignition is operated at lean fuel mixtures and also controlling is a major hurdle to more widespread commercialization. Homogeneous compression ignition is more difficult to control using other combustion methods (Standing, 2005). In a homogeneous compression ignition engine, the fuel and air mixture is compressed, and combustion begins whenever the required conditions are reached. This means that there is no combustion initiator available to control the combustion (Yap, 2005). Engine can be designed, so that the ignition conditions occur at a desirable timing. However, this would only happen at one operating point. The engine could not change the amount of work it produces. This could work in a hybrid vehicle, but most engines must modulate their output to meet user demands dynamically (Wolters, 2003).

Experimental Setup: The engine used was a single cylinder direct ignition engine (Agricultural type water cooled) which is fitted to a brake drum dynamometer. The engine specifications are, it is a water-cooled, vertical, 4 stroke cycle, direct injection, naturally aspirated. The fuel is heated by a 1000 watts water bath provided with an electrical thermostat which enabled us to maintain the fuel at the desired temperature. The fuel is injected in to manifold using an electronic fuel pump through a fuel secondary injector. The spray angle of Secondary injector is 30º, the fuel line pressure is maintained at 6 bars. The current rating of the main fuel injection pump is 20 ampere and the secondary injector is kept at 0.3 ampere.

The injection is controlled by electronic circuit having a limit switch with frequency of about 750 cycles per minute. The limit switch is actuated by means of a bolt attached to the inlet valve rocker, effectively utilized the 8mm travel of the rocker arm for generating the electrical signal for initiating the injection during the suction stroke.

With the experimental setup shown in Figure 1, the study was conducted in the conventional and homogeneous compression ignition mode with all the samples which is analyzed. Initially, the engine is operated in the conventional mode using diesel and bio-diesel as a primary fuel; there is no secondary fuel supply. The efficiency, fuel consumption, exhaust gas temperature and emissions are measured under different load conditions. The different percentages of varying loads are: 0%, 20%, 40%, 60%, 80% and 100%.

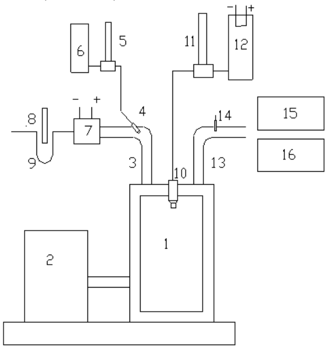

Figure.1. Experimental Setup

1. Engine
2. Electrical Dynamometer
3. Inlet manifold
4. Secondary injector
5. Secondary injector fuel measurement
6. Secondary fuel tank (with heating and thermostat arrangement)
7. Air tank (with heating and thermostat arrangement)
8. Orifice meter
9. Manometer
10. Main Fuel Injector
11. Main Fuel Measurement
12. Main Fuel Tank
13. Exhaust Manifold
14. Thermocouple
15. Exhaust Gas Analyzer
16. Smoke meter

In the homogeneous compression ignition mode, the secondary injector is used to supply secondary fuel to the combustion chamber to get the premixed combustion ignition. The secondary injector works by means of the signal from the rocker ram. The opening and closing of the secondary injector for supplying the secondary fuel depends upon the position of the rocker arm, which depends upon the position of the piston inside the combustion chamber. The air is heated to a temperature of 80°C before it is sent into the combustion chamber. The primary fuel is supplied to the combustion chamber without heating. In the case of the secondary fuel supply, the fuel is heated before entering the inlet manifold. The heating is done by an electrical heating arrangement. The secondary fuel is supplied into the combustion chamber in the suction stroke. The exhaust gas is analyzed by a five-gas analyzer to measure the HC, CO, CO_2, NOx and O_2 present in the exhaust gas. The exhaust gas temperature and smoke are measured by means of the thermocouple and smoke meter respectively. The primary fuel, secondary fuel, and air quantity are measured before they enter the combustion chamber. The experiments have been conducted in the following modes:

Mode 1 - Diesel as Fuel: The experiments are conducted only with primary injection. The diesel is used for combustion. The secondary injector is closed in this mode; there is no fuel supply through the secondary injector.

Mode 2 - Bio-Diesel as Fuel: In this mode, Bio-diesel (Jatropha oil) is used as a fuel instead of diesel, as in the case of mode 1.

Mode 3 - Diesel-Diesel PCI-DI Combustion: Here both the primary and secondary injectors are used to supply the fuel to the combustion chamber. Diesel is used as a fuel in both the primary as well as the secondary injectors. The secondary injector supplied the diesel to the combustion chamber before the actual injection of the diesel into the combustion chamber through the primary injection port. The premixed compression ignition is created by supplying the fuel through Secondary injector after the bottom dead centre of the piston. The procedure followed in this mode is used for all other modes.

Mode 4 - Bio-Diesel - Bio-Diesel PCI-DI Combustion: In this mode both the primary and secondary injectors are used to supply bio-diesel. The Secondary injector supplied the bio-diesel to the combustion chamber before the actual injection of the bio-diesel the primary injection port.

Mode 5 - Diesel - Bio-Diesel PCI-DI Combustion: In this mode both diesel and bio-diesel are used as primary and secondary fuel respectively. The diesel is injected into the cylinder through the primary injector; the injected diesel is compressed to increase the pressure. The secondary injector supplied the bio-diesel to the combustion chamber before the actual injection of the diesel into the combustion chamber through the primary injection port.

Mode 6 -Biodiesel – Diesel PCI-DI Mode Combustion: In this mode both bio-diesel and diesel are used as primary and secondary fuel respectively. The bio-diesel is injected into the cylinder through the primary injector; the injected bio-diesel is compressed to increase the pressure. The secondary injector supplied the diesel to the combustion chamber before the actual injection of the bio-diesel into the combustion chamber through the primary injection port.

3. RESULTS AND DISCUSSION

Experiments were conducted with the present experimental setup in order to analysis the performance of the developed premixed compression ignition system. Detailed graphs comparing: the conventional and premixed compression ignition methods, different fuels in the premixed compression ignition mode, variation of the hydrocarbon, Nitrous oxides and specific fuel consumption, brake thermal efficiency and variation of carbon dioxide emission presented here.

Effect of Load on Specific Fuel Consumption: Figure 2 shows the variation of specific fuel consumption versus load for different modes. The specific fuel consumption decreases with an increase in the load for all modes of operations (both conventional and premixed compression ignition mode). The specific fuel consumption is found to be of lower value in the modes bio-diesel-bio-diesel PCI-DI mode and also biodiesel and diesel PCI-DI combustion modes as compared to that of all other modes for all the load conditions. This could be due to the secondary fuel supply in the case of the premixed compression ignition mode operation as compared to the conventional mode, in which only primary fuel is supplied. The study also found that for all the higher load conditions, the specific fuel consumption is observed to be the same for all the cases other than bio-diesel-biodiesel PCI-DI and bio-diesel and diesel PCI-DI modes, which is much lower than all other modes.

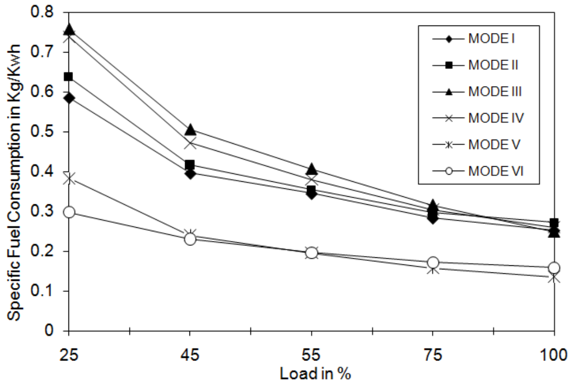

Figure.2. Specific Fuel consumption Vs Load for different Modes

Effect of Load on Brake Thermal Efficiency: Figure 3 shows the variation of the brake thermal efficiency versus load for different modes. The brake thermal efficiency is measured with the increase of load from 25% to 100%. The study found that for all the modes of operations, the brake thermal efficiency increases with the increase in load. In the case of diesel and bio-diesel in the conventional mode of operation, the brake thermal efficiency has increased from 13% to 32% and 14% to 32% respectively when the load is increased from 25% to 100%. For the same fuels, the premixed compression ignition mode of operation produced lower thermal efficiency as compared to the conventional mode. Mode 1, Diesel as a primary fuel produced higher brake thermal efficiency. The study identified that for all the load conditions, the diesel and diesel combination under the PCI-DI mode of operations have produced lower thermal efficiency.

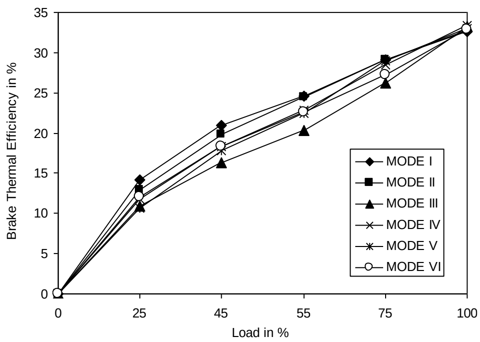

Figure.3. Brake Thermal efficiency vs Load

Effect of Load on Hydrocarbon: Figure 4 shows the variation of the hydro carbon in ppm versus load for different modes. It is found that for diesel and diesel premixed compression ignition combustion hydro carbon in ppm is high for all loads as compared to any other mode. The increase in the hydro carbon emission is due the inability of the injection system used to inject the fuel in to the inlet manifold, to vary the fuel quantity in no load and part load operation, reduction in the oxygen concentration due to increase in the air temperature and due to the fact that the quantity of fuel injected as pilot injection does not have sufficient quantity of oxygen to react because the combustion chamber is occupied by the premixed charge in which the oxygen concentration is relatively less. In the case of bio-diesel in the conventional mode of operation, the hydro carbon in ppm is 20 to 11 when the load is increased from 25% to 100%. Mode 3, Diesel and diesel PCI-DI combustion hydro carbon in ppm is high 120ppm during 25% load condition. The study identified that for all the load conditions, the bio-diesel conventional combustion mode 2, the value of hydro carbon is very less compared to any other mode.

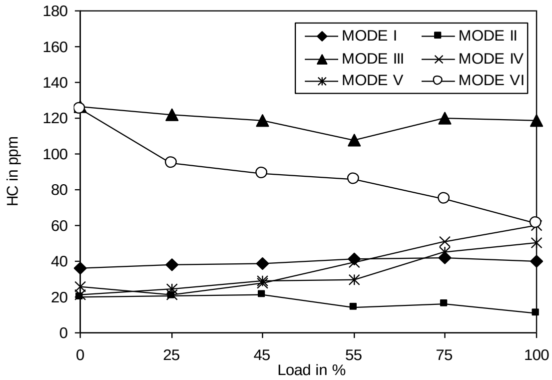

Figure.4. Load vs HC in ppm

Effect of Load on NOx: Figure 5 shows the variation of the NOx in ppm versus load for different modes. It is found that in all modes the NOx value increases with increase in load. The value of NOx is increases from 22ppm to 336ppm from no load to 100% load, which is less compared to any other mode. The reduction in this emission is due to the following three main reasons, reduction in oxygen availability due to increase in air temperature, reduction in oxygen availability due to early mixing of air and fuel in the inlet manifold itself, and due to lower combustion temperature in full load operation complimented by the homogenous mixture. The emission is very high in case of conventional modes of diesel and bio-diesel.

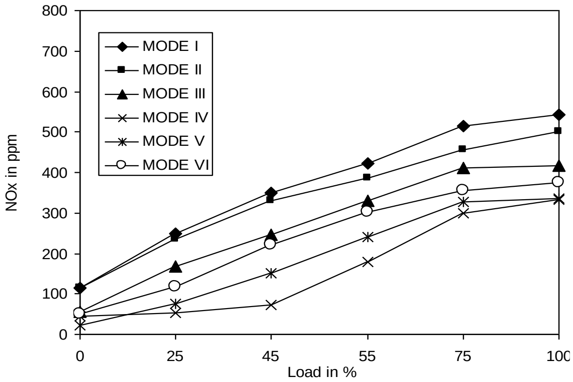

Figure.5. Load vs Nox in ppm

4. CONCLUSION

The study concludes that specific fuel consumption is found to be of lower value in diesel and bio-diesel PCI-DI mode and also biodiesel and diesel PCI-DI mode as compared to that of other modes for all the conditions used here. The study also concludes that for all the conditions compared, the diesel and diesel combination under the PCI-DI mode of operations have produced lower thermal efficiency and also the bio-diesel conventional combustion mode the value of hydro carbon is very less compared to any other mode. NOx is lower in biodiesel-biodiesel PCI-DI mode and is very high in case of conventional modes of diesel and bio-diesel.

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