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Effect of Premixed Diesel Fumigation on Performance and Emissions Characteristics of Homogenous Charge Compression Ignition Engine

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ABSTRACT:

The effect of premixed diesel fumigation (PDF) on performance and emissions characteristics of Homogenous Charge Compression Ignition (HCCI) engine and optimisation of the diesel fumigation temperature are prime focus of this study. The experimental investigations were carried on single cylinder, four stroke, water cooled, port injected Kirloskar SV1 engine. For this research, the engine was modified as HCCI engine with electric air heater, fixed at suction pipe. During the experimental investigation the diesel fuel was premixed by the port injector and vaporised or fumigated the fuel by heated suction air. After heating process, the diesel has changed its phase and mixed with air and form partially homogenous mixture. During the test, the engine was operated with different diesel fumigation temperature from 100°C to 150°C in steps of 10°C and observed the performance and emissions characteristics of the engine. The effective diesel fumigation temperature for creating better homogeneous charge is identified. The diesel fumigation made huge impact on NO_x and smoke formation. The level of NO_x and smoke emissions were decreased simultaneously as 10% and 16% compared to compression ignition (CI) engine. At the same time, the HCCI engine has emitted high CO and HC emissions at low fumigation temperatures and they were reduced at high fumigation temperatures, because of improved combustion. The suction air temperatures of 120°C and 130°C for the HCCI engine registered low NO_x and smoke emissions. From the performance point of view, the HCCI engine consumed much more fuel due to low volumetric efficiency and slightly affected the brake thermal efficiency.

KEYWORDS:

Homogenous Charge Compression Ignition; Diesel fumigation; Emission controls; Brake thermal efficiency

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ACRONYMS:

HCCI	Homogeneous charge compression ignition
CI	Compression ignition
NO_x	Oxides of Nitrogen
PDF	Premixed diesel fumigation
BTE	Brake thermal efficiency
CO	Carbon monoxide
HC	Hydrocarbon
TDC	Top dead centre
BMEP	Brake mean effective pressure

1. Introduction

The protection and conservation of both the environment and the energy sources have become important issues in the industrial and transportation sectors. In response to these social trends, many automotive companies and research centres have attempted to develop new engine and fuel technologies in order to meet stricter exhaust emissions regulations. While a diesel engine with a high thermal efficiency has the advantage of conserving energy, it has some drawbacks with regards to higher exhaust pollutants such as NO_x and smoke. To satisfy the goals of saving energy and protecting the environment, many researchers and automotive companies have attempted to use new combustion technologies and trying to change the mode of fuel inducted into the engine [1]. Homogeneous Charge Compression Ignition (HCCI) is a new combustion concept that constitutes a valid approach to achieve high efficiencies and low NO_x and particulate matter (PM) emissions in comparison with traditional compression ignition (CI) engines [2]. HCCI has been successfully applied for both spark ignition (SI) and CI engines. HCCI has been achieved with gaseous fuels such as propane or natural gas and liquid fuels like traditional gasoline or diesel fuels.

The HCCI process operates on the principle of having a lean, premixed and homogeneous charge that reacts and burns volumetrically throughout the cylinder as it is compressed by the piston [3]. In HCCI engine, the mixture can be prepared either internally or externally. When the liquid fuel is going to be injected through either port or direct injector, in the short time the fuel cannot be mixed with air and unable to create homogeneous air-fuel charge. If the mixture is not homogeneous, it leads to shorter combustion and initiates the combustion process before the piston reaches the TDC position. Poor mixing and non-homogeneous charge in HCCI engine leads to smoke formation and increased engine fuel consumption rate.

Moreover, the advanced start of combustion and uncontrolled combustion in HCCI engine leads to higher gas temperatures, thus increases NO_x emissions, while using liquid fuels [4]. Diesel and other alternative fuels that can be used in HCCI engine by applying different methods such as blending, fumigation, dual fuel, and premixing; the methods of dual fuelling and fumigation are frequently preferred [5-6].

Liquid fuels such as alcohols and biodiesel are generally used by applying the methods of mixing and fumigation in CI engine. There are some difficulties in the use of alcohol - diesel fuel blends; as alcohol addition to diesel fuel results in different physiochemical changes in diesel fuel properties, particularly reduction in Cetane number, viscosity, and heating value [5,7]. For these reasons, mixing method rarely is preferred and if it is applied here, certain improving additives are employed. Consequently, for using alternative liquid fuels in diesel engines, usually fumigation method is preferred. Here, a suitable volatile light liquid fuel, such as ethanol and gasoline, is simply added into intake air, and without sophisticated modifications or additional equipment. Also, by this way, the worsened effect of lower Cetane number on ignition delay can be eliminated. For these reasons, alcohol fumigation especially ethanol fumigation has generally been applied in DI diesel engine. In the previous related studies, it has been stated that ethanol fumigation gives lower emissions and better performance [8-10]. Also, the effects of the methanol fumigation on engine performance and exhaust emissions have been investigated by various researchers [10-13]. The results of these studies generally show that methanol fumigation has a potential for reducing both NO_x and PM emissions, but it increases in HC and CO emissions.

Although there are a lot of alcohol fumigation studies, fewer studies on gasoline fumigation in DI diesel engines have been reported [14]. Derry et al [15] studied the gasoline, kerosene, and diesel fuel fumigation effects in a six cylinder DI diesel engine. In this study, by reducing injected diesel fuel quantity at full load and aspirating a weak mixture of air and fuel into the engine, the power and efficiency was increased over 20% and 4%, respectively, without producing more smoke than when the engine was operated at full load under normal conditions. From the above literature survey, it is clear that fumigation is the better way to mix fuel with air and it has an ability to create homogenous charge. [5, 8, 10]. For these reasons, the current study focused on the effects of diesel fumigation on performance and emissions characteristics of HCCI engine and also found effective temperature for better operation of HCCI engine. The results were compared to that of traditional CI engine.

2. Experimental setup and procedure

The experimental investigations have been carried on single cylinder, 4 stroke, water cooled, port injected Kirloskar SV1 engine, which was modified as HCCI engine for this research work. Fig. 1 shows the experimental setup of test engine. The technical specifications of the engine are given in Table 1. For this research, the multi-point port injector was fixed on the engine suction manifold near to the suction-valve for avoiding accumulation of fuel in the suction pipe. In addition, an electric heater was attached with engine suction pipe for heating the inlet suction air. Both port injector and electric heater were controlled by EC unit (EUC). The proximate sensor was placed near to the engine crank shaft to identify the position of the piston and send an input to the ECU. Therefore ECU can control the fuel injection timing and quantity depending up on the engine load and speed conditions. The hydraulic dynamometer acted as a loading device and it was coupled with test engine as shown in Fig. 1. The dynamometer was controlled manually by electronic panel to change the load on the engine. The control panel had all temperature indicators such as inlet air temperature, exhausts air temperature, cooling water in and out temperatures and electric heater temperature. The engine exhaust pollutants like NO_x, CO, HC and CO_2 were measured by using AVL gas analyser. Smoke was measured by a smoke meter.

Table 1: Engine specification

Parameters	Specification
Bore diameter	87.5 mm
Stroke length	110 mm
Cubic capacity	0.661 lit
Rated output	5.9 kW at 1800 rpm
Compression ratio	17.5:1
Inlet valve open BTDC	4.5 Deg
Inlet valve close ABDC	35.5 Deg

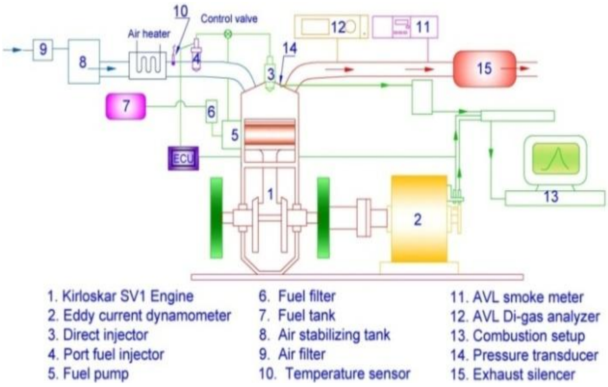

Fig. 1: Experimental setup

During this investigation, the engine was operated initially at no load condition, to achieve the saturated engine temperature. In the beginning of the test, the engine was started at conventional mode and then switched to HCCI mode. During HCCI operation, the fuel was injected through the port injector operated with using pre-mixed homogeneous charge. The fuel injection timing was fixed as 10 CAD (crank angle degree) for both the operating conditions. The engine speed was maintained as 1800rpm. The test engine was operated under different suction air temperatures such as 90°C, 100°C, 110°C, 120°C, 130°C, 140°C and 150°C. The performance and emission characteristics of HCCI engine were observed by operating under different charge temperature. From the results, the optimum inlet air temperature for diesel fumigation can be found based on engine outputs.

3. Results and discussion

3.1. Performance characteristics

Fig. 2 shows the variation of specific fuel consumption (SFC) with BMEP of HCCI engine operated with different inlet air temperatures. The HCCI engine consumed minimum rate of fuel at part load conditions compared to traditional CI engine. However, at low load conditions the HCCI engine consumed more fuels than the CI engine due to lean air/fuel charge. The rate of SFC of HCCI engine decreased with increasing diesel fumigation temperature. When the HCCI engine was operated with the diesel fumigation temperatures of 120°C and 130°C, the engine consumed minimum rate of fuel for all load conditions compared to other temperatures operated engine. The 130°C air temperature operated HCCI engine has registered lower SFC values for all loads. If the engine operates with low fumigation temperature, the fuel cannot change its phase as homogeneous due to low suction air temperature. Thus the air-fuel charge becomes non-homogeneous and delayed combustion takes place, which means some portion of charge will start to ignite at end of the compression stroke and will spread to entire charge present in the combustion chamber. There is a lack of power due to improper combustion and leads to more fuel consumption to run the engine.

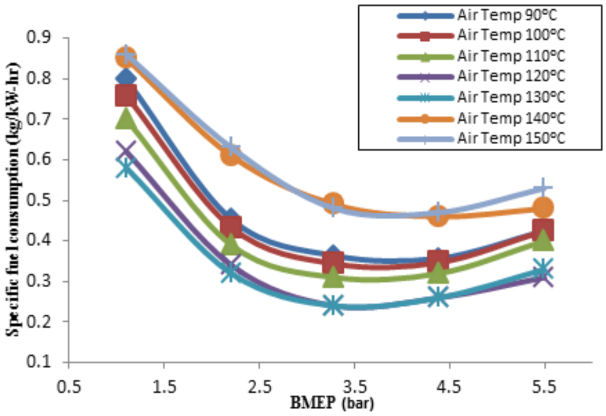

Fig. 2: Variation in SFC with BMEP

When the HCCI engine was operated with high fumigation temperatures of 140°C and 150°C, the engine registered high SFC values for all operating conditions. The start of combustion and combustion duration are dependent on chemical kinetics of the charge. Increasing the inlet charge temperature made the diesel fuel to have more fumigation. It will reduce the ignition delay and combustion duration of the charge. Thus the combustion may be started, before the piston reached TDC position. Due to this, high inlet air temperatures such as 140°C and 150°C operated HCCI engine consumed more fuel to compensate the engine output.

Fig. 3 shows the variation of brake thermal efficiency (BTE) with BMEP of HCCI engine operated for different inlet air temperature. In general the HCCI engine has much lower BTE compared to traditional CI engine due to lean burn and misfiring of charge. The results of this study was also reflected the same conclusion. When the HCCI engine was operated with the fumigation temperatures of 120°C and 130°C, it produced high BTE compared to other temperatures. The 120°C operated HCCI engine registered high BTE values such as 15%, 24.3%, 25.5%, 27.3% and 24.9% for 20%, 40%, 60%, 80% and 100% of loads respectively. This is due to correct and enough temperature for making the diesel as homogeneous charge compared to other temperatures. This may favour the combustion to start at correct timing. As a result, the engine has produced high BTE compared to other temperatures. However the engine operated with inlet air temperatures of 140°C and 150°C registered lower BTE than for other temperatures. If the fumigation temperature crosses certain limit, it favoured misfiring, so the power output of the engine went down. The value of BTE increased with increasing the charge temperature from 90°C to 130°C.

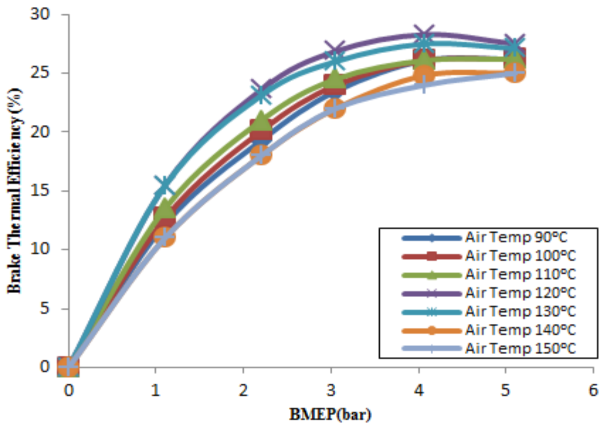

Fig. 3: Variation in BTE with BMEP

3.2. Emission characteristics

Fig. 4 shows the variation of smoke density with BMEP of HCCI engine operated for different fumigation temperature. In general HCCI engine emitted low smoke emissions compared to traditional CI engine due to their lean burn combustion characteristics. Increasing diesel fumigation temperature has to be favouring further reduction in smoke emissions. If increasing the diesel fumigation temperature in terms of increasing suction air temperature, the hot air vaporized the fuel and formed a better homogeneous mixture compared to low air temperature. This homogeneous charge supported the engine to make complete combustion leading to low smoke emissions. The air temperature of 120°C and 130°C operated HCCI engine registered low smoke emissions compared to other air temperatures. The smoke density values decreased with increase in the temperature up to particular limit and then increased with the increase in the charge temperature. If the inlet charge temperature is increased, it may increase the air-fuel homogeneity percentage because of high inlet air is used to atomize and vaporise the fuel to create the homogeneous charge. The homogeneous charge mixture in the HCCI engine has been burnt completely with less smoke in the exhaust. If the charge temperature is increased beyond the limit, smoke emission may increase due to high inlet temperature which accelerates the misfire in the chamber and also reduces the power output.

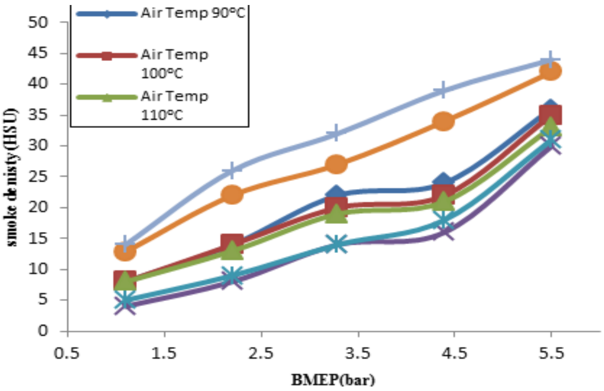

Fig. 4: Variation in smoke density with BMEP

The variations in NO_x emissions of HCCI engine operated for different air temperature is shown in Fig. 5. In general, HCCI engine has ultra-low NO_x emissions due to low combustion temperature. The result of this study identified that the value of NO_x emissions increased with increase in diesel fumigation temperature. The inlet air temperature of 90°C and 100°C operated engines have low NO_x emissions compared to other inlet air temperatures operated HCCI engine. At low inlet air temperature, the diesel fuel does not completely vaporise and unable to create homogeneous charge. This may cause higher ignition delay. Due to this longer ignition delay, the combustion percentage has to be decreased at lower combustion temperature. Hence, 90°C and 100°C inlet air temperature operated engine produced lower NO_x emission. But, the charge temperature of 140°C and 150°C operated HCCI engines emitted high NO_x emissions - maximum of 230ppm of NO_x emission at 80% load.

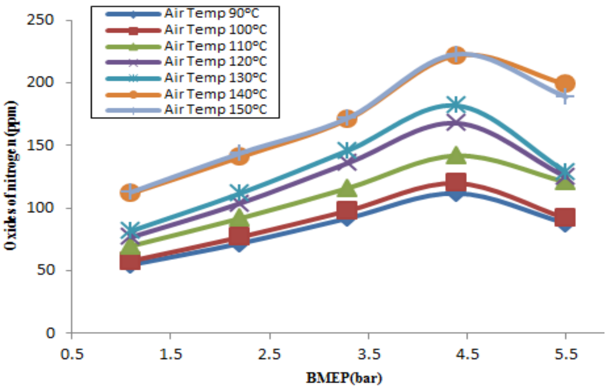

Fig. 5: Variation in oxides of nitrogen with BMEP

Fig. 6 shows the variation in CO emissions with BMEP of HCCI engine operated for different fumigation temperature. The level of CO emission from HCCI engine decreased with increase in the inlet air temperature up to 130°C due to the better combustion and high combustion temperature. Beyond the temperature of 130°C, the engine has higher CO emissions compared to other temperatures. Higher inlet air temperature could reduce the volumetric efficiency of the engine. There is not enough percentage of oxygen present in the combustion chamber. Hence, the HCCI engine has been emitting more CO when operated with high inlet air temperature. Fig. 7 shows the hydrocarbon (HC) formation in diesel fuelled HCCI engine with variation of inlet charge temperatures. The value of HC emission decreased with increasing temperature of inlet air. The charge temperature of 150°C operated HCCI engine has resulted lower HC emission than the other temperatures. The formation of HC emission is generally dependent on the latent heat of vaporisation of fuel and combustion chamber temperature.

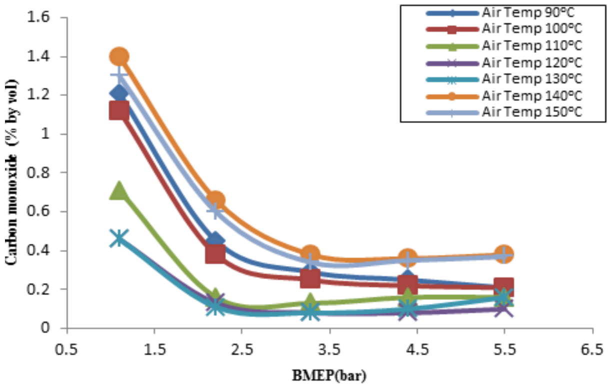

Fig. 6: Variation in carbon monoxide emission with BMEP

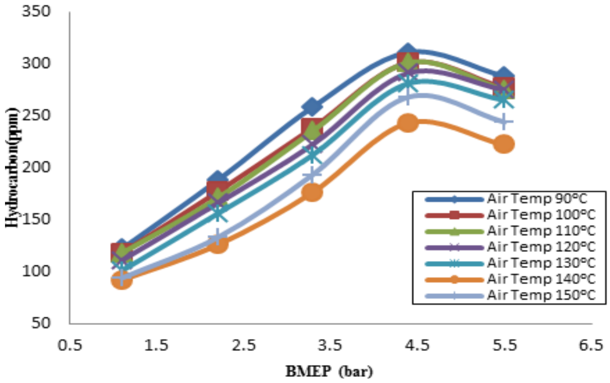

Fig. 7: Variation in hydrocarbon emission with BMEP

4. Conclusion

The SFC of HCCI engine was lower than conventional DI diesel engine. The conclusion of this research is that the fuel consumed by the HCCI engine depends on the inlet charge temperature. The rate of fuel consumption was decreased with increasing the inlet air temperature. The inlet air temperature of 130°C operated engines has lower value of specific fuel consumption about 0.273 kg/kw.hr at 60% of load on the engine. The 130°C inlet air charged HCCI engine has consumed less amount fuel and generated high BTE compared to other charge temperature operated HCCI engine. The increase in BTE was 3% more than 90°C operated engine. The charge temperature of 120°C and 130°C operated HCCI engine has lower smoke density values compared to other inlet air temperatures.

The maximum value of smoke emission for 130°C air temperature operated HCCI engine was 27HSU. Higher charge temperature of 140°C and 150°C operated HCCI engine has higher NO_x emissions. The charge temperature of 90°C gave a minimum level of NO_x emission of 55ppm for all conditions. The exhaust emissions of CO and HC were decreased with increasing charge temperatures. During low load operations there is no major differences in HC emission. The temperature of

120°C and 130°C operated engines had lower CO emissions for all operating conditions. The 150°C charge temperature operated HCCI engine has CO emission of 210ppm for full load operation, in this case increased air temperature has reduced the HC emissions by 60ppm.

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