Influence of EGR and Inlet Temperature on Combustion and Emission Characteristics of HCCI Engine with Micro Algae Oil

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The performance and emission characteristics of homogeneous charge compression ignition engine, with micro algae oil blended B20 was investigated. The DI engine was converted to HCCI engine mode by adopted PFI technique (diesel vaporize through air heating and external mixture preparation of air-fuel). All the experiments were conducted at constant speed of 1500 rpm with four different EGR percentage ranges (0%, 10%, 20% and 30%) and three different intake air temperatures (100°C, 120°C and 140°C). Experimental results indicated the BTE and SFC are optimal at 120°C injected air temperature and 20% of EGR. The increment in load conditions induced high knocking tendency further lead to increase in emission and high heat release rate (HRR). The increased in inlet air temperature resulted the quality combustion as well as reduced CO & HC slightly and more NOx emissions. High inlet air temperature and high EGR produced more emissions.

Keywords: Biofuel, HCCI Engine, EGR, Break thermal efficiency, Particulate Matter, Emission

Introduction

The fossil fuel crises and atmospheric pollutions made most of the researchers to focus on the alternative fuels¹, ². The bio-diesels are one among the alternative fuels as they made from renewable raw material also satisfied the required criteria about biodegradation³-⁶. The vegetable oil, seed oil and animal fat oil have been proposed as suitable diesel engine fuels⁷, ⁸. However, bio diesel-fuelled engine has emitted more amounts of NOx emissions. Homogeneous Charge Compression Ignition (HCCI) is an alternative combustion engine to reduce the NOx and PM emissions⁹, ¹⁰. HCCI combustion takes place multi points in the combustion chamber during the end of the stroke without the flame front. The Exhaust Gas Recirculation (EGR) system effectively controls over HCCI engine to attain better combustion¹¹. This paper an attempt was made for the preparation of the homogeneous mixture with the external mixture formation technique. The schematic of modified HCCI engine is shown in Figure. 1 and the specifications of the engine is listed in the Table 1. The experiment was conducted at constant speed of 1500 rpm at all engine conditions. The oil extracted from algae is used to prepare biodiesel fuel; the transesterification process conducted to extract the bio diesel fuels. The extracted bio diesel fuels were blended with the pure diesel fuel in the ratio 20 % bio diesel and 80% diesel (B20). The optimal blending ratio B20 was chosen based on the previous literature studies. The properties of the bio diesel fuel were determined using the ASTM method. The properties of the diesel and bio diesel fuel are listed in the table 2. The controlled and better combustion were achieved by exhaust gas recirculation (EGR) process. Under cooled EGR was circulated in between the intake fresh air and external injection system. Exhaust gases are controlled by manual controlled valve.

HCCI engine was operated with different exhaust gas recirculation of 0%, 10%, 20% and 30% of EGR mixed with the fresh air. The emission characteristics of variation intake air temperature with modified HCCI engine with 20% bio diesel was performed. The exhaust emission ranges: AVL Gas analyzer and AVL smoke analyzer were used to measure the emission of HCCI-mode engine, such as NOx, PM, HC, CO₂, CO and percentage of the smoke density.
Results and Discussions

In the present work, the HCCI engine modified with PFI technique for exhaust gas recirculation and inlet air heating. The combustion and emission characteristics are compared with baseline diesel operation. In the test, the speed was fixed at 1500 rpm and the temperature was selected with ranges of 100° C, 120° C and 140° C.

The changes in break thermal efficiency with respect to various loads for different fuels are illustrated in Figure 2(a-c). The engine was operated at different loads conditions along with variation in the EGR about 0%, 10%, 20% and 30%. The engine loads were varied likely low load at Air–fuel ratio (λ) maintained 4.0 - 5.25, medium load at λ of 2.5 - 3.0 and high load at λ of 1.5 - 2.25. At initial level, the break thermal efficiency increases with an increase in load, later it shows a negative trend at maximum load. At high load condition the HCCI engine encountered with excessive knocking which resulted an erratic behavior in engine performance. The high load condition contains increased air fuel ratio; it leads to availability of lesser fuel quantity in the combustion.
chamber which resulted leaner air-fuel mixtures. The Figure 2 shows that the break thermal efficiency is improved by inducing the EGR in the inlet air. The EGR helps to increase the combustion duration due to enrichment of oxygen in the combustion chamber. The 10% EGR with inlet air mixture resulted favorable increase in the thermal efficiency compared with none or 0% EGR. The EGR reduces the amount fuel consumption up to some extent; later the increase in EGR to 30% reduces the break thermal efficiency, as more amount of EGR lead to incomplete combustion. The HCCI engine with 20% of the EGR exhibited a better performance compared with rest. The maximum breaks thermal efficiency attained at medium load condition in case of all the EGR levels tested. The effect of inlet air temperature with break thermal efficiency is illustrated in the Figure 2. The increase in temperature from 100°C to
120°C helps to achieve improvement of 10 – 20% break thermal efficiency; however, further increase in temperature to 140°C resulted with reduction in thermal efficiency. The increase in temperature induced advance in combustion phasing, which is detorius. The optimal condition for improved thermal efficiency in HCCI engine was achieved at injection temperature and Exhaust gas recirculation was 120°C and 20 \% of the EGR in case of all the loading conditions. The maximum break thermal efficiency was 28.2 \% in medium load condition at 120°C for 20 \% of the EGR.

**Specific fuel consumption (SFC)**

The variation of specific fuel consumption with respect to various load conditions for the EGR enabled HCCI engine is shown in Figure. 2(d-f). The specific fuel consumption decreased with increasing engine load in all tested conditions. The similar phenomenon was also observed by many researchers\(^\text{10}\). The EGR enabled HCCI engine exhibited further reduction in specific fuel consumption compared with 0\% EGR and this trend continued up-to 20\% EGR. However, the value of the specific fuel consumption slightly increased with increasing from 20\% to 30\% EGR. The 30 \% of the EGR was consuming more amount of the fuel because of the more amounts diluted in the combustion chamber. The increase in temperature from 100°C to 140°C also induced the further reduction in the specific fuel consumption slightly. The increase in inlet temperature and EGR brought increase in combustion temperature and faster kinetic reaction. The improved reaction in combustion lead to relatively advanced auto ignition. The observed combustion was maximum, which resulted in more power output at relatively lower specific fuel consumption. At high inlet temperature, the fuel-air mixing is improved. It enhanced the degree of completeness of combustion and resulted with the higher heat release rate. The optimal condition for reduced specific fuel consumption in HCCI engine was achieved at injection temperature and Exhaust gas recirculation was 120°C and 20 \% of the EGR in case of all the loading conditions.

**Nitrogen oxide (NOx)**

The chain reaction of nitrogen and oxygen in the air causes the NOx. The NOx emission is inevitable in diesel engines, as it always operates with excessive air. Many researchers have done on HCCI engine; one of the most important properties is reduce the oxides of nitrogen up to 85 \%\(^\text{13}\). The variation in the NOx emissions with different loads and variation of the EGR is shown in Figure. 2(g-i). The HCCI engine at low load and medium load conditions produced very less NOx emission. The availability of lean mixture at low and medium load conditions burnt near to the misfire region. Hence, the engine cylinder temperature was less and produced less Nox emission. However, the rich mixture produced more amounts of NOx, as it increased with engine cylinder temperature. At high loads the NOx emission was increased, as the supplied rich mixture closed to knock regime limit. The influence of the EGR percentage in NOx emission is illustrated in the Figure. 2(g-i). The observation reveals that the increase in EGR percentage significantly reduced the oxides of the nitrogen. The increase in temperature prompted NOx emission. The increase in inlet temperature and EGR increased the NOx emission due to significant increase in engine cylinder temperature. Diesel Engines mainly running with biofuels are more prominent to produce more amount of the NOx. The high cetane number reduces the ignition duration, hence, the combustion take place before TDC. However, some studies indicated that the biofuel could show both increasing and decreasing trends with NOx emissions\(^\text{14, 15}\). The subsequent investigations revealed that blends of up to 20\% of biofuel have no or less significant impact on NOx emissions compared with other ratios or regular diesel. The optimal condition for reduced NOx emission in HCCI engine was obtained at injection temperature and Exhaust gas recirculation was 100°C and 30 \% of the EGR at medium loading conditions.

**Carbon monoxide (CO)**

The comparison of CO emission at different EGR percentage is shown in Figure. 2(j-l). The observed CO emission indicated that the emission rate was decreases while varying the load condition from low to medium load, while further increasing to maximum load condition resulted with severely increased CO emission. The biofuel having more oxygen concentration than the pure diesel fuel and the CO emission mainly depends on the availability of carbon and oxygen content in the fuel\(^\text{16, 17}\). Low loads were observed reduction of the CO emission with increasing the inlet temperature. Better conversion kinetics of CO to CO\(_2\) at higher engine loads was another important reason for higher CO\(_2\) emission.
However, at high load condition the available oxygen content was less which prevented conversion of CO to CO$_2$. In HCCI engine homogeneous mixture preparation before SOC helps the fuel to spread over the entire area of combustion chamber. It prevents the formation of rich mixture in combustion chamber and it favours for complete combustion with lower CO emission. The presence of more oxygen in the combustion chamber converts the CO into CO$_2$. The EGR percentage plays a vital role in the CO emission and it shown favourable reduction in the CO emission up to 20% of the dilution. It is also observed the maximum CO emission at 30% of EGR due to more amount of dilution. It reduced the peak temperature and less time energy for burning fuels. It is also observed that more amounts of the CO presented at 30% EGR with inlet temperature of 100°C at high load condition.

**Particulate Matter (PM)**

The PM is the most significant parameter has to be addressed in the HCCI engine. It produces more amount of the PM than compared to normal direct injection engine. The PM emission was influenced by various factors likely piston and wall wetting, charge heterogeneity, condensation of volatile species, nucleation, and ash and trace metals in HCCI engine. The formation of PM leads to increase in the level of smoke$^{15}$. It can be addressed by providing improved mixture preparation in the HCCI engine, as it helps to reduction of solid carbon condensation. The variation of PM with varying loads, inlet temperature and different EGR is shown in Figure: 2(m-o). The PM concentration increased with increase in the load and observed particle size was also increased, it produces more amount of soot. At 0% EGR rate, PM increased with increasing inlet air temperature from 100°C to 140°C. At 10%, 20% and 30% EGR rates, particle matter is varied depending on the dominance of inlet temperature and EGR. The EGR and inlet temperature are major influencing parameter against the PM. The increased EGR enhanced the tendency of particle agglomeration by reducing the maximum cylinder; however, increasing inlet temperature resulted in higher soot nucleation. The particulate of sizes distribution converted into small particulate of size with increased inlet temperature and EGR at all loads. PM was showed an important observation that despite large difference’s in combustion results with different loads, EGR rates, and temperature, particulate results were quite comparable with these variables. For all the conditions of experiment was observed, maximum variation of the PM at inlet temperature 140°C and 20% EGR.

**Conclusion**

The experiment was performed at different inlet temperature, load and EGR rate in HCCI engine with bio diesel fuel. The results indicated that prepared HCCI engine is more suitable for best performance at medium load condition. Adopted this technique by using the air heater and EGR, the mixture preparation is most stable for all the loads. The optimal condition for improved break thermal efficiency in HCCI engine was achieved at 120°C injection temperature and Exhaust gas recirculation of 20% in case of all the loading conditions. The maximum achieved break thermal efficiency was 28.2% in medium load condition at 120°C for 20% of the EGR. The best suitable condition for reduced specific fuel consumption in HCCI engine was achieved at injection temperature and Exhaust gas recirculation was 120°C and 20% of the EGR in case of all the loading conditions. The optimal condition for reduced NOx emission in HCCI engine was obtained at injection temperature and Exhaust gas recirculation was 100°C and 30% of the EGR at medium loading conditions. The more amounts of the CO emission presented at 30% EGR with inlet temperature of 100°C at high load condition. The maximum variation of the PM at inlet temperature 140°C and 20% EGR was observed for all the conditions of the experiment.

**References**


