Experimental investigation on effects of gasoline premixed - Al₂O₃ additive blended fish oil biodiesel fuelled HCCI-DI engine

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Abstract. A HCCI-DI engine is examined using fish oil bio-fuel at various proportions with neat diesel in DI fuels and petrol as the pilot energy. 20% of petrol is admitted as premixed fuel and the 80% of the charge is injected straight away to chamber at 23°bTDC. The effect of Al₂O₃ nano additive on DI engine is also investigated. An investigational observation is analysed with DI engine. First, HCCI-DI engine firing is compared at premature stage of combustion. Upto 1.84% improvements in the brake thermal efficiency is witnessed at petrol mixed HCCI-DI engine compared as DI combustion. The blending of Al₂O₃ nano additive showed 5.88% increase in the performance of the engine. Significant reduction in NOx is observed from the HCCI-DI ignition matched via DI combustion. Fish oil biodiesel fuelled combustion showed decrease in the HC besides CO issues

1. Introduction

Depletion of the conventional fossil fuels and stringent emission norms urge the researchers to find a new fuel with modified combustion methodology. HCCI technology was identified through ultra-low NOx and PM releases [1-10]. HCCI engine has combined benefits of conventional direct injection (DI) diesel engine and spark ignition (SI) gasoline engine together [11-15]. The gasoline was introduced at air bay manifold for preparing for homogeneous mixture and it was delivered towards the engine in inlet stroke as in an SI engine. In compression stroke, the combination of blends with atomized air is compressed by piston motion and it ignites automatically by diesel engine. Blends with air preparation at inlet manifold [16], adjusting IT for wide variation in loads and combination of speeds, difficulty in covering its functional parameters to higher loads without knocking and high HC and CO productions are reported as challenges of the HCCI burning. Exhaust gas recirculation (EGR) [17-27], supercharging / turbocharging [28-30], improved injection pressure [31-33], by changing a CR, [34-36] then increasing an inlet air density [37,38] were some of the suggestions made by researchers for reducing the knocking tendency besides increasing an operational range to upper loads. Many researchers [39-42] proposed external mixture preparation using preheated air for better evaporation of fuel at the inlet manifold. Some proportion of fuel injection at the inlet manifold as premixed fuel and remaining fuel by direct injection (HCCI-DI) also gained reasonable responses to overcome the above mentioned issues [43-47].

Metal based fuel additives have gained attention due to their superior characteristics towards its improved engine output parameters and emission characteristics. In this work, one metal-based...
additive (Al₂O₃) was added to improve engine performance parameters of Fish oil biofuel-fueled HCCI-DI engine. Al₂O₃ (Alumina) improves the combustion characteristics of engine owed toward that high surface to volume ratio besides high heat transfer characteristics [51,52].

2. Experimental Set-up

A naturally aspirated single cylinder diesel engine is considered for conducting experiments. An engine specification exists in the Table.2. Fig.2 exhibits the graphical representation of investigational arrangement. The engine provided with supplementary injection system to ensure identical fuel to be delivered to given CI engine. Supplementary arrangement was composed with four constituents, a gasoline sprayer, a HCCI oil reservoir, a fuel pump then an ECU. The fuel injector is fixed with inlet pipe of an engine and received the fuel from the HCCI fuel tank. The ECU is used for controlling a volume of fuel delivered besides the injection timing. Loading device of Swingfield electrical dynamometer is attached through the engine for testing.

An outpouring chamber was mounted at entry of an engine to uphold a persistent airflow over the orifice device and was measured by manometer. An AVL GH14D/AH01 piezoelectric pressure transducer is fixed inside the chamber for pressure monitoring, a sampling break angle for 0.5°CA. A $p - \theta$ data for 50 sequential cycles were recorded with DAQ speed sensor. AVL 365C is mounted on engine shaft for measuring crank angle. Gaseous emanations such as NOx, UHC, CO, CO₂ and O₂ remained measured by an AVL DI GAS 444 gas analyser.

3. Experimental Procedure

At first, the engine is operated in direction injection mode for warming up; to get cooling water temperature as 80°C and the coolant should reach 85°C. Tests are carried in DI and HCCI-DI mode. Engine is slowly loaded as 0 to maximum (100%) of its rated value. Diesel, B25, B50, B75 then B100 biofuel are considered as fuel for direct injection mode. A 50 ppm proportion of Al2O3 fuel additive was blended with fish oil-diesel blend with petrol as premixed fuel as 20%. All tests in this study are accompanied through a constant rpm of 1500.
Table 1. Engine Specifications

| Parameter                                | Specification                                      |
|------------------------------------------|----------------------------------------------------|
| Engine Type                              | Single cylinder naturally aspirated engine         |
| Rated Power                              | 4.4 kW                                             |
| Rated Speed                              | 1500 RPM                                           |
| Compression Ratio                        | 17.5:1                                             |
| Bore                                     | 87.5 mm                                            |
| Stroke                                   | 110 mm                                             |
| Injection Timing of DI fuel              | 23° before TDC                                      |
| Premixed Fuel Injector Nozzle Type       | Electronic fuel injector with 4 hole nozzle        |
| Premixed Fuel Injection Pressure         | 3 bar                                              |
| DI Fuel Injector Nozzle Type             | Plunger type fuel injector with 3 hole nozzle      |
| DI Fuel Injection Pressure               | 200 bar                                            |

4. Results and Discussion

HCCI-DI engine is investigated with petrol mixed as pilot one besides various mixtures of fish oil biodiesel as the direct injection (DI) fuel. Diesel, B25 (25% fish oil blended with diesel), B50, B75 then B100 biofuel are considered in the trial. The effect of different blends of 50 ppm Al2O3 fuel additive was also investigated. Combustion factors such as maximum pressure and HRR, performance parameter $\eta_{bth}$ and emission parameters such as NOx, UHC, Smoke and CO gaseous fusions also analysed.

4.1 Combustion characteristics

4.1.1 In-cylinder pressure

Maximum pressure during combustion is recorded by AVL GH14D/AH01 pressure sensor. Figure 3 shows in-cylinder pressure for diesel, B25, B50, B75 and B100 biodiesel with and without Al2O3 nano additive during DI besides HCCI-DI mode of setups at 100% load. The investigational observations revealed that, in DI mode, maximum combustion pressure was increased for diesel in comparison by fish oil biodiesel. The Pmax observed from DI combustion for Diesel and fish oil biodiesel are 70.3 bar and 66.7 bar respectively at 100% load. The Pmax for fish oil biodiesel is 5.12% lesser compared with diesel fuel. The major causes of reduction in cylinder pressure were (i) excessive viscidness and lower instability of the fish oil biodiesel [51], (ii) lower micro flare-up and (iii) lower calorific value [54] of fish oil biodiesel. The excessive viscidness of biodiesel results poor atomization besides small instability character of fish oil biofuel results inferior mixing of fish oil biodiesel with air. An inferior caloric value of fish oil biofuel results lesser heat energy release.

The 20% of gasoline premixing shows significant enhancement in the in-cylinder pressure values. During HCCI-DI combustion, for diesel direct injection, up to 11.1% improvement in the Pmax values
The major reasons for the higher Pmax are, (i) higher fuel availability at the start of combustion and (ii) the homogeneous mixture of gasoline availability in the cylinder. In HCCI-DI mode, 20% of gasoline was provided at entry pipe during the suction stroke, which results higher homogeneous mixture in in-cylinder during combustion. This higher homogenous air fuel mixture results in high combustion pressure during combustion. In HCCI-DI combustion was also, the direct injection of fish oil biodiesel results reduction in the Pmax values. In HCCI-DI combustion, the direct injection of fish oil biodiesel results 7.55% reduction in the Pmax values compared with diesel direct injection. However, the Pmax value for fish oil biodiesel in HCCI-DI combustion is 2.7% higher compared with diesel fuelled DI mode.

The accumulation of Al2O3 nano additive with the direct injection improves the combustion features of the blend and delivers better combustion pressure compared with neat biodiesel. During DI combustion, 2.13% increase in the Pmax was found for diesel fuel with Al2O3 nano additive compared with neat diesel. The (i) higher surface to volume ratio of the Al2O3 nano additive (ii) High thermal conductivity of the Al2O3 nano additive and (iii) O2 present in the nano additive is the reasons for the improvements in the burning features for nano additive blended fuel. During HCCI-DI combustion, the blending of the Al2O3 nano additive in the DI fuel showed significant improvements in the combustion characteristics.

Figure 2. Variation of in-cylinder pressure for DI and HCCI-DI combustion at maximum load
**Figure 3.** Maximum in-cylinder pressure for DI and HCCI-DI combustion at maximum load

**4.1.2 Performance Characteristics**

**Figure 4.** Brake thermal efficiency for DI and HCCI-DI combustion at maximum load
Figure 4 shows BTE under DI mode and HCCI-DI mode. From Fig.4, the BTE was reduced with improved fraction of fish oil biofuel. For direct injection combustion, brake thermal efficiency was reduced by 4.23% for fish oil biofuel in comparison with diesel. An improved oxygen particle in blended biofuel was the reason besides increased specific fuel consumption. During HCCI-DI combustion augmented brake thermal efficiency is observed up to 3.39% than DI combustion. This is because of the lean HCCI-DI combustion, which could decrease the specific fuel consumption.

During DI mode, brake thermal efficiency was improved by 3.68% for Al2O3 additive blended Fish Oil biodiesel compared to neat Fish Oil biodiesel at maximum load. In HCCI-DI mode, brake thermal efficiency was enhanced by 2.82% for gasoline premixed (HCCI-DI) Al2O3 additive added Fish Oil biodiesel compared to diesel direct injection at maximum load.

![Figure 5. NOx Emissions for DI and HCCI-DI combustion at maximum load](image)

### 4.1.3 Emission Characteristics

NOx emanations of gasoline premixed HCCI-DI combustion with fish oil biodiesel for DI mode as presented in Fig.5. Experimental outcomes exposed that the injection of fish oil biodiesel results in the NOx formation. In DI combustion, there was an increase in 37.8% of NOx formation was found for fish oil biodiesel compared with diesel fuel. The (i) higher exhaust gas temperature delivered from the fish oil biodiesel, (ii) higher oxygen concentration in the fish oil biodiesel, (iii) increased cetane index of blended fuel [52] and (iv) presence of unsaturated fatty acids [55] in the biodiesel are the reasons for the high NOx formations from the fish oil biodiesel.

During direct injection combustion, NOx emissions were decreased by 10.83% for Al2O3 additive added Fish oil biodiesel compared to neat Fish Oil fuel. NOx emissions were increased by 10.25% for Al2O3 additive added Fish Oil biodiesel compared to diesel fuel direct injection. In HCCI-DI combustion, NOx emissions were decreased by 3.18% for diesel premixed Fish Oil biodiesel with Al2O3 additive than diesel fuel direct injection.
Figure 6 shows the HC formations from the fish oil biodiesel fuelled HCCI-DI engine with and without Al2O3 nano additive. The investigational outcome, during direct injection combustion, hydrocarbon release is reduced as 33.33% of fish oil biofuel in comparison with diesel fuel. An increase in diffusive combustion with exhibit oxygen viability [56]and increase in flame travel during the mixture interactions could increase flexibility of the ignition at different spots. In HCCI-DI mode, premixing of gasoline increased leanness of mixture, this increased the hydrocarbon emission. In test observations of HCCI-DI mode, premixing of gasoline the hydrocarbon releases rises as 24% compared to diesel during direct injection combustion. Merely 20.83% decrease in hydrocarbon emission observed for gasoline premixed fish oil biodiesel-fueled HCCI-DI engine than diesel direct injection.

The doping of Al2O3 nano additive in the fuel resulted reduction in the formation of HC emissions due to the improved combustion characteristics attributed by the nano additive. A trial outcome revealed that, up to 8.33% and 4.17% reduction in the formation of HC emissions from the Al2O3 nano additive blended fuelled combustion in DI and HCCI-DI mode, respectively.

**Figure 6.** HC Emissions for DI and HCCI-DI combustion at maximum load

HC formations from the fish oil biodiesel fuelled HCCI-DI engine with and without Al2O3 nano additive as indicated in Fig.6. Higher oxygen existence besides absence of sulfur presence decreases smoke emission from fish oil biodiesel fuelled engine. An oxygen molecule of blended fuel confirms diffusive combustion then it increases the flame travel in combustion phase and reduced smoke emission. From the experimental investigations, it is observed that smoke is reduced as 22.69% of fish Oil methyl ester-fueled direct injection compared to diesel fuel DI mode.
The doping of Al₂O₃ nano additive in the fuel resulted reduction in the formation of HC emissions due to the improved combustion characteristics attributed by the nano additive. The investigational outcomes exposed that, up to 8.33% and 4.17% reduction in the formation of HC emissions from the Al₂O₃ nano additive blended fuelled combustion in DI and HCCI-DI mode, respectively.

![Graph showing CO emissions for DI and HCCI-DI combustion at maximum load](image)

**Figure 7.** CO Emissions for DI and HCCI-DI combustion at maximum load

A variations of carbon monoxide emissions from the fish oil biodiesel-fueled HCCI-DI and direct injection engines as depicted in Fig.7. An observed outcome of direct injection mode, carbon monoxide release is lessened by 50.05% for fish oil methyl esters in comparison with diesel fuel. Oxygen existence of fish oil blends and inferior carbon presence of the fish oil esters reduced carbon monoxide productions. But lean combustion from the HCCI-DI operational mode increased carbon monoxide emission.
Figure 8. Smoke Emissions for DI and HCCI-DI combustion at maximum load

The smoke emission formations from the fish oil biodiesel fuelled HCCI-DI engine with and without Al₂O₃ nano additive as shown in Fig. 8. Higher oxygen existence and absence of sulfur presence of fish oil blends decreased smoke emission from fish oil biodiesel fuelled engine. Oxygen existence of blends confirms diffusive combustion and it increases the flame travel in mixture interactions, improves fuel evaporation and reduced smoke emission [53]. From the experimental investigations, it is observed that smoke production is reduced as 22.74% of fish oil methyl esters -fuelled direct injection compared to diesel fuel DI operational mode. In an investigational approach, an additional decrease in smoke emission is witnessed in petrol premixed HCCI-DI operation. Smoke emission decreased by 41.07% for gasoline premixed fish oil biodiesel compared to diesel fuel direct injection combustion. Up to 25.99% fall in smoke production is noted for Al₂O₃ additive blended fuel in comparison with CI engine fuel without gasoline premixing.
5. Conclusion

Al₂O₃ additive blended fish oil biodiesel-fueled HCCI-DI mode operation is examined and combination of various mode of operation is investigated. HCCI-DI combustion decreased ignition delay and started the combustion earlier than DI combustion. Brake thermal efficiency of HCCI-DI engine was superior to DI combustion. up to 1.84% increase in the brake thermal efficiency was observed from the HCCI-DI engine compared with DI engine. The addition of Al₂O₃ nano additive increased the brake thermal efficiency up to 3.31% and 5.88% for DI and HCCI-DI combustion respectively. HCCI-DI combustion showed a significant reduction in the NOx emissions. Up to 7.03% reduction in the NOx formations observed from the gasoline premixed HCCI-DI engine. Up to 33.33% reduction in the HC emissions were found in the fish oil biodiesel fuelled combustion. The significant reduction in the CO emissions also found from the experimental investigations.

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