# Experimental Investigation of HCCI Engine performance and emission characteristics using waste cooking oil and alumina as additive

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***Abstract***— **In this experimental investigation, the performance, combustion and emission characteristics of a HCCI (Homogeneous Charge Compression Ignition) engine are analyzed using various biodiesel blends such as B10, B20, B30, B10A30, B20A30 and B30A30 respectively. The alumina (Al2O3) nanoparticles of 30 ppm are mixed with the various prepared fuel blends by using an ultrasonicator which would help to fetch a uniform suspension of nanoparticles over the blend fuel. The prepared samples of biodiesel were tested for its chemical composition by using GCMS method. SEM analysis and X-ray diffraction have been done for the alumina nanoparticles to test the size of the particles that are blended to the biodiesel blends. The chemical reactivity and rate of mixing are better though the characteristics of nanoparticles exhibit high surface area/volume ratio during the combustion, which ultimately results in good performance and emission characteristics in the diesel engine. Among the test fuels, B10A30 shows better performance both in terms of efficiency and emissions such as HC, CO, NOx and Smoke.**

INTRODUCTION

Biodiesel is conceived as a renewable and environment-friendly fuel benignant to petro-diesel with benefits of lower level of smoke, unburned hydrocarbons and carbon monoxide than petrol-diesel. Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters. Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, soybean oil, animal fat with an alcohol producing fatty acid esters. Biodiesel is an alternative fuel similar to conventional or 'fossil' diesel. Biodiesel can be produced from straight vegetable oil, animal oil/fats, tallow and waste cooking oil. The process used to convert these oils to Biodiesel is called transesterification. The largest possible source of suitable oil comes from oil crops such as rapeseed, palm or soybean.

**The brake thermal efficiency for the fuel B10A30 was significantly improved when it is compared to the fuel B100. The HC emission will be reduced, CO emission will be reduced , NOx emission will be reduced and smoke emission will be reduced when it is compared to the pure biodiesel (B100). It is seen clearly that the blending of biodiesel at varying proportions in the diesel fuel has increased the performance and reduced HC, CO and smoke emission owing to the increase in NOx emission due to better combustion characteristics. From this investigation, the addition of alumina nanoparticles has improved the combustion quality showing better performance and shown reduced NOx, HC, CO and smoke when compared to the neat diesel and neat biodiesel fuels.**

***Keywords—Biodiesel,Alumina,SEM analysis,XRD analysis,Brake thermal efficiency, emission characteristics.***

Most biodiesel produced at present is produced from waste vegetable oil sourced from restaurants, chip shops, industrial food producers.Recently, many researchers focused their attention on fuel formulation technique for achieving better performance and emission characteristics. Among the recent fuel additives to biodiesel, the nanoparticles as additive in biodiesel has emerged as a new promising fuel additive for achieving utmost improvement in the performance and level best reduction of exhaust emission. Currently , India produces only 30% of the total petroleum fuels required for its consumption and the remaining 70% is imported, which costs about Rs. 80,0000 million per year. It is evident that mixing of 5% of biodiesel fuel to the present diesel fuel can save Rs.40, 000 million per year.Over last few years, Biodiesel(fatty acid methyl esters) has become the part of the equation in the 1990's as the effects of global warming began to get political acknowledgement, because of its benefits over petroleum diesel like significant reduction in greenhouse gas emissions, non- sulfur emissions and non-particulate matter pollutants, low toxicity,biodegradable and is obtained from renewable source like vegetable oils, animal fat etc.

A. *Importance*

Biodiesel is superior to fossil diesel fuel in terms of exhaust emissions,cetane number, flash point and lubricity characteristics, without any significant difference in heat of combustion of these fuels . Moreover, biodiesel returns about 90% more energy than the energy that is utilized to produce it. Biodiesel mixed with conventional diesel in some proportions can be used to run any existing conventional compression ignition engine and does not require any modifications to be done to the engine .Due to benefits like renewable in nature, low cost and greenhouse gas reduction potential, biodiesel is nowadays incorporated all over the world especially in developed countries like USA, France, Brazil in different proportions with diesel. It is also estimated that India can supplement 41.14% of its total diesel fuel consumption, if resources like waste cooking oil and other bio wastes were used as raw material for biodiesel production.

### B. *Blends*

Blends of biodiesel and conventional hydrocarbon-based diesel are products most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix.100% biodiesel is referred to as B100. For example,

20% biodiesel, 80% diesel is labeled B20
5% biodiesel, 95% diesel is labeled B5 2%
biodiesel, 98% diesel is labeled B2

### C. *Properties*

The color of biodiesel ranges from golden to dark brown, depending on the production method. It is slightly miscible with water, has a high boiling point and low vapor pressure. The flash point of biodiesel exceeds 130 °C (266 °F), significantly higher than that of petroleum diesel which may be as low as 52 °C (126 °F). Biodiesel has a density of ~0.88 g/cm3, higher than diesel (~0.85 g/cm3). Biodiesel contains virtually no sulfur,and it is often used as an additive to Ultra- Low Sulfur Diesel (ULSD) fuel to aid with lubrication, as the sulfur compounds in diesel provide much of the lubricity.

### D. *Fuel Efficiency*

The power output of biodiesel depends on its blend, quality, and load conditions under which the fuel is burnt. The thermal efficiency for example of B100 as compared to B20 will vary due to the differing energy content of the various blends. Thermal efficiency of a fuel is based in part on fuel characteristics such as: viscosity, specific density,and flash point; these characteristics will change as the blends as well as the quality of biodiesel varies.

### E. *Fuel Emissions*

Recently , As per conducted experiments by blending two nanoparticles alumina and cerium oxide of each 30 ppm in biodiesel as separate and combined addition as fuel in a HCCI diesel engine and observed prominent percentage reduction of NO, CO, UBHC and smoke emission by 13, 60, 33 and 32% respectively..

### F. *Various types of oil used*

There is ongoing research into finding more suitable crops and improving oil yield. Using the current yields, vast amounts of land and fresh water would be needed to produce enough oil to completely replace fossil fuel usage.

#### 1. *Rapeseed oil*

The biodiesel is produced mainly from rapeseed with doubly improved varieties of seeds. The composition of rapeseed oil must meet specific quality requirements that are included in the standard for methyl esters as fuels for diesel engines.

#### 2. *Palm Oil*

Palm oil is the most prospective biodiesel feedstock compared to other oilseeds. Palm oil has higher production yield, low fertilizer, water and pesticide needed for the plantation. Palm oil production takes less sunlight in terms of energy balance to produce a unit of oil as it produces more oil per hectare. However, in terms of the basis of palm oil yield per man in a day, it is not as competitive as other oilseeds because of the difficulty of labor plantation management and harvesting of the fruit. Among the vegetable oils in the world market today, crude palm oil and refined palm oil tops the list. Palm oil is known for its nutrient fact that makes it suitable as vegetable oil used for daily cooking.

#### 3. *Waste cooking oil*

Waste cooking oil refers to the used vegetable oil obtained from cooking food. Repeated frying for preparation of food makes the edible vegetable oil no longer suitable for consumption due to high free fatty acid (FFA) content . Waste oil has many disposal problems like water and soil pollution, human health concern and disturbance to the aquatic ecosystem , so rather than disposing it and harming the environment, it can be used as an effective and cost efficient feedstock for Biodiesel production as it is readily available. Furthermore, Animal fats with high acid value and fat-containing floating sludge discharged in water systems are subject to environmental concern due to their high pollutant potential and it is a challenge for wastewater treatment plants to purify it. Therefore, conversion of low quality lipid-rich sources from slaughterhouses into commercial grade biodiesel is an opportune strategy for minimizing environmental damages while it can help meeting the energetic challenge. The biodiesel product from second-used cooking oil is appropriate with the Indonesian Standard of Biodiesel, with Specific Gravity 877 kg/m3, Viscosity Kinematic 4.971 mm2/s, Flash Point 180.5oC, and Pour Point 3oC .

### F. *Homogeneous Charge Compression Ignition (HCCI) engine*

It is highly required from the automobile sector to develop clean technologies with lower fuel consumption for the improvement of the ambient air quality, reduction of the greenhouse gases, security of the primary energy resources and fulfilment of the increasingly stringent emission norms. Therefore, the fuel and the engines used in transportation sector have to cope up with two major challenges of improving efficiency and reducing emissions in a highly competitive era .Some of the next generation advanced combustion concepts, which have the potential to reduce NOx and PM emissions simultaneously while maintaining high thermal efficiency are- Homogeneous Charge Compression Ignition (HCCI), Stratified Charge Compression Ignition (SCCI) and Low Temperature Combustion (LTC) among others.

## I. LITERATURE SURVEY

Wanodya Asri Kawentar and Arief Budiman, “Synthesis of biodiesel from second used cooking oil”. This paper reports that transesterification process depends on several parameters which are reaction temperature and pressure, reaction time, rate of agitation, type of alcohol used and molar ratio of alcohol to oil, type and concentration of catalyst used and concentration of moisture and FFA in the feed oil. It was observed that biodiesel of good quality could be obtained from used frying oil in reaction conditions: molar ratio of methanol to oil 6:1, with 1% KOH, temperature at 25°C and reaction time of 30 min.

Hwanam Kim , Byungchul Choi, "The effect of biodiesel and bioethanol blended diesel fuel on nanoparticles and emissions from CRDI diesel engine". This paper concludes that the use of biofuel-blended diesel fuels reduced the total number of particles emitted from the engine. However, when compared to the use of diesel, the use of biodiesel–diesel blends caused the emission of more particles smaller than 50 nm, which are harmful to human body. The fuel consumption also increases due to the lower calorific value of the biodiesel.

C. Syed Aalam, C.G. Saravanan, "Effects of nano metal oxide blended Mahua biodiesel on CRDI diesel engine". This paper analyses the performance and emission characteristics of Mahua based biodiesel blended with Aluminium Oxide Nanoparticles (APN). It is found that the flash point of the fuel increases, fuel consumption decreases and the harmful emissions are reduced considerably.

M. Annamalai, B. Dhinesh, K. Nanthagopal, P.SivaramaKrishnan, J. Isaac Joshua Ramesh Lalvani, M.Parthasarathy, K. Annamalai, "An assessment on performance, combustion and emission behavior of a diesel engine powered by ceria nanoparticle blended emulsified biofuel". This paper reports that for cerium oxide ($CeO_2$) nanoparticle blended test fuel, the drastic reduction of carbon monoxide (CO), unburned hydrocarbon (HC), oxides of nitrogen (NOX) and marginal decrease of smoke opacity emission could be achieved compared with the LGO emulsion and diesel fuel at various power outputs.

Padhi. S.K., Singh.R.K., "Optimization of esterification and transesterification of Mahua (Madhuca Indica) oil for production of biodiesel". This is paper concludes that for maximum (95%) biodiesel production the transesterification reaction shows that the concentration of alkali catalyst is 8 % Sodium Methoxide, 0.33%v/v alcohol/oil ratio, 1 hr reaction time, 650C temperature and excess alcohol 150%v/v.

R. El-Araby , Ashraf Amin , A.K. El Morsi , N.N. El-Ibiari , G.I.El-Diwani, "Study on the characteristics of palm oil–biodiesel–diesel fuel blend". This paper has experimentally arrived at the conclusion that the properties of palm oil/palm oil biodiesel blends showed that there is no significant difference in fuel properties of the blends up to 30% volume of oil/biodiesel of palm Oil.

Ayat Gharehghania , Sasan Asiaeib , Esmail Khalifec , Bahman Najafid , Meisam Tabatabaeie, "Simultaneous Reduction of CO and NOx Emissions as well as Fuel Consumption by Using Water and Nano Particles in Diesel Biodiesel Blend", Restrictive emission regulations and climate change are the main motivations for improving engine combustion characteristics to decrease engine-out emissions and fuel consumption. Fuel additives are effective solutions to improve fuel properties to address these challenges. In this study, simultaneous application of water and cerium oxide nanoparticles in diesel-biodiesel fuel blend on performance and emission characteristics of a single cylinder diesel engine operated at start of injection of 20 before top dead center was experimentally investigated.

*Objectives of the current research work*

The main objectives of current research work which are outlined as follows:

1. Production of different blends of biodiesel
2. Analysis of the alumina and blending it in the prepared biodiesel.
3. To find the performance and emission characterstics of the HCCI engine.

## II. BIODIESEL PRODUCTION

### *A. Materials*

The raw materials for biodiesel production are vegetable oils, animal fats and short chain alcohols.Although the properties of oils and fats used as raw materials may differ the properties of biodiesel must be the same, complying with the requirements set by international standards.

#### *1. Stages of Biodiesel production*

The various stages of production of biodiesel includes

- Treatment of raw materials
- Alcohol-Catalyst mixing chemical reaction
- chemical reaction or transesterification
- Separation of reaction products
- Purification of reaction products

#### *2. Collection of Waste Cooking Oil*

A survey of waste cooking oil (WCO) management among the community of local residentials was conducted. A questions were given to 30 participants, which were randomly chosen regardless of gender or occupation. 70% of the respondents were females and among them, 50% were housewives. It was found that 27% of the participants consumed 2-5 kg of oil per month. The survey revealed that 17% of respondents discarded the WCO into dustbin while another 7% and 60% discarded the WCO onto soil and into drainage system, respectively. The remaining 16% sold the WCO and/or consumed it completely in their cooking. In terms of health awareness, it was found that 57% of the respondents used the WCO 2-3 times before disposing it, while 13% of the respondents used the WCO until depletion. The necessary waste cooking oil used in this research were collected from various houses who all are used refined vegetable oils for their cooking purpose.

#### *3. Test Sample Preparation*

The biodiesel used in this work was produced in a pilot plant by basic methanolysis of crude palm oil using a methanol/oil molar ratio of 12:1, with 0.6% sodium hydroxide by weight as the catalyst. The reaction temperature and time were 60 C and 1 h, respectively. The commercial grade diesel fuel (D) used had an elemental composition by weight of 87.2% carbon, 12.8% hydrogen and 0.0225% sulphur, and an aromatic content of 29.3% (13% mono aromatics, 13.3% di aromatics and 3% polyaromatics). Blends were prepared on a volume basis at 25C.

*Figure 1 : Biodiesel Preparation*

*Addition of nanoparticles to the biodiesel blend*

For the experimental investigation, for types of test fuels are prepared, denoted as BxAy (x means volume fraction and y means ppm). They are: B10 (containing 10% biodiesel and 90% diesel in volume percentage), B10A30 (containing 10% biodiesel in volume percentage, 30 ppm Alumina), B60 (containing 60% biodiesel and 40% diesel in volume percentage and B60A30 (containing 60% biodiesel and 40% diesel in volume percentage, 30 ppm Alumina). Dispersion of nanoparticles with fuels is prepared by using an apparatus called Ultrasonicator for 45 min to prepare the test fuels.

*Figure 2 : Instrumentation of Ultrasonicator*

## III. ANALYSIS

A mass spectrometer is typically utilized in one of two ways: full scan or selective ion monitoring (SIM). The typical GC-MS instrument is capable of performing both functions either individually or concomitantly, depending on the setup of the particular instrument. The primary goal of instrument analysis is to quantify an amount of substance. This is done by comparing the relative concentrations among the atomic masses in the generated spectrum.

### *A. X-Ray Diffraction*

X-ray crystallography is a technique used for determining the atomic and molecular structure of a crystal, in which the crystalline atoms cause a beam of incident X-rays to diffract into many specific directions. By measuring the angles and intensities of these diffracted beams, a crystallographer can produce a three-dimensional picture of the density of electrons within the crystal. From this electron density, the mean positions of the atoms in the crystal can be determined, as well as their chemical bonds, their disorder, and various other information.X-ray crystallography is related to several other methods for determining atomic structures. Similar diffraction patterns can be produced by scattering electrons or neutrons, which are likewise interpreted by Fourier transformation. If single crystals of sufficient size cannot be obtained, various other X-ray methods can be applied to obtain less detailed information; such methods include fiber diffraction, powder diffraction and (if the sample is not crystallized) small- angle X-ray scattering (SAXS). If the material under investigation is only available in the form of nanocrystalline powders or suffers from poor crystallinity, the methods of electron crystallography can be applied for determining the atomic structure.

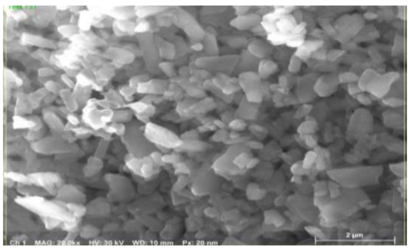

*Figure 3 : XRD of Alumina*

## IV. EXPERIMENTAL SETUP

### *A. Experimental Procedure*

A single cylinder, 4 stroke,HCCI water cooled diesel engine, coupled with electrical dynamometer is used for this project. The tank is provided with 20mm orifice plate through which air is admitted into the engine. The pressure difference due to air flow through orifice is measured with inlet air thermocouple. The exhaust gas side of the engine consists of series of devices such as exhaust gas thermocouple, gas analyzer, smoke meter, and quartz piezoelectric pressure transducer with 8 bit data acquisition system. The combustion analyzer is attached with the test rig to study the combustion behavior of the engine. The experimental setup also consists of two fuel tank fitted with burette and are usually connected with three way valve. This fuel measuring device is used to measure the fuel consumption of the engine. The output side of the engine consists of an electrical dynamometer followed by a load rheostat. The arrangement is provided with digital ammeter, voltmeter and wattmeter to record the current, voltage and power respectively of each load. The output is measured in terms of watts using digital watt-meter mounted on the panel. An 8-bit data acquisition system (DAS) is also connected with the test rig to acquire the combustion pressure, crank angle, heat release rate for a stipulated number of cycles. The signal acquired from the data acquisition system is set to the computer and then various combustion parameters of fuel are analyzed


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*Figure 4 : Experimental Setup (HCCI)*

## V. RESULTS AND DISCUSSIONS

The parameters which governs the performance of the fuel is given by the following

- Specific fuel consumption
- Mechanical efficiency
- Brake thermal efficiency
- Indicated thermal efficiency.

1. *Exhaust emissions*

From the emission control point of view, measurement of emissions from the engine is very important. The exhaust of the engine may contain the following gases.

- Carbon monoxide (CO)
- Unburned hydrocarbons (HC)
- Carbon dioxide (CO2)
- Oxides of nitrogen (NOx)
- Oxygen (O2)

The various emissions were analysed and the graph has been plotted accordingly. For instance it showed,

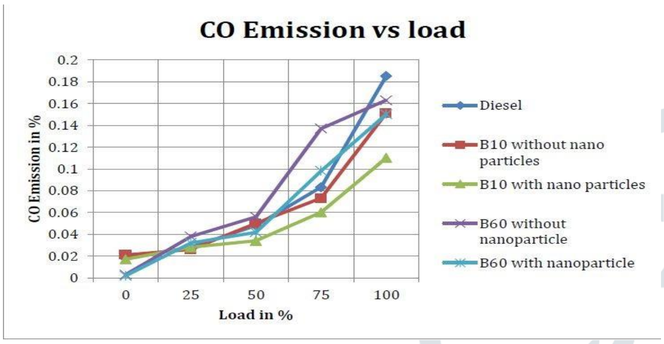


*Figure 5 : Co Emission vs load graph*

Among these the B10A30 showed the best results.

*Figure 6 : Prepared Biodiesel blend (B10A30)*

## Ⅶ CONCLUSION

The waste cooking oil based Methyl Ester (with and without the Nano alumina additives) used here as a biofuel is compared with the diesel and it results that waste cooking oil based methyl ester with Nano additives is having a potential to be used in diesel engines. The trans-esterified waste cooking oil is blended with diesel by proportion of B10, B10A30, B20, B20A30. The performance and emission characteristics was carried out on HCCI engine.The results are compared with that of Diesel on same engine.

The brake thermal efficiency of the other blends was found to be B10 33.15%, B20 32.54%, B20A30 33.47% The brake thermal efficiency of the B10A30 blend is 36.52% which is better when compared to 33.63% Brake thermal efficiency of the normal diesel. The NOx emission was reduced by 1661 ppm (B10A30) and CO emission was around 0.093%.Therefore, the WCO Methyl Ester based biodiesel blended with Aluminium oxide Nanoparticles B10A30 can reduce pollutant emission like NOx and HC to a considerable extent as well as improve the performance of the engine considerably by increasing the Brake Thermal Efficiency.

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