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A Major Project Report on

" Synthesis and Characterization of Aluminum hydroxide Nano particles for enhancing engine performance"

Bachelor of Mechanical Engineering

8^{th} sem Major-Project Report

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ABSTRACT

Recently, the application of nanotechnology in the fuel blending is on the rise as evidenced by the number of researches undertaken in the past few years. The search to develop new technologies that can address challenges currently facing the diesel engines. This present work is carried out in two stages. In the first stage, synthesis of nano particle of AlOOH has been carried out by precipitation method and as prepared nano particles are characterized by various techniques.

Further in the next phase of the work, influence of AlOOH NPs and hydrogen on the performance; combustion and emission characteristics of a single cylinder four stroke direct injection diesel engine working on dual fuel mode using dairy scum oil methyl ester (DSOB) has been investigated. In this work three AlOOH NPs proportions such as 20, 40 ppm and 60 ppm were used and hydrogen was injected in inlet manifold. Results showed that, DSOB combination with 60 ppm of AlOOH NP and hydrogen addition showed increased thermal efficiency and hydrocarbon (HC) and carbon monoxide (CO) emissions were decreased, except NOx emissions. More research and development of technology should be devoted to this field to further enhance the performance and feasibility of these fuels for dual fuel operation and future exploitations.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

One of the most used mineral flame retardants is aluminum hydroxide. As the temperature increases aluminum hydroxide shows endothermic decomposition(about 220℃ with an endothermic reaction of 1.17kj/g) and absorbs energy. It also releases non-flammable water which dilutes combustible gases. Aluminum oxide provides heat insulation by reflecting heat when it accumulates on surface. Its widely used because of its low cost and non-toxicity. Metal oxide nano-particles have been extensively developed in the past decades. They have been widely used in many applications such as catalysts, sensors, semiconductors, medical science, capacitors, and batteries [1–4]. Among them aluminum oxide (Al_2O_3) and its compounds have long been known for more than a century, for example, aluminum oxide hydroxide (AlOOH) and aluminum hydroxide ($Al(OH)_3$).

In the recent years, AlOOH nano-particles were synthesized in liquid using various trial and error method by using aluminum nitrate and ammonium hydroxide with the use of precipitation method. since there aren't many research on usage of nano-particles on engine applications are happening, it could be fascinating to see that we can increase the power of engine using hydrogen and reduce its emission in vehicles using oxygen present in the nano-particle. Need for using AlOOH nanoparticles (i) To make the performance of the engine gets better (ii) To reduce the emission.

1.1 Statement of the problem

The depleting nature and ever increasing cost of fossil with their increased demand associated with increased pollution from CI engines has caused an interest in finding alternative fuels. These conventional sources of energy are depleting in nature and may be exhausted at the near middle end of this century. Therefore, sincere, and untiring efforts have to be made by scientist and researchers in exploring the possibilities of harnessing energy from renewable energy sources (Biofuels). The evaluation of feasibility of using an alternative fuel has been of utmost concern. Rapid progress in the direction of using biodiesel for compression ignition is undertaken in order to become independent of diesel. The performance of biodiesel operated single fueled engine highly depends upon optimization of injection and combustion chamber geometry. CI engine is modified to operate on biodiesel (BIODIESEL) fuel mode. In single fuel mode was a suitably developed apart from provision made to use manufacturer injection and combustion chamber.

1.2 Objectives of the study

- To produce or synthesize aluminum hydroxide nanoparticles.
- To study the properties of nano particle using XRD, SEM, TGA etc.
- To conduct performance, emission characteristics of a CI engine.
- To generate base line data using diesel fuel in a CI engine operated on single fuel mode.
- Compare the results obtained with base line data.

1.3 Scope of the Study

Scope of the study is limited to experimental investigation of dairy scum oil as injected fuel in a CI engine operating on single fuel mode of operation. It includes feasibility study of biodiesel in a normal engine operation with respect to optimum conditions. Further the study on single fuel operation is limited to dairy scum oil only. Optimum operating conditions in terms of nozzle and combustion chamber geometry are within the range of values selected for the study.

1.4Justification of the work

The present work focuses on the feasibility of biodiesel use in the existing compression ignition engine. The depletion of fossil fuels augmented by exponential growth in energy demands has made it necessary to take a conservative stand in the utilization of the fossil fuels. Developing countries like India are hit hard by this oil embarrassing situation hence it is the need of the hour to conserve oil to spare resources for other developmental activities. Also, high polluting nature of petroleum fuels is another factor to justify the use of biodiesel as an alternative to the fossil fuels. Thus, this project is justified in the present contest as it aims at elimination of fossil fuels, through efficient utilization of biodiesel of non-edible vegetable oil.

1.5 Methodology

The methodology adopted for the study includes

- Literature survey of the topic is done.
- Synthesis of aluminium hydroxide nanoparticles by using chemical method.

- Engine performance, emission Testing using experimental setup for single fuel operation.
- SEM, XRD, TGA tests of the synthesized material.
- Results obtained from dual fuel engine and diesel-based operation compared with DSOB based operation.

1.6 Organization of the report

This study is organized into five chapters. Chapter 1 deals with introduction highlighting the potential and importance of biofuels and Problem definition. It is followed by chapter 2 which provides detailed literature survey on properties of biodiesel, and brief summary of research works carried out on single fuel engine operating on diesel/biodiesel. Fuels used for the present research work is dealt in chapter 3. Production of nanoparticles is discussed in chapter 4, Chapter 5 deals with results and discussion. Chapter 6 deals with conclusion and reference.

Chapter 2

LITERATURE SURVEY

Srinivasa Rao and Anand (2012) has proposed the paper that describes a sequence of experimental investigations conducted on a biodiesel fueled Direct Injection Compression Ignition (DICI) engine with an objective of improving its working characteristics using Aluminum oxide hydroxide AlOOH nano-particles as a fuel additive. Systematically prepared biodiesel from Jatropha oil and commercially available nano-sized AlOOH were used in this investigation. The AlOOH nano-particles crystallite size and morphology were studied using XRD (X-ray diffraction) and Transmission Electron Microscope (TEM).[1-3]

Ganesh (2011) had thought that increasing efficiency of the combustion of fuel and reducing the emission produced by the diesel is the main objectives of the many research. Much research has been taken up on biodiesel as a alternative fuel in CI engine to increase the performance and reduce the emission. One such way of improving the performance and reduce the emission is adding nano-particles as a fuel additive in biodiesel. Nano-particle additives have been utilized in fuels for some time and have been shown to dramatically increase in combustion enthalpies and quality.

Ramkumar and Kirubakaran (2016) reported performance and emission characteristics of biodiesel fueled diesel engines. They investigated the use and influence of modifications, various additives, and proportions of blends of biodiesel with diesel. They reported that the physical and thermal characteristics of biodiesel have a great influence on the performance and emission levels.

Bang (2016) reported characteristics of oxides of nitrogen (NOx), particulate matter (PM) and polyaromatic hydrocarbon (PAH) emissions found in recent years when various biodiesel fuels with different physicochemical properties were used in diesel engines. They presented mainly the effect of ethanol addition, exhaust gas recirculation (EGR) and various catalytic converters on the emissions and particle size distributions of diesel engines. engine electronic control systems, proper method to improve conversion efficiency of catalysts, particulate trapping efficiency and method of biodiesel preparation can be used to lower exhaust emissions.[4-6]

Lokanadham and Ravindranath (2013) studied the performance of diesel engine performance fueled with biodiesel, and cycle by cycle (CBC) variations. They found many changes in the behavior of combustion leading to changes in engine performance values. They obtained maximum brake mean effective pressure (BMEP) with the biodiesel and it was slightly higher than diesel combustion, with the difference being just slight under maximum power. The best engine performance for biodiesel operated at the engine speed of 2000 - 2500 rpm.[10]

Veeraragavan and Sathiyamoorthy (2014) reported performance and emission tests carried out on a single cylinder diesel engine operated on blends of diesel with methanol, ethanol and biodiesel. They observed maximum blending ration at which the engine performs better performance with low emissions. They obtained biodiesel by transesterification of castor oil. They suggested using blends to achieve improved efficiency of the diesel engine with reduced emissions. They have also reported many advantages of using blends.[3-8]

Akhand and Shrivastava (2012) showed alternative fuels are the most promising in present days and are produced by transesterification of vegetable oils or animal fats. They studied the biodiesel production from transesterification process and they found that the base catalysts are more effective than acid catalysts. The main purpose of transesterification process is to lower the thickness of the oil. They studied effect of reaction parameters on conversion of biodiesel yield. Also they highlighted the use of biodiesel in diesel engine and obtained combustion, performance and emission characteristics. They showed lower performance for biodiesel operation. They showed biodiesel properties can significantly lower emission levels such as CO, SOx, HC and PM emissions.

Jeyaseelan, Mehta (2015) studied diesel and biodiesel injection settings effect on NOx emission levels. They conducted experiments on diesel engine at higher torque and loads and maintained same power for both diesel and biodiesel operation. Increased injection timing experienced higher NOx emissions with biodiesel. However, they showed lower NOx for retarded or decreased injection timing. They carried out fuel modifications by recycling 5% by volume of exhaust gas to the fresh charge and 10% by volume of methanol to Karanja biodiesel. These two NOx control strategies showed 35 to 45 % decreased NOx and 90% lower smoke. However, they reported that recirculation of exhaust gas increases the soot levels in the engine exhaust. Therefore, they suggested using of biodiesel-methanol blends to lower both nitric oxide and smoke.[2]

Lopes and Cushing (**2012**) studied diesel engine technologies that are compatible with B6-B20 biodiesel blends meeting ASTM D7467. They highlighted the problems of biodiesel utilization in diesel engines and reported effects of properties of biodiesel fuels on engine and fuel system performance. They suggested using B20 that meets the ASTM D7467 specification and showed the effects of biodiesel usage in diesel engines such as internal injector deposits, combustion chamber deposits, sticking of piston rings and fuel filter clogging.

Bouilly *et al.*, (2012) studied the effects of biodiesel oxidation stability on diesel fuel injection equipment (FIE) behavior using newly developed test rig and methodology. Their results of investigation showed injector deposits were reproduced and injector body temperature increase leads to increased degradation of fuel.[6]

Roy et al (2009) investigated biomass used for producer gas generation if it has greater hydrogen composition then it results into increased thermal efficiency with enhanced cylinder pressure with lowered carbon based emissions. In a dual fuel engine, greater importance is given to increased primary fuel substitution. Therefore, investigators have used alternative fuels for diesel engine applications and offer freedom in managing fuel substitution ratio. In this context, hydrogen influence, injection pressure, fuel injection quantity and various fuel–air equivalence ratios and different injection timings on the combustion and emissions of a supercharged producer gas fueled diesel engine.

Dhole et al (2016) utilized hydrogen in producer gas fueled diesel engines. They found amplified power output and reduced consumption of pilot fuel with slightly enhanced NOx emissions. In addition, they have observed increased delay period and combustion duration.

Literature review has been published by **Yaliwal et al (2014)** and observed that producer gas fueled diesel engines always resulted in reduced performance with amplified carbon based emissions. Also increased ignition delay, reduced cylinder pressure and heat release rate has been reported. Hydrogen addition at 8 lpm to producer gas amplifies thermal efficiency (BTE) by 5.16% and marginally lowers HC, CO, and smoke emissions, except marginally increased NOx emissions.

Mohammad *et al.*, (2021) investigated properties of Aluminum oxide (Al2O3) blended with butanol-diesel blend (B20) and combustion and emission characteristics under different engine loads. Increased cylinder pressure, rate of heat release, and brake thermal efficiency by 4.7% and particulate matter decreased by 30.5%, total particle mass decreased by 13.3%, and particle diameter increased by 9.2% for the different concentrations of nanoparticles added to the B20 under different engine loads. Drastic reductions in CO, HC, and NOX emissions by 42.71%, 37.46%, and 12.37%, respectively has been reported with addition of 100 mg/l of nanoparticles to the B20.

Mina *et al.*, (2020) studied the effects of nanoparticles addition and urea-SCR system on NOx emissions. They stated that manganese oxide and cobalt nanoparticles have less pollutants reduction efficiency compared to urea-SCR system with B20 blended biodiesel.

Ang F. *et al.*, (2018) investigated the effect of aluminum oxide, carbon nanotubes and silicon oxide nano particles blended with pure diesel in a dosage of 25ppm, 50ppm and 100ppm on combustion, performance and exhaust emission characteristics of a diesel engine. They have analyzed stability of nanoparticle-diesel fuel blends and experimented with varying loads. The results showed that silicon oxide blends were better than aluminum oxide blends and they found with 19.8% reduced brake specific fuel efficiency and 18.8% increased thermal efficiency and also provided amplified combustion pressure and lowered carbon emissions. They found that aluminum and silicon oxide are stable with 28.1% and 22.0% absorption ratio respectively while carbon nanotubes have the potential for further research for diesel blending due to its significant improvement in the reduction of NOx emissions.

Manzoore *et al.*, (2021) evaluated the performance and emission characteristics of a common rail direct injection (CRDI) diesel engine fueled by biodiesel blended fuel (B20) with strontium-zinc oxide (SrZnO) nanoparticles. They synthesized the nano particles using aqueous precipitation of zinc acetate dehydrate and strontium nitrate. The SrZnO nanoparticles were steadily blended with B20 blend. They have used mass fractions of 30, 60 and 90 ppm nano-particles in a blend and added Cetyltrimethylammonium bromide (CTAB) for long term stability of nano-particles. They have used 60 ppm of SrZnO nano-additives in B20 and showed that overall enhancement in engine performance and emission characteristics compared to the operation same blend operation without nano-particles.

Gharehghani *et al.*, (2019) investigated the effect of water and cerium oxide nano-particles in diesel-biodiesel fuel blend on performance and emission characteristics of a single cylinder diesel engine operated at start of injection of 20 bTDC. They found amplified thermal efficiency by 13.5% and 6% compared to B5W7 and B5 respectively. They showed combustion improvements and reported that this could be due to catalytic effect of cerium oxides nano-particles. They showed increased NOx emissions by 14% when 90 ppm CeO_2 was added into the B5W7 and still 21% lower than the NOx emitted by B5 operation.

Jiaqiang *et al.*, (2018) conducted experiments on a marine medium-speed diesel engine using varied mixtures of biodiesel-diesel, water, cerium oxide and compared with pure diesel operation in terms of combustion, emissions, and performance. They showed improved air - fuel mixture due to micro-explosion. They have reported that improved performance and decreased CO, PM, NOx, and HC emissions with adequate water additive. In addition, metal-based additives in the blends further improved the combustion quality and decreased emissions. They concluded that metal-based additives are beneficial to improve the engine performance and decrease the brake specific fuel consumption (BSFC) and emissions. This could be due to the improved combustion caused by the catalytic activity during the combustion process.

Hussain *et al.*, (2020) examined the effect of ZnO nano-particles blended diesel-water emulsion on the performance and emission characteristics of a VCR diesel engine at various compression ratios using as diesel, diesel water emulsions consisting of 88% neat diesel, 10% of distilled water and 2% surfactants. They varied CR from 16.5 to 18.5 in step of one, and load was varied from 0% to 100% in steps of 25. They showed significant improvement in BTE and BSFC when ZnO nano-particles are blended with base fuel. They observed reduced emissions of CO, HC and increased CO_2 emissions for ZnO nano-particles blended fuels with an increase of CR. They found optimal results at CR 18.5 for DW10Z100 blend.

Anish et al (2022) prepared homogenous solution containing biodiesel with two nano-particles titanium oxide (TiO_2) and zinc oxide (ZnO) with 30 ppm concentration. They found improved combustion, performance, and emission characteristics due to increased mixing and chemical reactivity provided by nano-particles' higher surface area-volume ratio. They observed 16% higher BTE, 32%, 48% reduced HC, 62% reduced CO, reduced NOx and 40% reduced smoke emissions compared to B100 operation.

Aalam *et al.*, (2015) reported that B25 and aluminium oxide blended fuel and used nano-particles proportion of 25 ppm and 50 ppm and checked stability of blended fuels. Significant improvements in specific fuel consumption and exhaust emissions at all operating loads have been reported. They found amplified brake thermal efficiency and heat release rate, lower smoke and HC emissions compared to the operation with 25 ppm.

Nagarajan and Balasubramanian (2021) have synthesized Calcium oxide from Mactra Corallina sea shell and tested homogeneity using ultra-sonication methods and they found stability of blends even with 100 ppm. They have used 2 % Tween 20 surfactant in a B20 blend. They found increased BTE up to 38.91 % and reduced BSFC up to 35 %. Further, they found lower HC, CO, NOx and smoke emissions with the addition of calcium oxide Nano fluid. Cylinder pressure and heat release rate are increased for nano particle blended fuels operation compared to diesel fuel.

Ferrao *etal*., (2021) conducted experiment using aluminum nanoparticles (particle size of 40nm and 70nm) and studied its effect on the combustion characteristics. They examined effect of size and concentration of aluminum nanoparticles at 1100 °C in a drop tube furnace This allowed them to study about combustion features of falling droplets. They have compared biofuel droplets with biofuel blended with nano-particles and showed improvements with aluminum nanoparticles added biofuel. Increased in the burning rate of nano-fuels was observed for decreased particle size. They found increased burning rate with the particle concentration increase.

Shaisundaram *et al.*, *(*2020) examines on the performances and emission characteristics of Tamarind Seed Oil Bio-diesel. The combination of Tamarind Seed oil with the additives of Aluminum oxide are B10 + 20 PPM Al_2O_3, B20 + 20PPM Al_2O_3, B30 + 20 PPM Al_2O_3. They have conducted trails tests on engine using blended fuels under varying loads and reported lowered engine exhaust gas emissions with increased biodiesel concentration.

Manzoore Elahi M. Soudagar et al (2019) have prepared nano-fuel blends using honge biodiesel and dispersed aluminium oxide in varying quantities in a B20 blended fuel. They used anionic surfactant, for stable dispersion of aluminium oxide nano-particles in the fuel blends. Blends with concentration levels of 20, 40, and 60 ppm of aluminium oxide nano-particles with varying ratios of Sodium dodecyl sulfate surfactants were prepared and prepared uniformly using ultrasonication process. The dispersion and homogeneity were observed and characterized by using the Ultraviolet–Visible spectrometry. The UV–Vi's spectrometry results showed an increase in absorbing capacity with a relative increase in the concentration of surfactant. The highest absolute value of UV-absorbency was observed at a mass fraction of 1:4 (Al_2O_3 NPs to SDS ratio). The fuel B20 showed increased BTE by 10.57% and declined BSFC 11.65%. Further reduced HC, CO, and smoke increased NOx by 11.27% have been reported. In addition, gradual reduction in the combustion duration , ignition delay period and improved peak pressure has been reported.

Saravanana and Nagarajan (2009) examined the influence of hydrogen injection into the intake manifold on the performance of a diesel engine operated on dual fuel mode. They observed improved efficiency by 15% with an increased NO_X emissions by 3% compared to diesel operation with manifold injection technique. Further they found decreased smoke emission by 100% and significant reduction in carbon based emissions. In addition manifold injection technique provided smooth engine operation.

Hamdan et al., (2014) varied hydrogen by increment of 2 lpm and kept engine under fixed output power condition (torque of 14.7 N-m and speed of 1,100 rpm). Hydrogen supplement has been used through the air intake manifold at the atmosphere condition and studied the effect of hydrogen supplement on the combustion characteristics, engine performance, emission and fuel consumption. They observed that the primary fuel starts knocking with hydrogen contribution increases. Hydrogen **e**nrichment with the Honge biodiesel blend and diesel fuelled diesel engine performance has been also investigated by **Surya Kanth et al., (2020).** Hydrogen flow rates used were 10 and 13 lpm and introduced into the intake manifold. They found that hydrogen enrichment of engine fuelled with Honge biodiesel blend enhances the thermal efficiency, combustion characteristics. They observed that increased BTE by 2.2% and 6% less fuel consumption for the B20 +13 lpm of hydrogen. In addition they have noticed reduction in the emissions of CO and HC by 21% and 24%, respectively.

Arkadiusz *et al.,* (2020) studied the effect of co-combustion of hydrogen and diesel fuel on the stability, performance and exhaust gas emission of the diesel engine. The hydrogen energy shares with diesel was varied in the range from 0 (D100) to 30% (DH30). They found that at full load, higher combustion pressure by 13%, rate of heat release by 46% and the rate of pressure rise by 35%. Hydrogen addition increases combustion rate and lowers total combustion duration causing an increased efficiency by 17% for 25% hydrogen energy share. In addition they found 85% reduction in soot emissions, and 57% reduction in CO, and an almost 27% reduction in CO_2.

Hüseyin (2020) used turbocharged, compression-ignition, light duty vehicle engine, loaded with a DC dynamometer. They have analyzed diesel engine performance using AVL BOOST simulation software. The real test engine was run at partial load (90%) and at different engine speeds with normal diesel fuel. They have examined multiple hydrogen injection strategies in the simulation program using pure hydrogen as pilot and post fuel and diesel as the main fuel. The results showed that 2 pilot injections and 1 post-injection strategy reduced soot emissions more than 1-pilot injection strategy. However, increased engine power and NOx emissions have been reported in all three injection applications.

Dahake M.R.et al., (2020) employed hydrogen in intake manifold for different injection duration and compared the performance of engine with baseline diesel performance at varying injection duration. They observed BTE by 3.17%, and reduced BSEC by 10.81% at fully loaded condition for hydrogen gas injection duration of 6 ms. Engine operation with hydrocarbon reduces CO by 43.33% at full load condition with same injection duration of 6 ms. They have claimed this may be due to homogeneous mixing of hydrogen with air resulted in to complete combustion of fuels with lesser emissions.

Saravanan, N. and Nagarajan G (2008) controlled hydrogen combustion in a diesel engine and examined methods to avoid the backfire and pre-ignition problems. They have injected hydrogen into the intake manifold and conducted experiments to identify the optimized injection timing, injection duration and injection quantity of the fuel in manifold. They observed that the optimized condition of start injection at gas exchange top dead centre (GTDC) with injection duration of 30° CA with the hydrogen flow rate of 7.5 lpm. They found increased BTE by 9 % compared to diesel and decreased smoke emissions by 4-fold. However, they found similar NOx emissions as that of diesel operation and decreased CO2 emissions by 2-fold.

Gupta et al (2015) carried out comprehensive overview of developing a dedicated hydrogen port injection kit to run a conventional 170 cc SI Engine on Hydrogen only. They have examined effects of hydrogen fuel compositions on BTE, BSFC, EGT, HC, CO, NOx and Smoke opacity. They have studied method to prevent knocking and ensured smooth running of hydrogen engine

Zareei et al., (2021) injected CNG of 10% of the total fuel mass fraction into the air manifold and the remaining 90% fuel HCNG was injected into the cylinder by direct injection. Initially CNG was injected at 160° BTDC with 20° stroke duration and HCNG fuel was injected at 130° BTDC with a50° stroke duration. They found that with 30% HCNG blend, increased BP, BTE and in-cylinder pressure and the reduced SFC from 6.2% to 18%. They have claimed that this is due to increased flame propagation speed in the combustion chamber and use of hydrogen has decreased HC and CO by up to 14% and NOx has been increased due to the increased EGT.

Saravanan and Nagarajan (2009) examined the effect of hydrogen port injection and use of selective catalytic converter (SCR) on the performance and emissions. They observed reduced NOx by 74% with marginal reduction in efficiency. However, they found reduced HC and NOx emission with use of SCR system. They observed maximum reduction in HC is about 83% at low loads and CO emission by about 63% with increased CO2 emission by 10%.

Oh et al., (2002) investigated the effects of piston geometry along with injection timing and swirl ratio on flame propagation characteristics. They have employed UV intensified high-speed CCD camera. For the study, flame propagation patterns and thermodynamic heat release analysis was introduced to analyse the flame propagation characteristics. Their results showed that correlation between the flame propagation characteristics, which is related to engine performance of lean region, and swirl ratio, piston geometry and injection timing. They have observed faster flame propagation under open valve injection with stronger swirl. They claimed that this is due to flame speed was affected by injection timing under open valve injection conditions.

Younkins et al., (2015) presented experimental study on reducing NOx emissions, and studied its effects of injection of water into the intake air charge on engine performance. They have injected hydrogen into the cylinder directly varied water injected amount into the intake charge, fuel injected amount, fuel injection phasing, fuel injection event numbers and ignition timing during. They have compared the results with hydrogen engine where load was controlled through changes in equivalence ratio. They found reduced NOx emissions by 87% with a 2% penalty in fuel consumption with water injection into the intake air charge.

Das and Das (2023) studied influence of iron nano-particle (75 ppm) and hydrogen (10 lpm) on the waste cooking palm biodiesel blend (WCB) powered CRDI diesel engine performance. They have added nano-particle based on the inbuilt oxygen of biodiesel. They found improvement of BTE by 7.1% for B20 with nano-particle of 75 ppm, and 10 lpm H2 enrichment compared to diesel at 90% loading. Improved combustion characteristics and reduced CO and HC emissions by 37.5% and 41.8%, respectively has been reported due to combined impact of nano-particle and hydrogen, increased NOx emissions. They also observed increased cylinder pressure and HRR by .3% and 6.7% compared to diesel for WCB + INP + H2.

Jami et al (2023) examined the combined effects of varying compression ratio (CR) and fuel injection parameters such as fuel injection pressure (FIP) and start of injection (SOI) / injection timing on the performance of a dual-fuel low heat rejection (LHR) engine operated on oxy-hydrogen (HHO) gas and Jatropha biodiesel-diesel blend (JME20). They have varied CR, FIP and SOI and at 18.5 CR, 240 bar FIP, and 26°CA bTDC SOI, JME20+HHO dual fuel operation provided 6.6% higher BTE than diesel with reduced CO, HC and smoke emissions and with a penalty in NO emissions.

2.1 Summary of literature review

In summary, the literature review on diesel engine operation using diesel/biodiesel with and without nano-particles and hydrogen on both single fuel and dual fuel engine suggests the following information.

- Research work on the production and utilization of Diary scum oil biodiesel is less investigated for diesel engine application
- Producer gas derived municipal solid waste for diesel engine application is not examined for dual fuel engine applications
- Use of producer gas in diesel engines operating on dual fuel mode provided in lower thermal efficiency, increased ignition delay, decreased premixed combustion, longer combustion duration, and increased fuel consumption rate.
- Producer-gas engines are the important components of biomass energy systems. Producer gas is used and a primary fuel and it significantly lowers the smoke and NOx emissions. However, literature showed that dual fuel engine resulted in increased HC and NOx emissions.

- Synthesis of novel nano-particles such as AlOOH is less investigated for blending with diesel and biodiesel. Also, utilization of both biodiesel blended fuel with AlOOH nano-particles and hydrogen for diesel dual fuel engine applications is less investigated. Hence it needs detailed experimental investigations.

It is evident that dual fuel operation with renewable fuels can reduce crude oil utilization and thereby improves the environment and country economy. Based on the literature, it has been found that fuel properties, mode of engine operation, operating and design parameters of diesel engine play a significant role in achieving greater performance with lowered emission levels.

Chapter 3

FUELS USED IN PRESENT WORK

The most extensively used fuels are included hydrocarbons and are obtained generally from fossil fills (petroleum). Fossil fills involve diesel, petroleum and liquefied petroleum gas, and low percentage of propane. Bothe petrol and diesel engines can be operated on Biofuels. Fluid and vaporous bio-fuels, such as ethanol and biodiesel can be utilized. Internal combustion (IC) engines can operate with suitable changes in engine design. This is essential to operate the engine on hydrogen gas, wood gas, or charcoal gas, and producer gas conveyed using another steady biomass.

The physical-chemical properties of various fuels play significant role during the combustion. Hence, the alternative fuels should have superior physical, chemical and combustion properties. Performance and emission levels are mainly dependent on fuel properties. The fuels used in the present work include Diesel and biodiesel.

3.1 Selection of dairy scum oil as an alternative fuel for CI engine applications

The alternative fuels selected for the present study in CI engine was biodiesel. It is a well-known fact that any liquid fuel can be used in CI engines on single fuel mode. Use of dairy scum oil and their respective biodiesel alone in a diesel engine produces higher hydrocarbon, carbon monoxide and smoke emission levels. However, biodiesel operation requires engine modification and it can improve their performance with lower emission levels. The main aspiration from the usage of single fuel engine is mainly to reduce nitric oxide emission levels. Also, it lowers the greenhouse gas and enhances the country economy and socio-economic issues. The presence of vapor of a high hydrocarbon fuel such as diesel or biodiesel would change its resistance to auto ignition. Thus, for most practical applications involving low volatile liquid fuels, single fuel mode of operation with minor engine modification in terms of nozzle and combustion chamber geometry is preferred. In the present work, the diesel engine is operated in single fuel mode using biodiesel as injected fuel.

3.2 Dairy scum oil and its properties

The compositions of dairy waste scum, including free fatty acids (8–10 %), triglycerides (more than 80 % in dry bases), and fats around 60 %, which have the potential to be used as the feedstock for biodiesel production in the presence of certain catalysts. To ensure more sustainability, the catalyst should be derived from waste (e.g., eggshells and cow bones) that consists of calcium oxide, which can then be used to catalyze the transesterification of dairy waste. This review emphasizes the current production of dairy waste globally and the potential of the waste and other types of organic waste as feedstock for biodiesel production, as well as determines the optimum reaction conditions for high-quality biodiesel production.

Table 3.1 Fuel properties

Property	**Diesel**	**DSOB**	**DSOB_ 20AlO(OH)**	**DSOB_ 40AlO(OH)**	**DSOB_ 60AlO(OH)**
Calorific value, kJ/kg	43500	39468	39602	39920	40141
Density, kg/m^3	840	872	876	880	894
Kinematic viscosity @ 40^0C, mm^2/s	3.25	4.8	5.01	5.5	5.9
Flash point, ^0C	56	215	210	195	180
Fire point, ^{0} C	68	226	218	218	222
Cetane number	54	60	---	--	--
Carbon residue, %	0.21	0.460	0.461	0.464	0.482

3.3 Additives

3.3.1 Aluminum hydroxide AlOOH nanoparticles blending in dairy scum biodiesel

AlOOH is amphoteric in nature with chemical name Aluminum hydroxide.

Aluminum hydroxide is also called Aluminic acid or Aluminic hydroxide or Aluminum (III) hydroxide. It is found in nature in the form of mineral gibbsite and its polymorphs viz dolerite, nonrestraint and bayerite. Aluminum hydroxide is an amorphous powder white. It is insoluble in alkaline and acidic solutions. Figure 3.1 shows AlOOH structure. Table 3.1 shows the properties of AlOOH i.e., Aluminum hydroxide nanoparticles.

Fig 3.1 Aluminum hydroxide structure – AlOOH

Table 3.2 Properties of Aluminum hydroxide – AlOOH [5]

AlOOH	Aluminum Hydroxide
Molecular weight of $Al(OH)_3$	78.00 g/mol
Density of Aluminum hydroxide	2.42 g/dm^3
Flashpoint of Aluminum hydroxide	Non-flammable
Melting Point of Aluminum hydroxide	300 °C

3.3.2 AlOOH Uses (Aluminum hydroxide)

- Aluminum hydroxide is used as a flame retardant in plastics.
- Used as an antacid.
- Used in aluminum Hydroxide gel.
- Used to manufacture activated alumina.
- Used as a filler in cosmetics.
- Used as a chemical intermediate.
- Used as a soft abrasive for plastics.

Chapter 4

PRODUCTION OF ALUMINUM HYDROXIDE NANOPARTICLES AND ENGINE SETUP

4.1 Materials used for synthesis:

- Aluminum nitrate ($Al(NO)_3$).
- Sodium hydroxide (NaOH).
- Distilled water.

4.2 Synthesis of aluminium hydroxide:

- Step 1: Take 18.756 grams of AlNO3 by using weighing tool on a blotting paper and mix it with 50 mL distilled water and keep it on a stirrer at approximately 1200 rpm and keep on increasing the temperature.
- Step 2: Now take 6 gm i.e., 3M of NaOH granules and mix it in 50ml of distilled water and the aqueous solution should be added to the alno3 mixture dropwise and stirred until 60°C is attained. Now switch off the temperature indicator and stir it constantly at 1200 rpm for almost 24 hours.
- Step 3: Keep it aside for some time and then centrifuge the sample for at least 5-6 times by adding distilled water followed by 5-7ml of ethanol to distilled water and again centrifuge. Figure 4.1 shows compounds to be used in the experimentation.

Fig 4.1 $Al(NO3)_3$ and NaOH

Fig 4.2 Weighing machine and Magnetic stirrer

Fig 4.3 Stirring of AlNO3 with distilled water and adding NaOH solution to it.

Fig 4.4 Infrared thermometer

- Step 4: After centrifuging the sample is going to be like a jelly type substance with good amount of moisture content in that which can be dried at 60°C using the heat oven or muffle furnace for 4-6 hours continuously or at equal intervals of time. Figure 4.5 shows

Centrifuge machine and sample after being centrifuged and 4.6 shows hot air oven and dried sample.

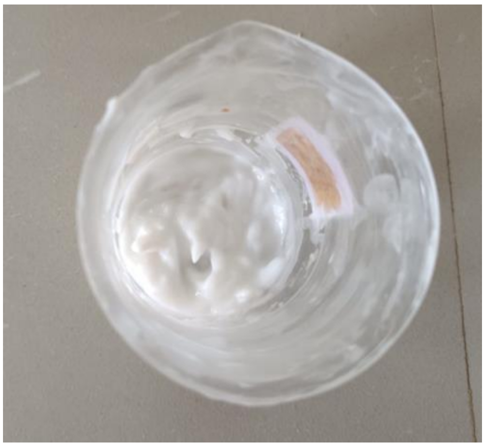


Fig 4.5 Centrifuge machine and sample after being centrifuged

- Step 5: The dried sample is then annealed at 150°C for 4-6 hours and the final product is obtained. Thermal annealing is essential for achieving ultrasmall size ferromagnetic properties in next-generation high performance nanocomposite magnetic materials. However, during the annealing process, growth and agglomeration of nanoparticles normally occurs, which destroys the narrow size distributions.

Fig 4.6 Hot air oven and Dried sample

Fig 4.7 Dried sample filled into transparent tubes.

- Step 6: Aluminum hydroxide nanoparticles obtained are then added to biodiesel and engine testing is done and. Figure 4.7 shows dried sample being transferred into transparent tubes.
- Step 7: Now the characterization is done for the nanoparticles i.e., TGA, SEM and XRD tests.

4.3 Diesel engine set up

Experimental tests were conducted using DI CI engine having 1 cylinder 4 stroke water cooling and functioning on various fuel combinations. It had the usual mechanical fuel injection arrangement with inlet and outlet valves functioning with the help of pushrods. It had a displacement volume of 662 CC and developed 3.72 kW at 1500 rpm. Figure 4.8 shows a photographic view of the experimental test rig. Specification of diesel engine is presented Table 4.1. Cooling of the engine was accomplished by circulating water through the jackets of the engine block and cylinder head and temperature of 700 C was maintained. Manufacturer of diesel engine set compression ratio, injection timing and injection pressure were 17.5, 23ºbTDC, 205 bar respectively. For other fuel combinations, these parameters were changed as per the requirement. The nozzle is with 3 hole and each orifice having diameter of 0.3 mm. Eddy current dynamometer is used for engine loading and water is circulated within the engine body and dynamometer. These signals coming from various sensors are interfaced to computer through engine indicator for performance and combustion (P-θ and P-V diagrams) parameters. Sensors are used for interfacing airflow, fuel flow, temperatures, and load measurement. The set up has two fuel tanks for dual fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables varying the compression ratio for measurement of engine performance parameters. The governor is used for regulating the speed of an engine. Air and fuel flow indicators are measured using air box method and stopwatch and burette method and a piezo-electric sensor was installed in the head of the cylinder to monitor the cylinder pressure at every crank angle. The engine was provided with a hemispherical combustion chamber with overhead valves operated through push rods. A piezoelectric pressure transducer was mounted with the cylinder head surface to measure the cylinder pressure.

Fig. 4.8 Experimental set up for single fuel operation

4.4 Dual fuel engine

Dual fuel engine is single cylinder four stroke diesel engine converted in to operate on dual fuel mode. The existing diesel engine was discussed in the previous section. Hydrogen cylinder is coupled to an existing diesel engine intake along with flow measurement. Engine system and photographic view is presented in Figure 4.9. Conventional fuel injection system was used. The static injection timing, injector opening pressure and the compression ratio as specified by the manufacturer was 23^0 bTDC, 205 bar and 17.5 respectively. However, to study the effect of H2 gas on engine performance, the injection timing was adjusted to 27^0 bTDC and compression ratio was kept constant 17.5. Suitable mixing chamber or carburetor was located at the intake manifold to induct hydrogen gas obtained for the dual fuel operation. Engine-Soft, software was used to communicate the data between test rig and data acquisition system through a control panel.

Table 4.1 Specification of CI Engine

SI. NO	PARAMETERS	SPECIFICATION
1	Machine supplier	Apex innovation private Ltd. Sangali, Maharashtra.
2	Engine Type	TV1 (Kirloskar made), Single cylinder. Four stroke. CR 17.5:1, 3.7 KW (5 HP) at 1500rpm, diesel engine.
3	Software used	Engine soft.
4	Fuel	H.S.Diesel.
5	Bore and Stroke length	0.0875 m and 0.11m
Eddy current dynamometer		
6	Model	AG-10
7	Type	Eddy current
8	Maximum	7.5KW at 1500-3000rpm
9	Flow	Water must flow through dynamometer during the use
10	Dynamometer arm length	0.180meter
11	Fuel measuring unit range	0-50ml

Fig.4.9 Photographic view of dual fuel engine

4.5 Hydrogen supply system

To augment the performance of DSOB operation, fuel combination quality is augmented by the addition of little H_2 amount. The H_2 was collected in a high-pressure tank at a 150 bar and 30^0C. During the test run, its pressure was decreased to 1.5-2.0 bar using 2-step pressure regulator and is made pass through shut off valve. A flow controller in the flow line of H_2 assists to regulate HFR. H_2 gas is also made to flow through digital flow meter and it gauges the HFR in liters per minute [lpm]. The H_2 can either be exactly metered by altering the pressure of injection or changing the duration of injection by regulating the signal pulse to the gas injector. Finally, the H_2 was injected in the air mixture (engine intake manifold). Mixing chamber used which mixes air mixture with H_2. To prevent hazardous things, during experimentation, dry and wet type flame arrestors and flame trap were employed in the flow line of H_2 shown in Figure 4.10. Dry type flame arrestor is non-return valves which avoids the H_2 flow in reverse direction and backfire. During a trial test, HFR was kept 8 lpm constant.

To have adequate timing of injection for H_2, an appropriate pro-circle is fixed on the cam shaft. In addition, proper marking is done suitably at required locations. Infra-red (IR) sensor is employed to give pulses to the ECU, hydrogen injection timing and duration arrangement is presented. IR sensor generates a signal when it cuts the light during cam shaft rotation. Hydrogen timing of injection is determined based on the speed of cam shaft. One revolution (360^0) of cam shaft in terms of time is determined. It equals to 0.11 mS.

Therefore, H_2 timing of injection of 1-degree is equal to 0.11 sec. similarly, for 5^0, 10^0, and 15^0 aTDC, the timings of injection of H_2 are 0.55 mS. 1.1 mS, and 1.65 mS respectively. Injection durations selected for the study are 3.3 mS, 6.6 mS and 9.9 mS. Finally, optimum timing of injection and duration of injection for H_2 was selected based on completed test runs.

Fig. 4.10 Gas supply to intake

4.6 Exhaust gas emission measurement

The five gas analyzer that measures the composition of exhaust gas after combustion. This can be done by inserting a probe or detector into the diesel engine tailpipe.

In the present study, Model AVL-444 make Exhaust Gas Analyzer was used and shown in Figure 4.11. The engine exhaust was measured by using a calibrated five gas analyzer. To measure five gases, working principle used for measuring CO_2 and CO was the non-dispersive infrared (NDIR); un-burnt hydrocarbon (UBHC) was measured through flame ionization detector, and NO was measured through chemiluminescence detector (CLD) and for O_2, from an electrochemical sensor. The CO, CO_2, and O_2 were recorded in volume percentage, whereas the HC and NO were recorded in ppm units. Finally, measured data is sent to AD converter and processes and stores in a memory. The specification of exhaust gas analyzer is given in the Table 4.2.

4.6.1 Measurement of smoke

Smoke density of exhaust was measured by AVL smoke meter and shown in Figure 4.12. The specification of smoke meter is given in the Table 4.2. In an AVL smoke meter, filter paper method was used to determine smoke number and soot concentration in mg/m^3. AVL 437C Smoke meter is a single compact unit with blue tooth connectivity, having RS232 interfaces for communication which has automatic zero calibration facility at the start of each free acceleration test, with in-built calibration facility at a press. This equipment also works on 230 V AC and 10-36V DC which can work on any diesel fueled engine The method adopted in this smoke meter with a exhaust gas variable sampling volume and thermal conditioning ensures an extremely high reproducibility. In addition, this smoke meter can perform carbon mass concentration measurements in exhaust gas and measurement is in line with ISO 8178-3 standards.

Fig. 4.11 Exhaust gas analyzer

Fig. 4.12 AVL smoke meter

Table 4.2 Specification of exhaust gas analyzer

Measured quality	Measuring range	Resolution	Accuracy
CO:	0... 15 % vol	0.01 % vol	0-10% +/- 0.02%abs +/-3% rel 10.01%-15% +/- 5%rel
CO_2:	0... 20 % vol	0.1 % vol	0-16% +/-0.3%abs +/- 3% rel 16.01%-20% +/- 5% rel
HC:	0... 30000 ppm	£ 2000: 1 ppm vol, > 2000: 10 ppm vol	0-4000ppm +/-8 ppm 3% rel 4001-10000 ppm 5% rel 10001-30000 ppm 10% rel
O_2:	0... 25 % vol	0.01 % vol	+/- 0.02% abs 1% rel
NO:	0... 5000 ppm	1 ppm vol	+/- 5ppm 1% rel

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Types of characterizations done for nano particles

- Scanning Electron Microscope (SEM)
- X-ray diffraction (XRD)
- Thermogravimetric analysis (TGA)

5.1.1 Scanning Electron Microscope (SEM):

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample.

An analysis of the images in Fig.5.1 reveals that with aluminum hydroxide nanoparticles contains microstructural imperfections that are more accentuated than in the materials incorporated with material. This result was expected, since the ALOOH particles have a smaller size and consequent lower dispersibility in the polymer matrix than the Na-Al. In nanotechnology, the larger surface area of nanoparticles determines at great measure the microstructural performance of their composites. In this sense, the presence of materials that are majorly in the micrometric scale in the residue strongly corroborates with the morphologic imperfection observed in the SEM micrograph. Furthermore, the increase in concentration of both the nanoparticles and microparticles in the polymer matrix alters the morphology of the material. However, this change is more evident in the residue, probably due to its smaller particle size. Figure 1 Shows SEM Images of Aluminum Hydroxide nanoparticles (ALOOH). Figure 5.2 shows SEM results.

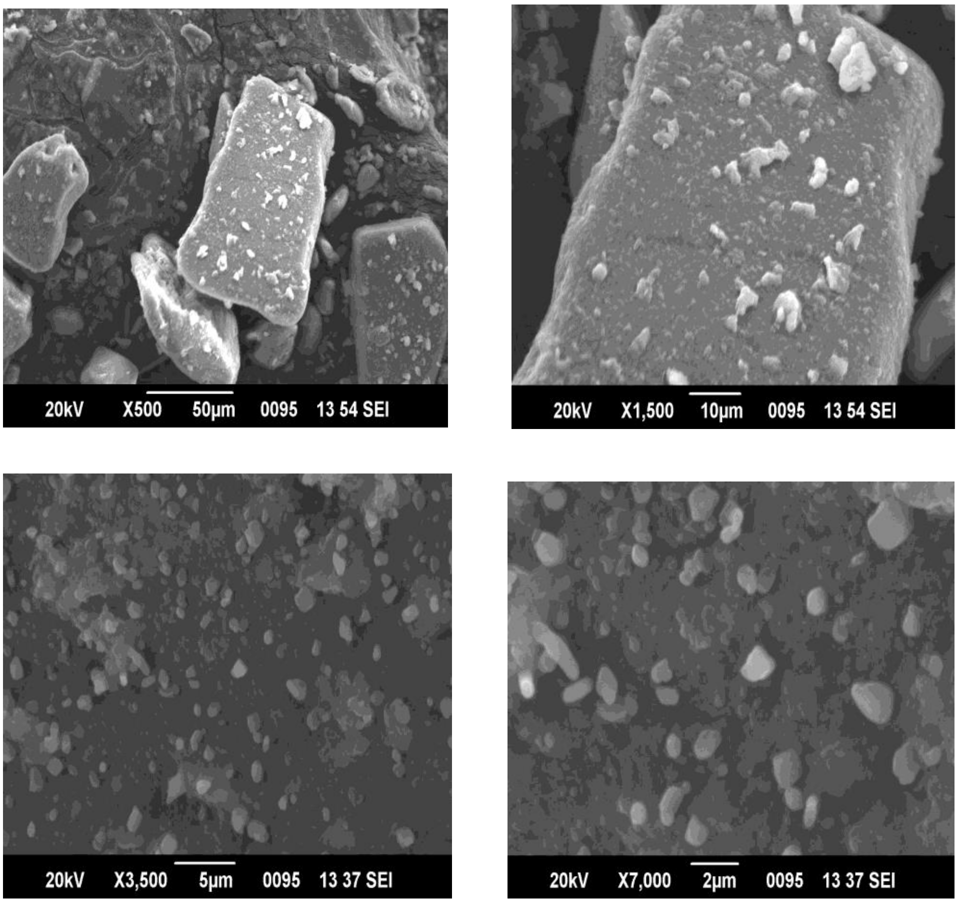


Fig 5.1: SEM Images of the sample

Table 5.1 shows amount of Aluminum, weight percent and atomic percent in the aluminum hydroxide nanoparticles. It shows that 63.13 percent of oxygen and 36.87 percent of aluminum is present in the material weight wise. Similarly 74.27 and 25.73 percent of oxygen and aluminum respectively is present atomic weight wise. Scanning electron microscope image does not show hydrogen because it does not have a K shell so SEM/EDS cannot detect very light elements like Hydrogen, Helium etc.

Table 5.1: Constituents of Material synthesized as per SEM results

Elements	Line type	Weight %	Atomic %
O	K series	63.13	74.27
Al	K series	36.87	25.73
Total		100	100

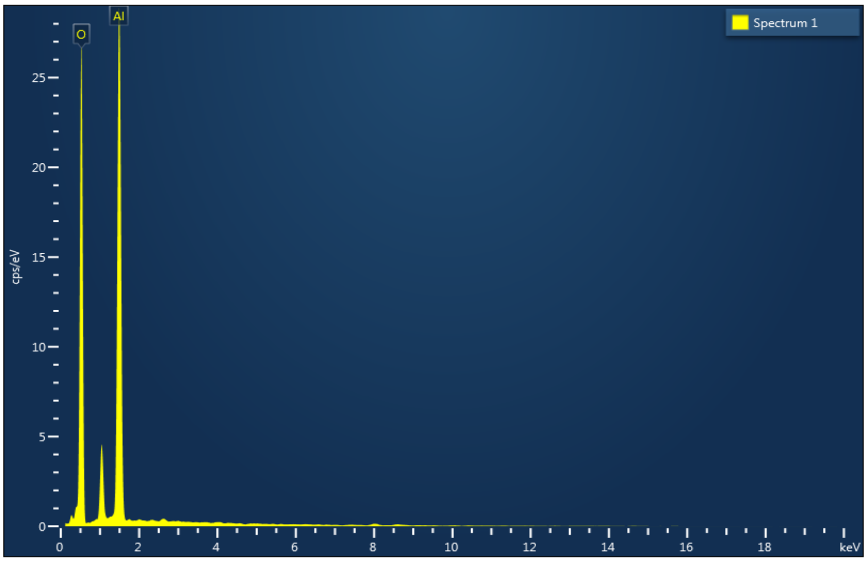


Fig 5.2: SEM Results

Figure 5.2 shows graph of constituents of the material as per SEM testing. This graph shows EDX results i.e., kilo electron volt (keV) vs counts per second per electron-volt (cps/eV). The percentage range of the elements in the composite mass, visualized in the adequate voltage range, counted in seconds per electron-volt. X-rays are generated using EDX following a twostep process. First, the energy transferred to the atomic electron knocks it off, leaving behind a hole. Secondly, its position is filled by another electron from a higher energy shell i.e., aluminum in this case.

The graph shows presence of aluminum and oxygen but lacks to show hydrogen presence due to very light weight of hydrogen and absence of K shell.

5.1.2 X-ray diffraction (XRD):

XRD is used for characterization of nano powders of any sizes, and the observed changes in positions of diffraction peaks are used to make conclusion on how crystal structure and cell parameters changes with the change in nano particles size and shape. The crystal structure of as-synthesized AlOOH nanoparticles is studied by X-ray diffraction (XRD); by applying Cu K_{β} radiation with wavelength 1.5406 Å and two-dimensional area detector. XRD is an analytical technique designed to provide more in depth information about crystalline compounds including identification of crystalline phase.
In our case, The crystallinity structure of Aluminum hydroxide AlOOH nanoparticles are studied by powder X-ray diffraction by measuring wide angle scattering.

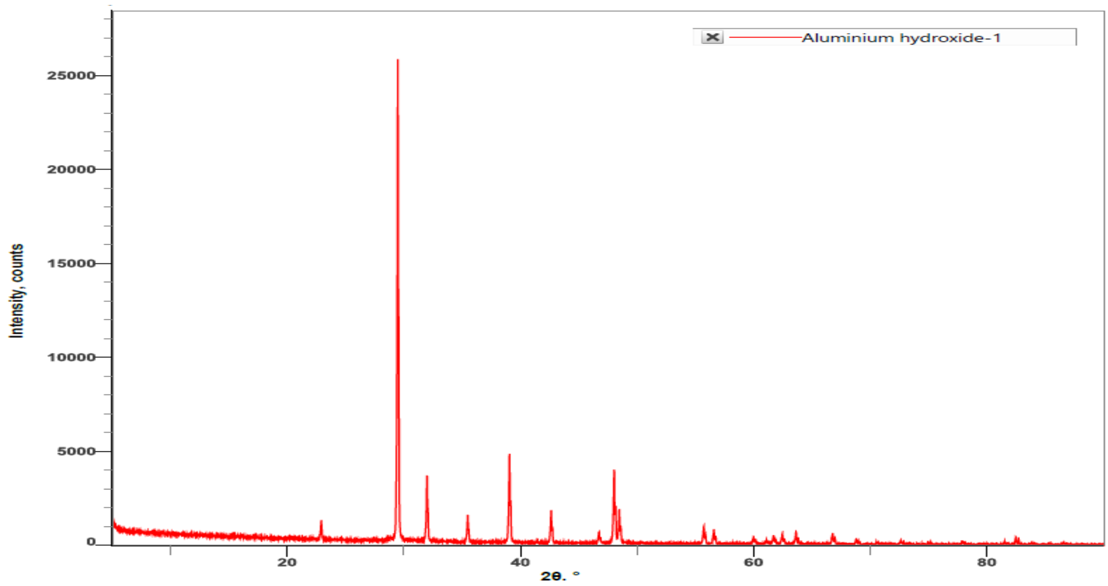


Fig 5.3 XRD Graph

The above figure shows there are broad diffraction peaks observed at 2θ =22^{o}, 29.5, 32, 35.5, 39, 42.5, 46.7, 48.76, 55.72, 56.6^{o}. The observed pattern well matched with the standard JCPDS number (030145). The calculated average particle size from the graph is around 74nm.

5.1.3 Thermogravimetric analysis(TGA):

Thermogravimetric analysis is an analytical technique used to determine a material is thermal stability and its fraction of volatile components by monitoring the weight change that occurs as a sample is heated at constant rate. The results obtained in TGA in determining purity and composition of materials, drying and ignition temperature of materials and knowing the stability temperature of compounds. This measurement provides information about physical phenomenon such as phase transition, absorption, adsorption, and desorption; as well as chemical phenomenon including chemisorption's, thermal decomposition, and solid gas reductions.

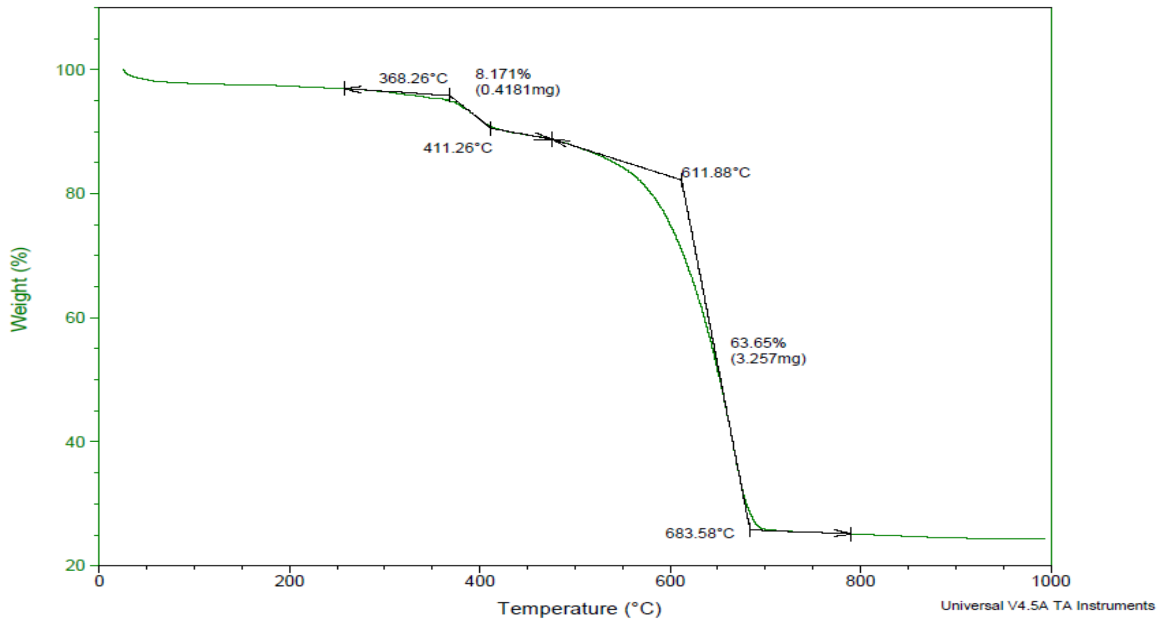


Fig 5.4 TGA Graph

In our case, the thermal stability of aluminium hydroxide is studied by TGA measurements in the temperature range of 20 °C to 400°C under an inert atmosphere with the heating rate of 10 °C/min. In the present case, there is a small endothermic peak close 100 °C associated with evaporation of material's water content. However, the aluminium hydroxide nanoparticles exhibit a sharp exothermic peak around 276°C and 309°C, a similar behaviour also has been observed by others. In the weight loss with temperature (TGA) measurements, the aluminium hydroxide appears more stable with temperature, till up to 368 °C there is only 8% weight loss and it remains almost constant, thereafter there is rapid loss in weight and it goes up to more than 63% around 611 °C.

5.2 Performance characteristics:

Influence of AlO(OH) NPs and hydrogen on the brake thermal efficiency (BTE) for dual-fuel operation at 80% load is presented in Figure 5.5 and 5.6. It is observed that the for the same hydrogen supply, DSOB combination resulted in decreased BTE at all SOI and injection duration (from 20to 80^0 CA) compared to diesel – H2 gas combination. This could be due to inferior properties of DSOB. Also input chemical availability for DSOB combination lower than diesel based operation. But at SOI 150^0 aTDC and 60^0CA injection duration and addition of AlO(OH)NPs and hydrogen, DSOB provided better performance than the same fuel combination withoutAlO(OH) NPs. This could be due to addition of

NP, increases the combustion rate due to improved volatility of DSOB and mixture quality. However, AlO(OH) has inbuilt oxygen and hydrogen which further provide improved oxidation and increased flame speed. This in turn leads to better combustion. It is observed that at other the SOI and injection durations, the performance is droppeddue to inadequate mixing of hydrogen with pilot fuel and H2 mixture. of hydrogen addition amplifiedthe lean limit and enhance oxygen reaching ability due to greater diffusion co-efficient of hydrogen which in turn leads to better combustion

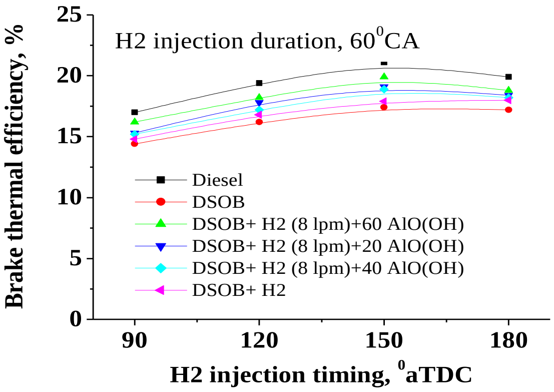


Fig.5.5 Effect of H2 IT on BTE

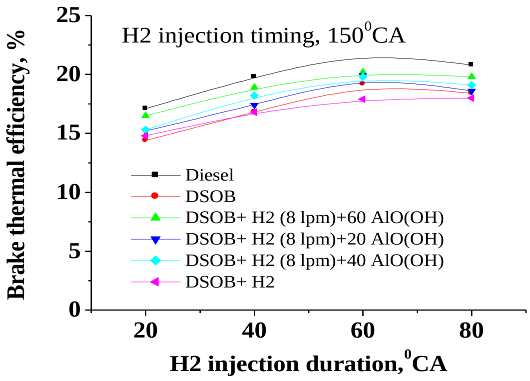
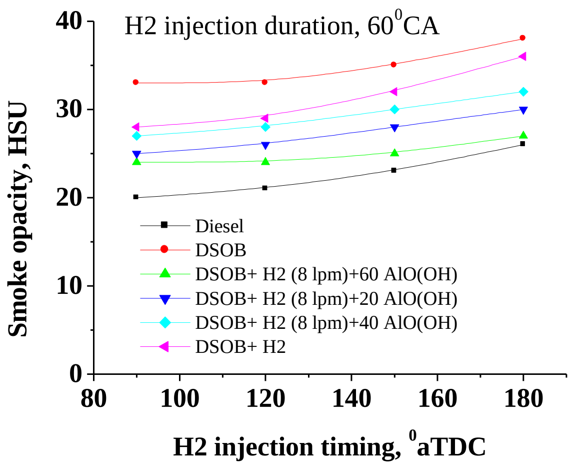


Fig.5.6 Effect of H2 ID on BTE

5.3 Emission characteristics:

Effect of AlO(OH) NPs and hydrogen injection on the smoke opacity diesel/DSOB combinations at 80% load was presented in Figure 5.7 and 5.8. For the same hydrogen supply diesel operation resulted in lower smoke levels in the exhaust compared to DSOB operation. This may be credited to inferior properties of DSOB along with H2 and was caused by the inadequate mixture quality and lowered oxidation rate when biodiesel was used. However, addition of AlO(OH) NPs and hydrogen and at injection timing of 150^0 aTDC and duration of 60 ^{0}CA, lowered smoke opacity was noticed. This may be credited to the fact that better mixing DSOB droplets with air-H2-hydrogen. Also, presence of NPs provides additional oxygen during combustion and presence of hydrogen and inbuilt hydrogen of NPs provide amplified flame speed which in turn amplifies the combustion rate resulted in better burning of the fuel combination. Also, improved mixture quality before combustion and amplified oxidation rate due to greater hydrogen diffusion co-efficient improved oxygen reaching ability. At an all other SOI and injection duration, smoke levels were increased owing to the inadequate mixing of gaseous fuels with DSOB-air mixture. However, at higher SOI and injection duration, delay period may increase due to presence of hydrogen which increases lean limit. This in turn reduces flame speed attainable during combustion.



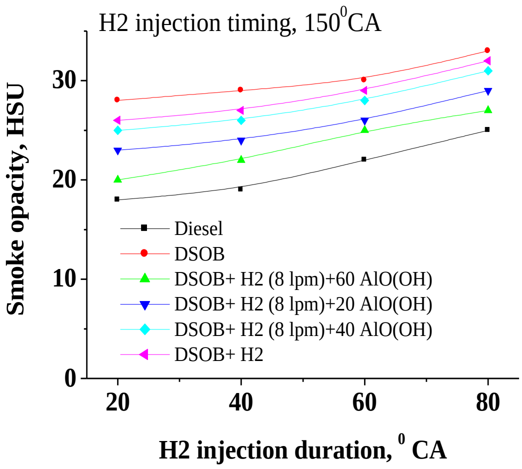


Fig.5.7 Effect of H2 IT on Smoke opacity

Fig.5.8 Effect of H2 ID on smoke opacity

Influence of hydrogen IT and ID on the HC and CO emission levels for diesel/DSOB fuel combinations are displayed in Figures 5.9 – 5.12. For the same gas supply and operating conditions, diesel-H2, based due fuel operation resulted in diminished HC and CO emissions compared to the DSOB combination. This could be credited to the partial combustion of DSOB combination caused by the reduced mixing rates caused by the lower volatility of DSOB and caused by occurrence of fatty acids DSOB. In addition, lower flame temperature of gas and lower calorific value of DSOB and H2 gas is also accountable. However, with addition of AlO(OH) NPs and at hydrogen injection timing of 150^0 aTDC and 60^0 CA ID, DSOB operation provided lower HC and CO emissions caused by the presence of inbuilt oxygen and hydrogen of AlO(OH) NPs. This may amplify the oxidation rate and flame speed of mixture. But at other hydrogen IT of 150^0 aTDC and 60^0 CA ID, the HC and CO were increased due to incomplete mixing and over leaning of mixture. At optimum hydrogen IT and ID, hydrogen addition amplifies gas temperature caused by the increased flame velocity and flame flammability limit improves the combustion rate. In addition, hydrogen addition improves homogeneity of fuel combination before combustion due to increased reaching ability caused by the greater diffusion co-efficient of hydrogen.

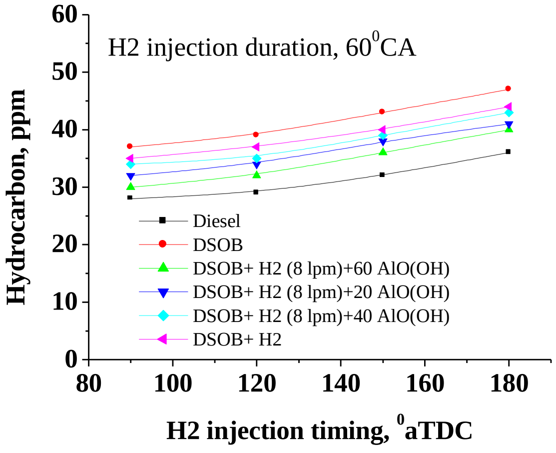


Fig.5.9 Effect of H2 IT on HC emission

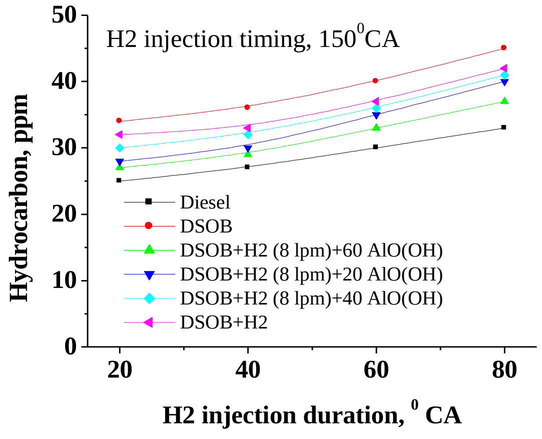


Fig.5.10 Effect of H2 ID on HC emission

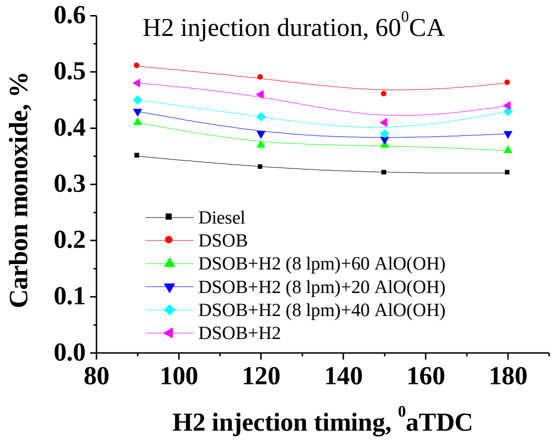


Fig.5.11 Effect of H2 IT on CO emission

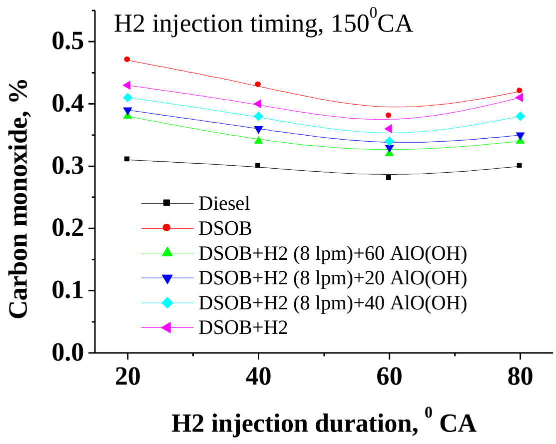


Fig.5.12 Effect of H2 ID on CO emission

Nitric oxide (NOx) emission with respect to hydrogen IT and ID for different fuel combinations at 80% load are shown in Figure 5.13 and 5.14. For the identical operating condition (hydrogen IT of 150^0 and ID of 60^0 CA), results indicated that hydrogen supply, diesel based dual fuel operation provided increased NOx levels compared to DSOB based operation. This is caused by, hydrogen addition and superior properties of diesel which in increases the premixed combustion. This may lead to increased NOx emission for diesel based operation. Further, for the same hydrogen injection and addition of AlO(OH) NPs to DSOB combination, increase the NOx emissions considerably compared to the same fuel combination without NPs addition. This could be due to participation of inbuilt oxygen and hydrogen of AlO(OH) NPs during combustion. This in turn improves oxidation rate and flame speed of biodiesel-H2 combination. However, at other hydrogen IT and ID, the mixture quality may be reduced and over leaning leads to inadequate combustion leading to reduced combustion temperature.

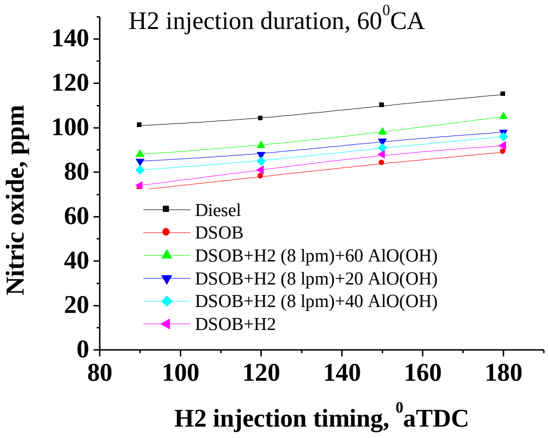


Fig.5.13 Effect of H2 IT on NOx emission

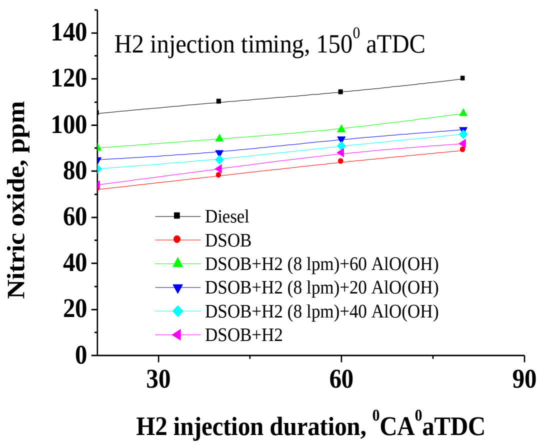


Fig.5.14 Effect of H2 ID on NOx emission

Chapter 6
CONCLUSION

The challenges associated with the use of nanoparticles are their stability, homogeneity in a liquid medium and analysis of combustion and emission levels. Herewith, synthesized the nanoparticle of AlOOH by precipitation method and as prepared nanoparticles are characterized by various techniques. It is found that the yield is maximum when synthesized at reaction temperature 60°C and at 45 mins reaction time and at 125 rpm stirring speed. The sample is dried at 60°C for 4-6 hours has given maximum yield. Annealing at 150°C was done. Also,

- Investigations showed that for all fuel combinations, hydrogen injection timing of 150^0 aTDC and injection duration of 60^0 CA resulted in better increased thermal efficiency with reduced carbon based emission levels. But increased NOx emissions were noticed.
- Further, with optimized parameters, diesel and DSOB based dual fuel operation with hydrogen injection and AlO(OH) NP provided both hydrogen and oxygen during combustion which in turn further increases thermal efficiency compared to same fuel combination without NPs. Similarly, emission levels were reduced except NOx levels.
- Dairy scum, and municipal solid waste derived fuels can be conveniently used for power generation applications and its use can reduce environmental degradation and addresses socio-economic issues.

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