EXPERIMENTAL STUDY ON PERFORMANCE AND EMISSION OF DIESEL ENGINE FUEL BLENDED WITH IRON OXIDE NANOPARTICLE ADDITIVES

Busa Tafese Ofgaa

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master of Science in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

May, 2024

Adama, Ethiopia

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CANDIDATE'S DECLARATION

I hereby declare that this Master Thesis entitled **"Experimental study on performance and emission of diesel engine fuel blended with iron oxide nanoparticle additives"** is my own work and has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Busa Tafese Ofgaa	________________________	________________
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Alemayehu Wakjira (PhD)	________________________	________________
Advisor	Signature	Date

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I, the advisor of the thesis entitled **"Experimental study on performance and emission of diesel engine fuel blended with iron oxide nanoparticle additives"** and developed by Busa Tafese, here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Busa Tafese have read and evaluated the thesis entitled **"Experimental study on performance and emission of diesel engine fuel blended with iron oxide nanoparticle additives"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Mechanical Engineering (Specialization in Automotive Technology).

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TABLE OF CONTENTS

CONTENT **PAGE**

CANDIDATE'S DECLARATION iii
RECOMMENDATION iv
APPROVAL OF BOARD OF EXAMINERS v
ACKNOWLEDGEMENT vi
TABLE OF CONTENTS vii
LIST OF TABLES ix
LIST OF FIGURES x
ACRONYMS xi
ABSTRACT xii
CHAPTER ONE 1
INTRODUCTION 1
1.1. Background of the Study 1
1.1.1. Metal Nanoparticle 2
1.1.2. Iron (III) oxide (Fe_2O_3) Nanoparticles 4
1.1.3. Application of Iron Nanoparticles 5
1.2. Statement of the Problem 7
1.3. Objectives of the study 7
1.3.1. General objective 7
1.3.2. Specific Objectives 7
1.4. Significance of the study 8
1.5. Scope of the study 8
1.6. Organization of the thesis 8
CHAPTER TWO 9
LITERATURE REVIEW 9
2.1. Introduction 9
2.2. Performance and emission characteristics of diesel engines 9
2.2.1. Performance characteristics of CI diesel engines 9
2.2.2. Emission characteristics of CI diesel engines 10
2.3. Emission reduction and performance improvement for diesel engine 10

2.3.1. Emission reduction and performance improvement for diesel engine using alternative fuels 11
2.3.2. Emission reduction and performance improvement for diesel engine using nano-additives 13
2.4. Related literature review on diesel fuel modification using nanoparticles 17
2.5. Summary of literature and research gaps 24
CHAPTER THREE 26
MATERIALS AND METHODS 26
3.1. Introduction 26
3.2. Experimental Setup 26
3.3. Materials 26
3.4. Methods 31
3.4.1. Nano-enhanced fuel Preparation 33
3.4.2. Engine performance testing using Nano-enhanced fuel 39
3.5. Engine test matrix 41
CHAPTER FOUR 43
RESULT AND DISCUSSION 43
4.1. Emission and performance characteristics 43
4.1.1. Engine performance testing using $\mathbf{Fe2O3}$ nano-diesel blend fuel 43
4.1.2. Emission characteristics of diesel engine using nano-enhanced diesel 51
CHAPTER FIVE 57
CONCLUSIONS AND RECOMMENDATIONS 57
5.1. CONCLUSIONS 57
5.2. RECOMMENDATIONS 58
REFERENCES 59
APPENDICES i
Technical specification of Engine test emission and performance chrematistics measured data i

LIST OF TABLES

TABLE **PAGE**

Table 1. 1. Characteristic of iron nanoparticles.......6

Table 3. 1. Technical specification of the test Engine.......27

Table 3. 2. Nanoparticle, surfactant, and diesel specification.......34

Table 3. 3. Engine test matrix for diesel fuel.......41

Table 3. 4. Engine test matrix for 0.5% Iron (III) oxide (Fe_2O_3) nanoparticles blended with diesel.......41

Table 3. 5. Engine test matrix for 1.0% Iron (III) oxide (Fe_2O_3) nanoparticle blended with diesel fuel.......42

Table 3. 6. Engine test matrix for 1.5% Iron (III) oxide (Fe_2O_3) nanoparticles blended with diesel.......42

Table A- 1. Specific fuel consumption Fe_2O_3 nano-diesel blend fuel.......i

Table A- 2. Engine brake power of Fe_2O_3 nano-diesel blend fuel (KW).......i

Table A- 3. Engine brake torque of Fe_2O_3 nano-diesel blend fuel (Nm).......i

Table A- 4. Exhaust gas temperature for Fe_2O_3 nano-diesel blend fuel (DegC).......i

Table A- 5. CO emission of Fe_2O_3 nano-diesel blend fuel (%).......ii

Table A- 6. C_2O emission of Fe_2O_3 nano-diesel blend fuel (%).......ii

Table A- 7. Unburned hydrocarbon emission of Fe_2O_3 nano-diesel blend fuel (ppm).......ii

Table A- 8. Nitrogen oxide emission of Fe_2O_3 nano-diesel blend fuel (ppm)....... iii

Table A- 9. BT, BP, SFC, AND EGT data of Fe_2O_3 nano-diesel blend fuel....... iii

LIST OF FIGURES

FIGURE **PAGE**

Figure 1. 1. Method of iron nanoparticle preparation [4] 4
Figure 3. 1. Schematic diagram of engine test bench 28
Figure 3. 2. Photographic view of TM 12-01 engine experimental setup 28
Figure 3. 3. Eddy current dynamometers 29
Figure 3. 4. Measurement of fuel consumption 30
Figure 3. 5. Exhaust gas analyser 31
Figure 3. 6. Schematic diagram of preparation, characterization, performance, and emission characteristics of testing of Fe_2O_3 nano-diesel blend 32
Figure 3. 7. Schematic diagram of performance and emission characteristics of testing of Fe_2O_3 nano-diesel blend 35
Figure 3. 8. Prepared fuel 37
Figure 3. 9. Iron (III) oxide (Fe_2O_3) nanoparticle mass measuring device 38
Figure 3. 10. Prepared Iron (III) oxide (Fe_2O_3) nanoparticle with different masses 38
Figure 3. 11. Made dissolve with fuel and Iron (III) oxide (Fe_2O_3) nanoparticle 39
Figure 3. 12. Schematic of emission and performance characterization process of nano-diesel fuel 40
Figure 4. 1. BT and BP with respect to compression ratio at load 25 for (Fe_2O_3) diesel blend 45
Figure 4. 2. BSFC and EGT with respect to compression ratio at load 25 for (Fe_2O_3) diesel blend fuel 45
Figure 4. 3. Specific fuel consumption with respect to load for (Fe_2O_3) nano-diesel blend fuel 46
Figure 4. 4. Engine brake power with respect to load for (Fe_2O_3) nano-diesel blend fuel 47
Figure 4. 5. Engine brake torque with respect to load for Fe_2O_3 nano-diesel blend fuel 49
Figure 4. 6. Exhaust gas temperature with respect to load for Fe_2O_3 nano-diesel blend fuel ... 50
Figure 4. 7. CO emission with respect to load for Fe_2O_3 nano-diesel blend fuel 52
Figure 4. 8. C_2O emission with respect to load for Fe_2O_3 nano-diesel blend fuel 53
Figure 4. 9. Unburned hydrocarbon emission with respect to load Fe_2O_3 nano-diesel blend fuel 55
Figure 4. 10. Nitrogen oxide emission with respect to load Fe_2O_3 nano-diesel blend fuel 56

ACRONYMS

BSFC	Brake Specific Fuel Consumption
CI	Compression Ignition
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CR	Compression Ratio
EGT	Exhaust gas temperature
IPCC	Intergovernmental Panel on Climate Change
UHC	Unburned Hydrocarbons
LTC	Low Temperature Combustion
NEDC	New European Drive Cycle
NOx	Nitrogen Oxide
PM	Particulate Matter
PPM	Parts per million
SI	Spark Ignition
BT	Brake Torque
BP	Brake Power
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
SFC	Specific Fuel Consumption
Fe_2O_3	Iron (III) oxide nanoparticle

ABSTRACT

Energy scarcity, pollution, and performance are the big current issues due to the growth of the world population and consumption of energy. Availability and effective energy conversion are the key issues that directly influence any nation socioeconomic status. The diesel engine is one of the energy conversion devices widely used in transportation sectors. However, its thermal conversion effectiveness is low due to the low thermal conductivity nature of diesel fuel and high thermal losses during the process. Various researchers improved thermal properties of diesel fuel by combining with nanoparticles to increase its thermal conductivity and hence, combustion efficiency. Adding nanoparticles, particularly iron (III) oxide nanoparticles, to diesel fuel can augment performance, minimize emissions, and reduce fuel consumption. However, inappropriately increasing the concentration of iron (III) oxide nanoparticles can affect engine performance and increase emissions. This is due to the reduction in convection heat transfer, sediment formation, and calorific value reduction. Thus, the objective of this study was to investigate the optimal concentration of Fe_2O_3 *nanoparticles in the diesel blend fuel. The mixture of iron (III) oxide nanoparticles blended into diesel fuel was prepared using three different concentrations (50 ppm, 100 ppm, and 150 ppm). Tween80 surfactant was added to the mixture for stability, and various characterizations were conducted to see the particle distribution within the diesel and to control sedimentation. Increasing the load up to 25 kg, brake torque and brake power increased, while those above 25 kg decreased. The specific fuel consumption SFC decreased up to a load of 25 kg and decreased above 25 kg. Additionally, the exhaust gas temperature linearly decreased as the load increased. A compression ratio of 16 demonstrated improved performance compared with 15 and 17 compression ratios. At 150 ppm* Fe_2O_3 *nano diesel blend, reduced UHC emissions by 29.20% at 0 kg load, increased EGT by 36.0% at 50 kg load, reduced SFC by 27.88% at 25 kg load, and reduced NOx emissions by 20.8% at 75 kg load. compared to that in the case of diesel fuel alone. At 100 ppm* Fe_2O_3 *diesel blend, reduced harmful emissions by 37.5% for CO at 0 kg load and by 33.0% for* CO_2 *at 75 kg load. Also increased brake torque and brake power by 30.0% and 24.0% at 75 kg and 25 kg loads, respectively, compared with diesel fuel alone. In conclusion, the optimum concentration of* Fe_2O_3 *is 100 ppm for both emission reduction and performance improvement cases.*

Keywords: *compression ratio, emission, greenhouse gas, nanoparticle.*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

The design and development of highly energy-efficient, low-hazard emission, and low-energy-consumption engines have drawn a lot of interest because of the increasing population, energy consumption, and concerns about global warming. The socioeconomic status of any country is directly influenced by two major factors: availability and effective energy conversion capacity. The diesel engine is one of the classes of energy conversion devices that has its own qualities apart from other energy conversion devices. These qualities include high thermal efficiencies, high compression ratios, low fuel consumption (SFC), the ability to use leaner air-fuel mixtures, dependability, and low maintenance and operating costs. These qualities assure the diesel engine's utility in a variety of industries, including the production of electricity, the automotive industry, farm tech machineries in agriculture, ships, and rail transportation (Art Miller, 2007). Despite having incredible advantages, diesel engines are known to release a large quantity of pollutants (NOx, CO_2, CO, PM, formaldehyde, and soot), which cause serious health hazards and environmental degradation. And also, its thermal energy conversion performance is too low due to the incomplete combustion and high thermal losses; not all of the fuel undergoes complete combustion within the engine, leading to wasted energy in the form of unburned hydrocarbons, carbon monoxide, nitrogen oxides, and other pollutants. The most important reason for this incomplete combustion is poor ignition and a cool combustion chamber temperature. This is due to the low thermal conductivity of diesel fuel.

To solve these problems, several methods have been utilized, such as fuel amendment or modification, and treatment of exhaust gases. By modifying the diesel fuel only, it is possible to enhance combustion efficiency to minimize emissions and reduce fuel consumption without requiring amendments to exhaust systems or the engine. Among the diesel fuel amendment methods, utilizing metal and metal oxide-based additives and emulsifying fuel are widely used as combustion catalysts to augment combustion performance and minimize engine exhaust emissions and reduce fuel consumption (C. Syed Aa, 2015).

1.1.1. Metal Nanoparticle

The science of nanotechnology examines how to manipulate matter at the atomic and molecular scales as well as at the scale of a billionth of a meter, or $10^{-9}\,m$ = 1 nm. The fundamental element involved in creating a nanostructure is a nanoparticle, which is larger than a simple molecule or an atom under the principles of quantum mechanics but far lesser than the universe of common things as defined by Newton's laws of motion. A nanoparticle typically has a size that ranges from 1 to 100 nm. Metallic nanoparticles differ from bulk metals in their chemical and physical characteristics, such as their mechanical strengths, unique optical qualities, lower melting points, unique magnetizations, and higher specific surface areas. These differences could make metallic nanoparticles desirable for a range of industrial applications

a) Modern approach of nanoparticle fuel

Nanofluids are widely used by various investigators in different applications, specifically, in engine cooling systems as high-thermal conductivity fluids, in propulsion systems as high-density fuels, and in diesel engine combustion due to the improved and high heat release rate of nano-fluid fuels. Nanofluid-based fuels are prepared by the inclusion of nanoparticles that originate from different sources, including metals and oxides of metals, carbon nanotubes, graphene, graphite, and ferro materials.

The ability to create multiple types of nano-fluid fuels from distinct nanoparticles is being investigated due to ongoing advancements in nanoparticle synthesis and processing techniques.

Diesel is mostly used as fuel in CI engines to produce power and emits harmful pollutants in the process. Nonetheless, it is commonly acknowledged that the burning of diesel produces dangerous pollutants that impair both the environment and human health (David G.Nash, 2013).

Various strategies are investigated to minimize the effects of harmful emissions from diesel engine combustion processes. Those problems associated with diesel can be minimized by the use of nanoparticles like fuel additives derived from metals, metal oxides, carbon nanotubes, graphene, and graphite materials. A fuel modification generally reduces pollution and improves combustion efficiency. Metal-based elements, such as Fe, Mg, Cu, Br, Ca, and Pt, etc., have been utilized as combustion catalysts for hydrocarbon-based fuels. Nano-sized materials are more effective compared to bulk materials because of their higher surface area-to-volume ratio. The selection of nano-sized material depends upon the catalytic influence on the combustion of hydrocarbons and size. In this regard, diesel blended with iron nanoparticles is considered an alternative technique to enhance the diesel fuel combustion process in CI engines. But when liquid phase fuels are processed with nano-sized particles, the alternative fuel offers numerous potential benefits over conventional existing diesel and biodiesel fuels.

b) How nanoparticle is prepared

Nano-sized particles are prepared either by the technique of the top-down (higher to lower) process or by the bottom-up (lower to higher) process. The higher-to-lower method is the process in which initially larger structures are used and reduced to a small or nanostructure. This can be controlled externally, as shown in Fig. (b). The top-down process comprises laser sputtering, plasma arcing, ball milling, and vapor deposition methods, while the bottom-up process comprises electrodeposition, the colloidal method, the sol-gel method, and solution phase reductions. Among these sol-gel methods, ball milling is more familiar to prepare the nanoparticles. The lower-to-higher method is the process in which materials are manufactured up to the atomic level with further self-arrangement, which helps to produce nanostructured particles, as shown in Fig. (a). At the stage of particle self-arrangement, the physical force between the nanoscales is used to form a larger and more stable structure. An example of a bottom-up process is quantum dot formation during epitaxial growth and the formation of nano-sized particles from colloidal dispersion.

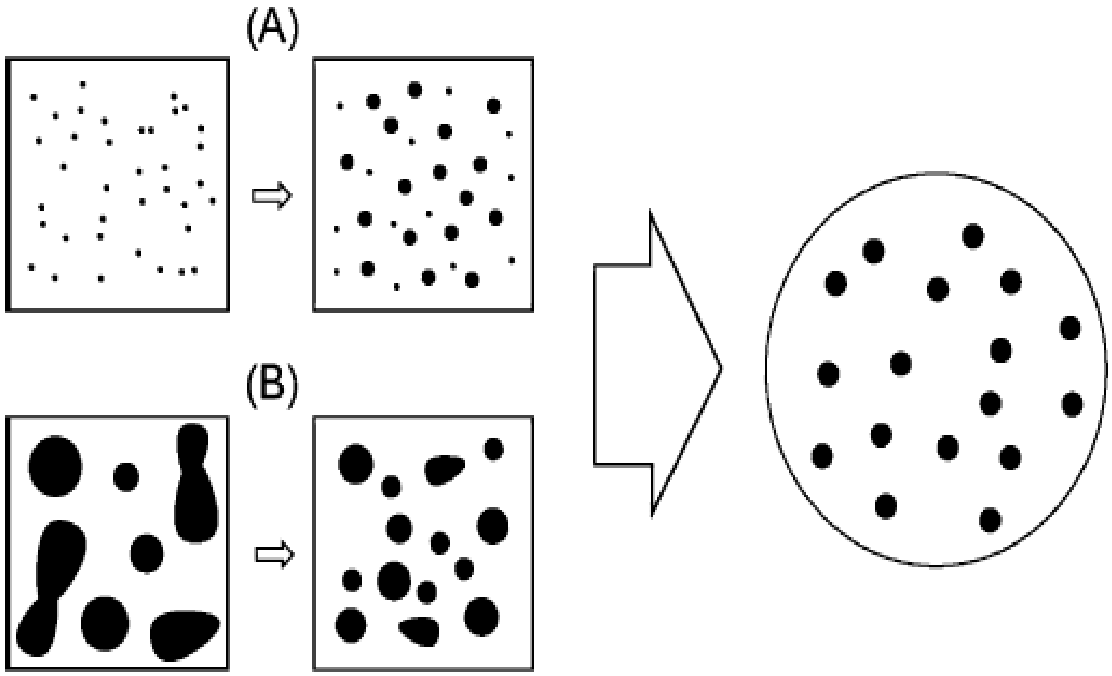

Figure 1. 1. Method of iron nanoparticle preparation [4]

1.1.2. Iron (III) oxide (Fe_2O_3) Nanoparticles

Iron is one of the transition metals found everywhere and the fourth most abundant element in the Earth's crust. It is the backbone in the development of modern infrastructure and is used as a structural material. Nanoparticles show a range of chemical, magnetic, and unique optical properties due to their finite size effects. The chemical and magnetic properties of iron have been studied for a while, with little interest in their optical effects. The most noticeable difference between nanoparticles and larger colloids or bulk materials is their tremendously high surface area-to-volume ratio.

Iron-based nanoparticles are particularly attractive for any surface-area-limited heterogeneous chemistry, but surface area is not the only factor contributing to nanoparticle reactivity. Nanoparticles retain a significant amount of energy as surface-free energy, which might result in changed magnetic characteristics or increased reactivity. The surroundings of the atoms on the surface of nanoparticles are very different from those of bulk materials and even from those of thin-film materials. It is thought that crystal defect sites are the centres of a large amount of catalytic activity, and because of their extreme curvature, nanoparticles have a very high concentration of defect sites. This provides a straightforward explanation for the widely observed fact that nanoscale catalysts are more reactive than their high surface areas alone (J.M. Bergthorson, 2015).

The characteristics of nanoparticles typically deviate greatly from those of bulk materials, but when they approach diameters of many tens of nano-meters, these characteristics gradually return to their bulk characteristics. That being said, there are some surprises in the size-dependent features. For instance, iron (III) oxide (Fe_2O_3) nanoparticles' magnetic coercivity does not merely increase monotonically with bulk behavior. Particles less than tens of nano-meters have zero coercivity, but as they get bigger, their coercivity rises to a maximum and then falls to become closer to bulk coercivity (Muhammad Ali Ijaz and Malik, 2021).

1.1.3. Application of Iron Nanoparticles

a). Catalytic Applications

Synthesis gas, which is a mixture of CO and H_2O, can be produced from coal or natural gas by its steam reforming process. Fischer-Tropsch synthesis process, which involves passing synthesis gas over a catalyst at high temperature and pressure, is one method of turning synthesis gas into hydrocarbons. The catalyst surface's new carbon-carbon bond formation is the crucial process for this synthesis. Typically, group VIII metals are selected as the catalysts for this process, with iron being a prime candidate. Iron is very cheap and is the second most active catalyst after ruthenium in the Fischer-Tropsch synthesis process.

It has long been an aim to use plentiful and relatively readily produced coal resources as a che mical feedstock to replace petroleum. A practical and affordable technique for dissolving coal into lower-molecular-weight components is required to achieve this goal. The selection of catalysts is crucial in order to accomplish this degradation in the least harsh circumstances possible. Many of the catalysts that have historically been employed for this purpose such as W and Mo sulphides are costly, and using them economically necessitates a challenging recovery scheme. Catalysts based on iron could be made cheaply enough to eliminate this need. These factors have led to research on nanoscale iron and its oxides as a coal liquefaction catalyst.

B). Magnetic and Electrical Applications

The customizability of iron nanocomposites brings so much excitement to magnetic materials. Due to the necessary need for strong coercivity in magnetic recording media, iron nanoparticles have seen the most practical application so far. In contrast, very low coercivity is preferred in transformer core materials. Using iron nanoparticles as magnetic recording media is currently their most common commercial application. Iron nanoparticles are utilized in several high-tech magnetic tapes, including backup tapes for computers and video recorders, to enable their extremely high capacity.

c). Biomedical Applications

Magnetic nanoparticles have several potential uses in medicine, such as the category and magnetic separation of biological materials, targeted medication administration, improving MRI contrast, and treating hyperthermia. Iron has never been the preferred material. In these applications, iron oxides particularly magnetite and maghemite are typically employed because of their greater adaptability to the buffered aqueous conditions seen in biological systems. It is well known that iron nanoparticles can be rapidly transformed into nonmagnetic ox hydrides in water with even modest salt concentrations. Due to its greater magnetic moment in the zero-valent state, iron does, however, have some potential advantages over its oxides. The benefit of increased magnetization is very evident in the cases of guided drug delivery and magnetic separation, where a force is applied to the particles using a magnetic field gradient.

d). Characteristic of iron nanoparticles

Table 1. 1. Characteristic of iron nanoparticles

Name	Source	Method	Particle size (dia.)	BET Surface area	Major phase	Minor phase
Fe^{H2}	Tada kongyo corp.	High temp. reduction of oxide with H_2	70nm	$29m^2/g$	α- Fe^o	magnetite
Fe^{BH}	W.X.Zhang,Le high univ.	Precip. w/$NaBH_4$	10-100nm	$33.5m^2/g$	Fe^o	Goethite, wustite
Fe^{EL}	Fisher scientific	Electrolytic	150mm	$0.1-1.0m^2/g$	99 % Fe^o	
Fe_3O_4	PNNL	Precip from $FeSO_4$ w/KOH	30.0-100nm	$4-24.0m^2/g$	Fe_3O_4	
Fe_2O_3	Nanophase Technologies corp.	Physical vapour synthesis	23nm	$50.0m^2/g$	γ-Fe_2O_3	

1.2. Statement of the Problem

According to IPCC fifth session in 2014, human activity contributes more than 95% to world climate change. One of the major causes of this climate change is the emissions from internal combustion engines. An IC engine is one of the devices that burns fossil fuels, generates power, and releases various emissions into the environment. Due to the inefficiency of the of the combustion of this engine, the mass of pollutants is exhausted into the environment, such as nitrogen oxide (NOx), carbon dioxide (CO2), carbon monoxide (CO), and hydrocarbons (UHC). There is various research to improve engine efficiency, such as adding nanoparticles and preparing and testing biodiesel and alcohols.

However, inappropriately increasing the concentration of iron (III) oxide nanoparticles can affect the performance of the engine and increase emissions. This is due to the reduction in convection heat transfer, sediment formation, and calorific value reduction. Additionally, the improper size and shape of nanoparticles also affect engine performance and emissions. Thus, the objective of this study was to investigate the optimal iron (III) oxide nanoparticles in the diesel blend fuel. In addition to concentration, nanoparticle diameter, size, and shape significantly affect performance and emission characteristics.

1.3. Objectives of the study

1.3.1. General objective

The general objective of this study is to study performance and emission of a diesel engine fueled with Iron (III) oxide (Fe_2O_3) nanoparticle as diesel blend that can be used for transportation and power generation purpose.

1.3.2. Specific Objectives

The specific objective of this thesis are:

- To preparation and thermophysical properties characterization of Iron (III) oxide nanoparticles blended diesel fuel.
- To experimentally examine the effect of Iron (III) oxide (Fe_2O_3) nanoparticle as a diesel fuel additive on the performance, exhaust gas emission, and burning characteristics of the diesel operated CI engine.

- To study the effect of varying compression ratios in the performance, emission, burning characteristics of diesel operated CI engine.
- To study the influence of Iron (III) oxide (Fe_2O_3) nanoparticles concentrations on the diesel engine performance and emission characteristics.

1.4. Significance of the study

The final outcome of this study indicates use of alternative fuel instead of commercial diesel. The implementation of the study, it is expected to have the following basic significance:

- It minimizes the effects of diesel engine emissions on environment.
- Improve in the diesel engine power generation performance.
- Decrease in the specific fuel consumption (SFC) of the diesel engines.

1.5. Scope of the study

Diesel fuel is modified by adding iron (III) oxide nanoparticle in different concentrations and the effect of the engine performance, exhaust gas emission characteristics at different engine loading conditions and compression ratio has bene investigated.

1.6. Organization of the thesis

The study is separated into five chapters. The introduction part is covered in the first chapter. The study's historical context, problem statement, goals, importance, extent, and structure of the investigation are all included. The literature evaluation based on earlier relevant publications is the main topic of Chapter 2. The third chapter outlines the supplies and procedures used to complete the thesis work. The topic of results and discussion is covered in Chapter 4. Chapter 5 discusses the conclusion and suggestions.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

This section demonstrates the overview of the current research literature studied related to the area. Diesel engines are unique in their class due to their useful features like high compression ratios, low specific fuel consumption, increased thermal efficiencies, the use of leaner air-fuel mixtures, dependability, and lower costs for engine operation and maintenance, which guarantee their utility in the production of electricity, the automotive industry, farm machinery in agriculture, ships, and rail transportation. Despite their superior performance, diesel engines are known to release a significant number of pollutants such as CO_2, CO, NOx, PM, acrolien, soot, and formaldehyde, which can be extremely harmful to the environment and human health. A number of strategies, including exhaust gas treatment and fuel changes, have been used to address this issue. In this paper the review focus on fuel modification by adding various nanoparticles. Various researchers have been done their study on diesel fuel alteration by using iron and iron oxide nanoparticle as fuel additive to mitigate pollution and health hazard problem of diesel engine.

2.2. Performance and emission characteristics of diesel engines

2.2.1. Performance characteristics of CI diesel engines

In this section the various CI engine performance characteristics has been discussed to identify the parameters that influence the performance of diesel engine during operation. The various performance characteristics of diesel engine includes brake torque (BT), brake power (BP), brake thermal efficiency (BTE), and specific fuel consumption (SFC). The performance of the diesel engine is characterized by higher power output, including high brake torque, high brake thermal efficiency, high brake power, and lower specific fuel consumption (Apazhev, 2020). In a pure diesel-operated diesel engine, these performance characteristics are very low due to various reasons. The various reasons include fuel quality, incomplete combustion, higher heat loss from the engine, exhaust gas recirculation, and mechanical friction.

The major causes of incomplete combustion inside the diesel engines include thermal conductivity of the diesel fuel. Recently, the properties of diesel fuel have been improved by using various nanoparticles. The combustion process can be improved by adding metal and metal oxide nano-sized particles to augment the thermal conductivity of conventional diesel fuels and, hence, the combustion process inside the engine.

2.2.2. Emission characteristics of CI diesel engines

In this section the various CI engine exhaust gas emission characteristics has been discussed to identify the parameters that maximizes as well as minimizes these emissions within the exhaust gas during operation. The various emissions characteristics of diesel engine includes hydrocarbon, carbon monoxide, particulate matter, carbon dioxide (CO_2), nitrogen oxides (NOx), and sulphur compounds. These emissions coming from diesel engine exhaust gas pollute the environment, and increase global temperature by reducing greenhouse gas (GHG) emissions (Mariusz BRZEZIŃSKI and Dariusz PYZA, 2021). The major causes of emissions production from diesel engines include diesel properties, inefficient combustion processes, particulate matter, low emission control strategies, and engine. Recently, the properties of diesel fuel have been improved by using various biodiesel blends of diesel fuel and nanoparticles. Additionally, the combustion process can be improved by adding metal and metal oxide nanoparticles to improve the thermal conductivity of diesel fuels and, hence, the combustion process inside the engine.

2.3. Emission reduction and performance improvement for diesel engine

Various techniques to improve the thermophysical properties of diesel include using various biodiesels produced from non-edible seeds and adding various nanoparticles to improve the thermal conductivity of the diesel and hence improve combustion during the process. The next section discussed the two important techniques to improve diesel properties. (Khalife, 2017) analyzed how diesel engine performance and emissions are affected by biodiesel and diesel additives. In this study, the additives were examined in five categories: water, polymeric-based additives, antioxidants, oxygenated additives, and metal and non-metal-based additives. They listed and examined the influences of each category on performance of the engine, including brake-specific fuel consumption and brake thermal efficiency, as well as various emissions, including HC, NOx, CO, and PM. Additionally, various water addition techniques, including water-diesel emulsion, direct water injection, and water addition through the inlet manifold, were demonstrated.

2.3.1. Emission reduction and performance improvement for diesel engine using alternative fuels

The properties of the diesel can be improved by blending various types of biodiesels. Researchers blended various types of biodiesels prepared from non-edible seeds such as castor seeds, jatropha seeds, palm oil, linseed and rubber seeds, algae, and Pongamia (Millettia) to improve the thermophysical properties of diesel that have low emissions and higher performance. Methanol also used by different researchers to improve diesel properties. Since there is a strong demand for biodiesel production and due to the higher production cost and pollution of diesel fuels compared to ethanol, adding ethanol to the diesel or biodiesel blend might enhance the renewable source of the additional fuel blend and decrease the biodiesel in percentage.

Methanol-diesel fuels with various mixing ratios (DM40, DM30, DM20, DM10, and DM0) were used to study the influences of methanol addition on the emission and combustion of a four-stroke engine operated with diesel fuel in terms of brake power inside cylinder, pressure, brake-specific fuel consumption, and emissions of soot, carbon monoxide, and nitrogen oxides. The outcomes demonstrated that the increased methanol level in the fuel mixture greatly augmented the diesel engine emission characteristics but had a negative impact on the engine performance (Zhang, 2021). Similarly, (Ahmad Fayyazbakhsh and Vahid Pirouzfar, 2016) analyzed experimental odelling and optimization techniques to study the impact of ethanol diesel mixtures on engine performance and exhaust pollution. The findings obtained demonstrate that it is preferable to use diesel-ethanol (NE + MN) in order to reduce soot emissions and raise the cetane number. The engine speed and load of 1500 rpm and 168 Nm, respectively, are found to be the ideal values for NE and MN. The model evaluated the soot content, CO_2, and Nox generation, brake power, and BSFC of 27.6 ppm, 28.1 ppm, 441.3 ppm, 26.5 kw, and 224.2 g/Kw h, respectively, under these conditions. Furthermore, (Freitas, 2022) assessed the emissions reduction of CO_2, Nox, and CO from a diesel engine running on blends of diesel and biodiesel fuels, and ethanol, specifically using B7E3 (B7 with 3 % ethanol) and B7E10 (B7 with 10 % ethanol).

(Örs, 2018) investigated the performance parameters of exhaust gas temperature, volumetric efficiency, BTE, and BSFC and the exhaust emissions including UHC, CO, Nox, and CO_2 of biodiesel derived from Jatropha seeds, which was used as fuel to run a single-cylinder, 4-stroke diesel engine using different blend ratios (B100, B80, B60, B40, and B20) and different loads. Blends of biodiesel (B20%) increase fuel consumption specifically for the brakes by 15% while reducing BTE by 6 % and brake volumetric efficiency by 3 %. Nox emissions rise with mixture concentration; with pure Jatropha biodiesel, Nox emissions rise by 30 % when compared with pure diesel. Furthermore, compared with diesel fuel, the emissions of CO and CO2 drop by 55 % and 35 %, respectively, for a 100% blend. Smoke and HC emissions decline as gasoline blends contain higher percentages of biodiesel.

(Tamrat, 2024) examined the effects of a castor oil-based biodiesel blend diesel fuel on performance and outlet gas emissions in a four-stroke, single-cylinder engine operated with diesel at different engine speeds. With cerium oxide (CeO2) nano additive (75ppm), the authors used the following proportions: B5 blend castor biodiesel (5% castor biodiesel and 95 % diesel), B10 blend castor biodiesel (5% castor biodiesel and 90 % diesel), B15 blend castor biodiesel (12% castor biodiesel and 85 % diesel), B20 blend castor biodiesel (2% castor biodiesel and 80 % diesel), and B25 blend castor biodiesel (5% castor biodiesel and 75 % diesel). All biodiesel-diesel blends for the engine operating speed ranging at 2700rpm without nano-additive and at 2900rpm with nano-additive have shown a considerable reduction in emissions and boost in the engine performance with the addition of CeO2 nano additive.

The reports show that B10 has the lowest BSFC decrease rates and B25 has the greatest. The average maximum gain in thermal efficiency for B10 with CeO2 addition was 22.2 %. CO emissions rose with engine speed. HC emission dropped with increasing speed for all blends, with and without CeO2 nano-additions. Higher Nox emission was measured with the nano-addition at 2900rpm and without it at the rated speed of 2700rpm. For all castor biodiesel-diesel blends, the CeO2 nano addition reduced the soot opacity by 11.56 % over the engine’s operating speed range. The use of CeO2 nanoparticles improved performance and reduced emissions.

(K, 2021) examine the effectiveness and emissions of diesel in conjunction with biodiesel made simultaneously from non-edible rubber and linseed seed oil. Various sample biodiesel blends were used in water-cooled, single-cylinder diesel engine output and emissions tests. In the experiment, they used five samples of each seed oil. According to the experimental investigation, samples 1 (5 % linseed and 5 % rubber seed biodiesel, 90 % diesel) and 2 (10 % linseed and 10 % rubber seed-based biodiesel, 80 % diesel) demonstrated the best performance efficiency when compared to the other blends. The SFC difference between base diesel and mixture is negligible at higher loads. The CO and NO2 emissions of sample blends are lower than those of basic diesel. On the other hand, the Nox and CO2 values are higher than those of basic diesel. Similarly, (S Bari and S. N Hossain, 2019) examined a diesel engine performance when running on palm oil-based diesel (POD). POD had an average of 10% greater break-specific fuel consumption than Petro-diesel because of its lesser calorific value. But because POD contained oxygen that was carried by the fuel, its thermal efficiency was almost identical to that of Petro-diesel. The highest possible efficiencies for Petro-diesel and POD are 21% and 20%, respectively. POD produced emissions of UHC and CO that were 55% and 51% lower, respectively, compared to Petro-diesel operated. As a result of the oxygenated fuel and greater combustion temperature, the emission of Nox with POD was, on average, 33 % higher than that of Petro-diesel fuel.

(Joy, 2019) examined how neat cashew nut shell biodiesel (CBD100) performed in terms of engine emissions and performance by using Di-Methyl-Ether (DME) as a cetane improver. A stationary diesel engine for research purpose was used to create and evaluate four types of fuels, including diesel, biodiesel (Cashew nut shell Methyl Ester), a blend of CBD100-10%, and 20% by volume of DME (CBD90DME10 and CBD80DME20). When compared to plain biodiesel under peak conditions, the parameters used in the experiment for CBD80DME20 revealed a 1.6 % gain in thermal efficiency and a 4.1% decrease in fuel consumption. According to experimental results, 20 % of DME shortened 4.2 % HC, 3.4 % CO, 8.8% Nox, and 8.4% smoke gas emissions compared to CBD100. It is evident from the work’s output that CBD80DME20 will be used as a diesel engine’s alternative fuel.

2.3.2. Emission reduction and performance improvement for diesel engine using nano-additives

The properties of the diesel can be improved by blending various types of metal nano-sized particles. Various researchers incorporated different nanoparticles into diesel fuel as well as diesel blend biodiesel fuels, including metal and metal oxide nano-sized particles, carbon nanotubes (CNTs), graphene, graphene oxide, and graphite. Incorporating these nano-additives significantly enhanced engine performance and also shortened exhaust gas emissions.

(Nouri, 2021) studied the effects on a diesel engine's performance, emission, and burning characteristics of adding Al_2O_3 and Fe_2O_3 nanoparticles (90, 60, and 30ppm) as well as Al_2O_3-Fe_2O_3 hybrid that combines two and more than two nanoparticles into the conventional base diesel fuel. The findings showed that fuel blends enhanced the engine's performance (fuel consumption, power, thermal, and energy efficiency), combustion (in-cylinder pressure and heat release rate), and emission characteristics. The findings demonstrated that the addition of the nanoparticles enhanced the peak burning pressure by 4 % and improved the heat release rate by 15% when compared to pure diesel. Furthermore, when in comparison with pure diesel with nanoparticle additions, the rate of pressure rise augmented by 18 %. Similarly,

The influences of adding ZnO nanoparticles to four-stroke and single-cylinder engine operated with diesel, performance and emissions characteristics were examined experimentally. ZnO nanoparticles were combined in different amounts (5-25 mg) with pure diesel. At 1500rpm engine speed, the test fuels were tested with different engine loads ranging from 2 to 12 Kw. It was found that, when compared to clean diesel, 20ZnO60DF (20mg of ZNP + 20mg of CTAB surfactant + 600ml diesel) at 12Kw diesel engine load resulted in an 11.11% decrease in brake-specific fuel consumption and an improvement in brake thermal efficiency of 15.58%. As compared to pure diesel fuel in 12Kw conditions with a compression ratio of 18, the harmful emissions of CO, Nox, CO_2 HC, and particulate matter were dramatically reduced by 58.93 %, 57.46 %, 41.85 %, 78.78 %, and 42.51 %, respectively, with the addition of 20ZnO60DF. The ideal blend of ZnO nanoparticles and diesel with the best compression ratio for enhanced efficiency and lower emissions was determined to be 20ZnO60DF with a compression ratio of 18 (Khatri, 2019).

(Chen, 2018) examined the influences of blends of pure diesel fuel and different nanoparticles including aluminium oxide, silicon oxide and carbon nanotubes on the diesel burning inside the engine, performance, and outlet gas emissions characteristics of the single-cylinder, four-stroke diesel engine. The blends of fuel and nanoparticles were tested experimentally at various engine loads with constant speed of the engine crank shaft. The reports revealed that brake thermal efficiency improved by 18.8%, and brake-specific fuel consumption was shortened by 19.8 %. Silicon oxide (SiO2) blends showed higher performance than aluminium oxide (Al2O3) blends in many areas, including lower carbon emissions, higher burning pressure, and lower brake-specific fuel consumption.

Researchers also investigated the influence of nanoparticle sizes on the engine performance and exhaust gas emission characteristics operated with diesel fuel. (Rangabashiam, 2019) analyzed the influence of SiO2 nanoparticle size on the exhaust gas emissions properties of a water-cooled, single-cylinder, four-stroke diesel engine running on tidy diesel (D100). When silicon oxide was added in different particle sizes of 10nm and 20nm, the experimental results demonstrated that, at 3.5 bar BMEP, the HC and CO emissions for D100SiO210 were shortened by up to 3.7% and 3.3%, respectively, compared with D100. For D100SiO220, SiO2 nanoparticles further reduced HC and emissions of CO by 3.2% and 2.6%, respectively, compared with D100.

Additionally, the effect of nanoparticles on engine outlet gas emission and diesel operated engine performance characteristics of biodiesel blended diesel fuel were investigated by different researchers. (El-Adawy, 2023) investigated the engine performance and outlet gas emission characteristics of various mixtures of diesel and biodiesel enhanced by zinc oxide (ZnO) nanoparticles. Blends of diesel with biodiesel fuel were treated with 50 ppm zinc oxide nanoparticles. Under various engine speeds and full-load running conditions, the performance was conducted. As demonstrated by the testing results, ZnO supplementation improved the burning characteristics and performance of diesel engines by mitigating the poor combustion of biodiesel. For gasoline blends B40ZnO, B20ZnO, and B0ZnO, the engine torque increased by 3.69, 4.9, and 6.74 %, while the BSFC shortened by 2.5, 6.44, and 5.6%, respectively, compared with B40, B20, and B0 at 2300 RPM.

Furthermore, (Vellaiyan, 2019) analyzed engine performance, burning, and outlet gas emissions when utilizing soybean biodiesel (SB), neat petroleum-diesel (PD), and 50 % SB blended PD (PD50SB) with the dispersion of carbon nanotubes (CNTs) at a concentration of 100 parts per million. The experimental evaluations were conducted at a constant engine crank shaft speed of 1500rpm in a four-stroke, single-cylinder, naturally aspirated diesel engine for research purpose with variable brake mean effective pressure (BMEP) circumstances. The findings show that, in comparison to PD, the SB and its blend encourage reduced period of ignition delay (IDP), which lowers the net heat release rate (NHR) and in-cylinder pressure (ICP). Due to their lower heating values and more efficient combustion, the SB and its mix enhance brake-specific fuel consumption (BSFC) while reducing outlet gas temperature (OGT) and brake-specific energy consumption (BSEC). Regarding the emission characteristics, the blend of SB and CO2 promotes lower levels of smoke, hydrocarbon (HC), CO2, and CO emissions than PD, with the exception of oxides of nitrogen (Nox) emissions. Regardless of the engine load, the addition of CNT nanoparticles to base fuels greatly enhances diesel burning, performance, and emissions levels.

(Suhel, 2021) investigated the impact of a nano-additive of ferrous ferric oxide at varying volume fractions of 150, 100, and 50ppm on the outlet gas emission characteristics and performance of CI engines powered by blends of chicken fat methyl ester. The added nanoparticles were mixed in with several blends of methyl ester. According to experimental data, adding 100ppm nanoparticles called ferrous ferric oxide to blends greatly enhances diesel burning and drastically reduces harmful emissions from the engine. Additionally, it was discovered that an experimental result showed that the nano-fuel B20FFO100 blend could improve brake thermal efficiency by up to 4.84%, reduce brake-specific fuel consumption by up to 10.44%, reduce brake-specific energy consumption by up to 9.44%, reduce outlet gas temperature by up to 19.47%, and reduce unburned hydrocarbon, carbon monoxide, nitrogen oxides, and smoke by up to 53.22%.

The influence of aluminum oxide nanoparticles on outlet gas emission and engine performance parameters using butanol-diesel was also investigated by (Fayad, 2021). The authors explored the influences of varying mass fraction of aluminum oxide nano-sized particles (100, 50, and 30 mg/l) on emission, particulate matter (PM), and combustion characteristics using a butanol diesel blend (B20). When studied on the engine powered by diesel fuel, the mixes of B20 + Al2O3 nanoparticles showed good homogeneity and stability. In comparison to the B20 without Al2O3 additions, the results showed that the addition of aluminum oxide nano-sized particles to the B20 improved the heat release rate and cylinder pressure by 13% and 6%, respectively. Furthermore, in comparison with the B20 without additives, the brake thermal efficiency augmented by 4.7% and the brake specific fuel consumption dropped by 7.3%.

Utilizing B20 + Al2O3 nanoparticle fuel under 3.5 bar of engine load resulted in a 30.5% reduction in PM concentration. Moreover, with varying Al2O3 concentrations injected to the B20 under varying engine loads, the average nanoparticle diameter augmented by 9.2 % while the overall particle mass fell by 13.3%. CO, Nox, and HC emissions were shortened by 42.71%, 12.37%, and 37.46%, respectively, for both fuels when 100mg/l of nanoparticles was incorporated to the B20. For a range of engine loads, the results showed that 100mg/l of aluminum oxide nano-sized particles had the greatest impact on gaseous emissions, concentration of particulate matter, and combustion parameters.

The effects of different nanoparticles on diesel powered engine emission, diesel burning, and performance characteristics using biodiesel only (B100) were studied by several researchers. The performance, combustion, and outlet gas emission characteristics of diesel-powered CI engine using clean biodiesel (B100: 100 % rubber seed oil methyl ester) combined with 50 ppm and 25 ppm concentrations of titanium and alumina oxide nanoparticles, respectively was investigated by (Srinivasan, 2021). The blends of biodiesel blended with nanoparticles, including (B100 + alumina with 25 ppm), (B100 + alumina with 50 ppm), (B100 + TiO2 with 25ppm), and (B100 + TiO2 with 50 ppm) are called B100A25, B100A50, B100T25, and B100T50, respectively. In a DI single-cylinder diesel engine, neat biodiesel mixed with titanium alumina dioxide nanoparticles was used in experiments under varied operating circumstances. According to the test results, the engine using fuel blended with nanoparticles (B100T50) had an improved in BTE by up to 5.2% and a decreased in BSFC by up to 10.56 %. In comparison to neat biodiesel at full load, the emissions of smoke, HC, and CO dropped by 44.0 %, 28%, and 44.0 %, respectively, whereas the Nox emissions were augmented by 21%.

2.4. Related literature review on diesel fuel modification using nanoparticles

In this section, the review addressed the different nanoparticles blended with diesel and biodiesel to increase engine performance and reduce outlet gas emissions. This review clearly addressed the preparation and characterization methods, including the experimental tests to measure emissions of exhaust gas from diesel powered engine, including carbon dioxide, carbon monoxide, unburned hydrocarbons, and nitrogen oxides. Additionally, the experimental test also addressed diesel fuel powered engine performance, such as brake thermal efficiency, brake torque, outlet or exhaust gas temperature, and brake-specific fuel consumption.

The study used nano-sized materials blended fuels, which were created by sonicating nanoparticles of iron (Fe), boron (B), and aluminium (A1) in the base diesel, to demonstrate engine performance, burning characteristics, and gas emission parameters of a vertical, direct injection, single-cylinder, water-cooled, compression ignition, and four-stroke engine. To measure engine torque, a test engine was connected to a dynamometer that used eddy current. Aluminium, iron, and boron (Nanoshel LLC, USA) were suspended in base diesel in a stable and homogeneous manner by ultrasonication (Sonics Vibra cell-USA, 750 W, 20 kHz) for 15 minutes, followed by the addition of the surfactant $\mathrm{span80}^{TM}$. The backscattering profiles (Turbiscan classic MA 2000; Formulation, France) were used to determine which nano-fuels were the most stable and had the largest particle loading. The fuels were composed of 0.5 weight percent nanoparticles (n-Al, n-Fe, or n-B), 0.1 weight percent span80, and the remaining diesel. Ultimately, they draw the conclusion that cylinder pressure changes in response to crank angle changes for various nano-fuels and diesel. For Al, Fe, B, and diesel, the peak cylinder pressures under full load conditions were 55, 60, 59, and 62 bars, respectively. Nano-fuels were found to reduce peak cylinder pressures when compared with diesel. The peak pressure decline is explained by the fact that the inclusion of nanoparticles causes a decrease in both chemical and physical delays. Therefore, early combustion is sparked by the enhanced ignition qualities of energetic Al, Fe, and B nanoparticles, which lower peak pressures. A wet Whatman (grade 44.3lm) filter paper was placed in front of the outlet pipe at full load for one minute in order to capture the soot particles, which were then examined under a microscope to determine the amount of soot created at the end of diesel burning process. Particle counts were not recorded, although weight increases of about 12 %, 9 %, and 8 % were noted for Fe, B, and A1 nano-enhanced fuels, respectively, in comparison to diesel (Muhammad Ali, 2021)].

Another investigator aimed to demonstrate how the combustion of Fe3O4 nanofluid fuel affected the performance and outlet gas emission properties of the single-cylinder, 4-stroke, water-cooled, naturally aspirated engine using direct injection CI when the engine was being driven by an electrical generator. Fe3O4 nano-sized particles dispersed into the diesel fuel at a mass fraction of 0.8 and 0.4 vol% were used in the diesel burning process. In contrast, exhaust gas temperature readings have been measured using K-type thermocouples. The outlet gas emissions and smoke capacity were measured using the analyzer called Testo 350 XL and a smoke meter called MDO2-LON, respectively. It has been determined that the characteristics of diesel engines are significantly influenced by nanoparticle additions, even at very low concentrations. According to the findings, a fuel containing 0.4 vol% of nanoparticles exhibits superior combustion properties than one containing 0.8 vol%. The findings of the experiments demonstrated that when the dosage level of nanoparticles is increased, the emissions of NOx and SO2 are drastically reduced, while the emissions of CO and smoke opacity are noticeably increased.

As a result, they were able to observe the engine's NOx emissions at various engine loads and nanoparticle concentrations. In the case of 0.4 vol% nanofluid and 0.8 vol% nanofluid fuels, the average reductions were approximately 56% and 67%, respectively. High surface areas of the magnetic nanoparticles boost their chemical reactivity, which lowers the igniting delay. For the purpose of reducing NOx, the iron oxide-based nanoparticles also absorb oxygen. The engine's SO2 emissions at various nanoparticle concentrations and engine loads were displayed using various figures. In the case of adding iron oxide nanoparticles with concentrations of 0.4 vol% NF and 0.8 vol% NF to the diesel fuel, it reduces the sulfur dioxide content by 14% and 20%, respectively (N. Mehta, 2013).

Aimed to demonstrate the relationship between the influence of nanoparticles using cerium oxide and ferrofluid on the operation and outlet gas emission characteristics of a computerized, 4-stroke, variable compression ratio, single cylinder, compression ignition, and direct injection engine connected to an eddy current dynamometer. The engine was fuelled with nanoparticles of cerium oxide and water-based ferrofluid.

At last, they were achieved and concluded that, for all brake mean effective pressures, the brake-specific fuel consumption of diesel-cerium oxide blends minimizes as engine load increases. The lowest BSFC, measured at a brake mean effective pressure (BMEP) of 0.44 MPa, is found 0.3586 kg/kW/hr at diesel plus cerium oxide blends containing 0.25 percent.

The BSFC was comparatively reduced by 3.23-6.45% and 5.06-10.85% when 0.4% and 0.8% ferrofluid were added to diesel fuel, respectively. The BTE increased by 3.33 %-6.89 % and 5.33 %-12.17 %, when 0.4 % and 0.8 % ferrofluid were added to the diesel fuel, respectively (Nasrin S., 2014).

The CO emission intensifies with the rise in engine load, but are optimum up to the BMEP of 0.44 MPa. When compared with neat diesel, the incorporation of cerium oxide further decreases the CO emissions. The experiment shows that the addition of ferrofluid into diesel fuel augments emissions of CO gases. Dispersing 0.4% ferrofluid to the diesel fuel augmented emissions of CO by 10 to 17 ppm, and incorporating 0.8% ferrofluid to the diesel fuel augmented emissions of CO by 21 to 42 ppm. Adding D+4F shortened emissions of NOx by 9.0 to 150ppm, and dispersing 0.8% ferrofluid to the base diesel fuel reduced emissions of NOx by up to 14ppm to 24ppm (Ramachandran, 2015).

They discussed the present effect of ferrofluid on the diesel burning efficiency and outlet gas emission of a single-cylinder, 4-stroke, water-cooled, diesel-operated engine coupled to an eddy current-type dynamometer. In this research, an oil-based ferrofluid was incorporated into diesel fuel to investigate the influences on performance and outlet gas emissions of diesel-powered engine. Emulsified diesel fuels of D+4F %, D+8F % and D+12F % ratios by volume were used. The experiment was taken place in a such a way that the engine is loaded at no load, 50% and 75% of full loads for diesel blend and pure diesel fuel operation.

Experimental results showed that, adding D+4F% shortened the SFC comparatively by 6.06 - 9.09 %, adding D+8F% reduced the SFC comparatively by 8.00 - 15.15 % and adding D+12F% shortened the SFC relatively by 10.52 - 18.18 %. Adding D+4F% relatively augmented the BTH by 6.21 – 9.10 %, adding D+8F% improved the BTH by 9.6% - 16.69% relatively, and dispersing D+12F% increased the BTH by 11.07 – 21.43 %. Adding D+4F% shortened the NOx emissions by up to 8 to 21 ppm, adding D+8F% minimized the NOx emissions by up to 12ppm to 25ppm and adding D+12F% shortened the NOx emissions by up to 17 to 30 ppm. Adding D+4F% augmented CO emissions by up to 11 to 18 ppm, D+8F% augmented CO emissions by up to 23 to 32ppm, and adding D+12F% augmented the CO emissions by 30 to 43 ppm (Ranaware A., 2022).

This study aimed to present the effect of nanoparticle, particularly, iron (II or III) oxide as a fuel additive on outlet or exhaust gas emissions and diesel burning characteristics of a single-cylinder, water-cooled, vertical, four-stroke, common rail direct injection diesel engine coupled to an eddy current type dynamometer. Mechanical homogenizer and ultrasonication are used to mix iron (II, III) oxide nanoparticles into diesel with mass fractions of up to 25 ppm and 50 ppm, respectively. Scanning electron microscopy (SEM) provides relevant information by directly examining nanotube size and alignment. The morphology of nano-sized particles was studied by field emission scanning electron microscopy (FE-SEM). The AVL-5 gas analyzer was utilized to quantity the number of pollutants.

The outcome demonstrated that, in contrast to the other scenarios, the BSFC values of clean diesel fuel and fuel including 25 ppm iron oxide nanoparticles are almost identical, whereas the fuel containing 50ppm iron oxide nano-sized particles exhibits a notable reduction of roughly 9%. The dispersion of 50 ppm IONP to diesel demonstrated in a 2% increase in brake thermal efficiency. The CO emission increases rapidly with higher loads, but it is marginal up to the brake power (BP) of 4.2 kW. Experimental results show that CO emissions are minimized with the addition of iron (II, III) oxide nano-sized particles to diesel fuel. At full load of the engine, the CO emissions decrease by up to 48% for 25 ppm iron oxide nanoparticle fuel and 52 % for 50 ppm iron oxide nanoparticle fuel. Utilizing iron (II, III) oxide nano-sized particles increases the oxidation of hydrocarbons by lowering the initiation temperature of carbon burning and acting as a catalyst for oxidation. With 50 ppm of iron oxide nano-sized particles blended into diesel fuel and 5.3 kW of brake power, the lowest HC emission is recorded at 55 ppm. Experimental results show that NOx emission increases significantly when IONP nanoparticle additives are used. The emission of NOx is about 890ppm for neat diesel, 9910 ppm for 25 ppm iron oxide nanoparticles, and 990ppm for 50 ppm iron oxide nanoparticles at the full load of the diesel engine (Shiva Kumar, 2017).

Aimed to present effect of ferrofluid on the performance and exhaust gas emission pattern of a four-stroke, four-cylinder, water cooled, in-line, four-stroke CI engine. Investigations on the impacts of incorporating water-based ferrofluid with diesel fuel in a diesel engine were conducted through experimental testing. These impacts encompassed diesel engine burning performance and outlet or exhaust gas emission features. Diesel fuels with emulsified particles at volumetric ratios of 0, 0.4, and 0.8 were utilized.

The authors came to the conclusion that the BSFC will drop when a ferrofluid is added to diesel fuel. The findings of the experiments showed that the BSFC was reduced by 3.23 %-3.45 % and 5.06 %-10.85 %, respectively, when 0.4 % and 0.8 % ferrofluid were added to diesel fuel. Diesel fuel's NOx emissions were reduced by 9 to 15 ppm when 0.4 % ferrofluid was added, and by 14 ppm to 24 ppm when 0.8 % ferrofluid was added.CO emissions are increased when diesel fuel is mixed with ferrofluid. According to Shiva Kumar (2017), adding 0.8 % ferrofluid to diesel fuel raised CO emissions by up to 21 to 42ppm, while D+4F increased CO emissions by 10 to 17ppm (Shiva Kumar, 2017).

Aimed to present effect of Diesel-polanga oil blends doped with iron oxide nanoparticles on the performance of computerized four stroke, single cylinder, direct injection, variable compression ratio, CI engine coupled to an eddy current dynamometer. The study examined the performance and outlet gas emission characteristics of engines powered by diesel fuels when neat diesel was mixed with polanga oil at weight percents of 10%, 20%, and 30%. To investigate the influence of iron oxide nano-sized particles on engine performance, three different quantities of the particles, including 100, 200, and 300 ppm, were added to each of the three polanga oil-diesel fuel mixes. Five distinct braking powers were applied to the engine for every blend of diesel, polanga oil, and iron oxide nanoparticle fuel.

Additionally, it was shown that POD blend combined with an iron oxide nano-sized particle materials could be utilized as a substitute fuel for traditional diesel engines that are currently in use without requiring significant engine modifications. The engine performance and outlet gas emissions were significantly affected by the dispersion of iron oxide nanoparticles at high POD blend ratios. When diesel with nanoparticles, particularly, iron oxide had a polanga oil content of 20 % or more, many of the performance and emission metrics were comparable to those of neat diesel under various load circumstances. At 80 % load, the performance of the blend consisting of 900ml of diesel, 300ml of polanga oil, and 100ppm of nanoparticles was found to be more similar to that of plain diesel (T. Shaafi, 2015).

A direct-injection, single-cylinder diesel powered engine operating at a constant speed and with three different engine loads was used to demonstrate the possible effects of ferrocene-doped ultralow sulphur diesel (ULSD) fuels on the chemical, physical, and toxicological properties of the particles it emits.

By adding ferrocene to ultralow-sulfur diesel (ULSD), they were able to significantly lower the emissions of diesel particulate matter (DPM). The decrease in elemental carbon (EC) emissions is primarily responsible for this drop. Nevertheless, the fuels doped with ferrocene raised the amounts of n-alkane emissions, PAHs in the particle phase, and the fractions of organic carbon (OC), and water-soluble organic carbon (WSOC) in the particles. The inclusion of ferrocene resulted in a noticeably higher total number of particles released. The creation of many self-nucleated metallic nanoparticles is the primary reason for the growth. Large numbers of self-nucleated metallic nanoparticles are the primary reason for the rise. Lower ignition temperatures and lower activation energies are found in the soot from ferrocene-doped fuels when compared to pure ULSD. A small reduction in cell viability was seen in the particles released by Fe-doped fuels. Fe is linked to the variation in cell viability (Vishal Saxena, 2016).

The aim of this research was to investigate the health aspects and environmental impacts of fuel-borne catalysts (FBC) in diesel fuels during combustion in diesel operated engines without diesel particulate filters (DPFs). However, instead of examine data from the arrangement of diesel-powered engines, the work emphasizes the effect of systematic variations in the fuel composition on outlet gas emissions from a single and small prototype diesel operated generator.

Finally, at fuel Fe mass fractions of 0 to 200ppm, the ferrocene experiments demonstrate decreases of 30-40 % in total particle volume, particle mass, and the black carbon (BC) gas emissions in addition to increases in particle number mass fraction associated with the 10-30nm Fe particles released during soot oxidation, which are close to a factor of 5. The concentrations of Fe in diesel particulate emissions (DPEs) increase from 0.1% to 7.5% in tandem with the fuel Fe levels, which grow from 0 ppm to 200 ppm. The ATOF-MS study shows that 98–99% of the iron in the emissions is fundamental, with very little quantities of FeO (1 %-2 %). A GC/MS study of DPE organic extracts shows that while the PAHs decrease with increased Fe, there is no obvious pattern in the emissions of organic acids and alkanes.

This is reliable with the planned mechanism in which the iron oxidizes PAHs associated with soot but leaves out condensed organic molecules associated with fuel that hasn't burned and lubricating oil that avoid flame processes (Y. Li, 2023)**.**

(Kishore, 2022) investigated the influences of iron (III) oxide (Fe_2O_3) nano-sized particle additives on the combustion, outlet gas emission, and engine performance characteristics of a single cylinder, common rail direct injection, four-stroke diesel engine operating at a fixed speed of 1500rpm and under variable operating conditions when incorporated to Mahua methyl ester (MME) blend. The following fuels: MME20 + Fe2O340, MME20 + Fe2O380, and MME20 + Fe2O3120 as well as the cationic surfactant cetyl trimethyl ammonium bromide (CTAB) were utilized in the experimental investigation. According to the experimental study, there was a notable 8.8% improvement in the BTE and a significant reduction in the number of harmful outlet gas pollutants such as smoke by 5.38%, HC by 6.39%, CO by 10.24%, and NOx, among others, when using the blended biodiesel with nanoparticle additives (MME20+ IONP80).

2.5. Summary of literature and research gaps

- In the literature, the effects of various nanoparticles, particularly iron (III) oxide nano-sized particles blended with diesel fuel, on engine emission and performance characteristics have been investigated. However, the effect of nanoparticle concentration, particularly iron (III) oxide concentration, on the engine performance and outlet gas emission characteristics was not clearly studied. Because the inappropriate concentration of iron (III) oxide nano-sized particles in the diesel fuel can increase the dynamic viscosity of the prepared nanofluid and hence the convection heat transfer within the nanofluid, Additionally, the calorific values of iron (III) oxide nanoparticles are lower than those of the base diesel fuel, and thus inappropriately increasing the concentration can diminish the calorific values of the nanofluid and hence the engine performance.
- In other cases, the performance of iron (III) oxide nanoparticles blended into diesel fuel strongly depends on the preparation and characterization techniques that are influenced by stability, distribution, and sedimentation. Thus, in this study, well-prepared and characterized iron (III) oxide nanoparticles blended with diesel fuel were

used by using ultrasonication and a magnetic stirrer for preparation, tween80 surfactant for stability, and various characterization devices such as XRD, FT-IR, and UV-VIS.

- Additionally, the influence of pressure ratios was not considered in most research outputs. Hence, in this research, the effect of compression ratio was considered to find the optimum compression ratio.
- Hence, this research was studied to fill the gaps listed above, including iron (III) oxide nanoparticle concentration with diesel fuel, preparation and characterization techniques, and studying the effect of compression ratios.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Introduction

In this section, the required materials and methodology of the experimental setup were discussed, which were helpful to quantity the diesel combustion, engine performance, and outlet gas emission characteristics of diesel engines operated with iron nano-sized particles with various concentrations by varying the load and compression ratio. And also, in order to achieve the general and specific objectives of this study, it contains details about the research approach as a science of studying how research was done scientifically. So, the appropriate materials and methodology were followed with ethical considerations.

3.2. Experimental Setup

The experimental study was carried out in AASTU (Addis Ababa Science and Technology University) CI engines laboratory with variable compression in an experimental engine test rig consisting of four-stroke, single-cylinder, vertical, stationary, constant-speed, and water-cooled diesel-powered engine connected to an eddy current-type dynamometer for loading. The test engine also contains a water-cooling system for engine cooling, a fuel supply system for supplying fuel, a lubrication system for lubricating engine parts, and different sensors and instruments integrated with a data acquisition system for online measurement of load, air and fuel flow rate, cooling water, and exhaust gas temperature.

The set-up helps with the evaluation of the emission constituents and thermal performance of the engine. The performance parameters used in thermal systems include brake-specific fuel consumption, brake thermal efficiency, brake power, and exhaust or outlet gas temperature. The experimental setup also includes the necessary measuring instrument for measuring outlet gas emissions and smoke density. The outlet gas emissions of the engine were investigated by using an outlet gas analyzer. The ingredients of the outlet gas, like oxygen, carbon monoxide, hydrocarbons, and NO_X, are measured with an exhaust gas analyzer.

3.3. Materials

The materials, tools, apparatus/devices required to prepare nanoparticle-enhanced diesel composition and to test its performance are listed below:

(a). Engine

The experiment test engine in the presented work was a single-cylinder, direct injection, and naturally aspirated CI engine of TM 12-01. This engine has a stroke length of 110mm and a bore diameter of 87.5mm. Table 3.1 below represented the engine specifications used for this experimental works. With the help of an electric panel, an eddy current-type dynamometer was used to apply the load to the engine. Specification of selected Engine. Figs. 3.1 and 3.2 represents the schematic diagram of engine test bench and its photograph of the 3D model experimental setup.

Table 3. 1. Technical specification of the test Engine

Make and model	TM 12-01
Type	Diesel, water cooled, four stroke
Bore and Stroke	87.5mm and 110mm
Number of cylinders	One
Cubic capacity	0.661 litres
Compression ratio	Modified to work at 15,16,17, and 17.5
Peak cylinder pressure	77.5kg/cm^2
Maximum speed	2000rpm
Minimum idle speed	750rpm
Minimum operating speed	1200rpm
Brake mean effective pressure at 1500rpm	6.35kg/cm^2

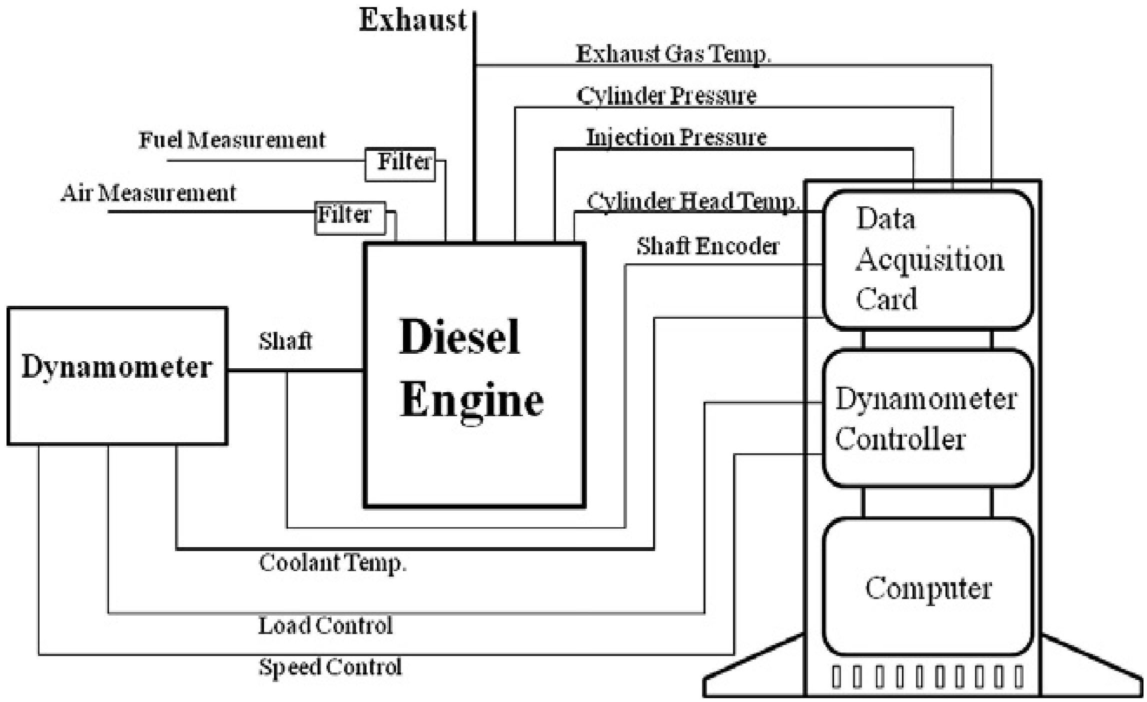

Figure 3. 1. Schematic diagram of engine test bench

Figure 3. 2. Photographic view of TM 12-01 engine experimental setup

(b). Speed measurement

The engine speed was measured using the electronic magnetic pick-up and stored in the data acquisition storage. This speed pick-up was fitted nearly in the flywheel.

(c). Dynamometer

Since the experimental study was carried out under a variety of load situations, a precise and trustworthy load measuring device was essential. This strain gauge-type load cell, an eddy current-type dynamometer, and a loading unit make up the load measurement system of this experimental test rig. By employing a loading device to supply current to the dynamometer, the load was applied. A load cell was used to quantity the load placed on the engine.

An instrument used to measure the torque, force, or power generated by an engine is called a dynamometer. The engine can also be subjected to load or torque using this method. An eddy current dynamometer with a water-cooling system was employed in this investigation. Rapid load setting is made possible by the faster rate of load change offered by eddy current dynamometers. Using a loading unit, the VCR diesel engine was directly connected to the eddy current dynamometer, enabling the application of required loads up to 12kg. A shaft fixed on a crank angle sensor is used to monitor speed, and a strain gauge load cell is used to measure load. Fig. 3.3 represents the eddy current dynamometer.

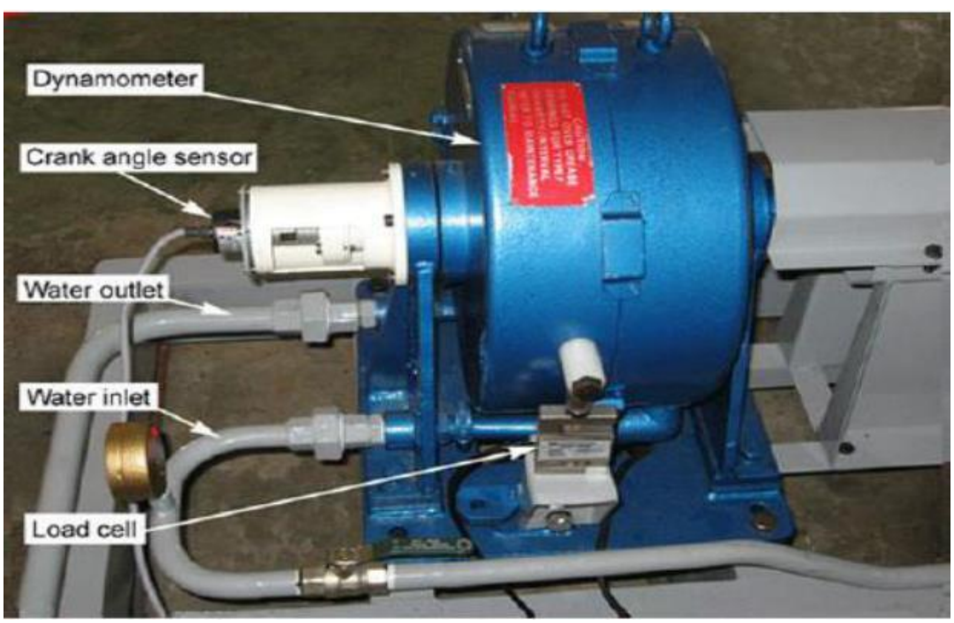

Figure 3. 3. Eddy current dynamometers

(d). Measurement of fuel consumption

Through the measuring device mounted on the data acquisition panel board, fuel is delivered to the engine from the fuel tank. By timing how long it took to use a known quantity of fuel, or 10 cc from the measurement device, the rate of fuel flow was determined.

Figure 3. 4. Measurement of fuel consumption

(e). Emission measurement

Emission gas composition and opacity (smoke number) were measured using the emission measurement equipment. This system is made up of a smoke meter and an exhaust gas analyzer. Oxygen (O_2), carbon monoxide, nitrogen oxides, unburned hydrocarbons, sulphur oxides, and carbon dioxide are all measured by the outlet or exhaust gas analyzer.

(f). Exhaust gas analyzer

Exhaust gas analyzers are devices that are used to study the chemical makeup of outlet gases that are generated by reciprocating engines. The analyzer (Model PEA205) was manufactured in Bengaluru by INDUS Scientific Pvt. Ltd. The device monitors the amounts of nitrogen oxide (NOx), hydrocarbons (HC), sulphur oxides (SOx), carbon monoxide (in % and ppm), carbon dioxide, and oxygen in percentage in the engine exhaust gas.

Figure 3. 5. Exhaust gas analyser

3.4. Methods

The general method to prepare and thermophysical properties characterization of Iron (III) oxide (Fe_2O_3) nanoparticles enhanced diesel composite and to test its performance are shown schematically in the Fig. 3.6 below.

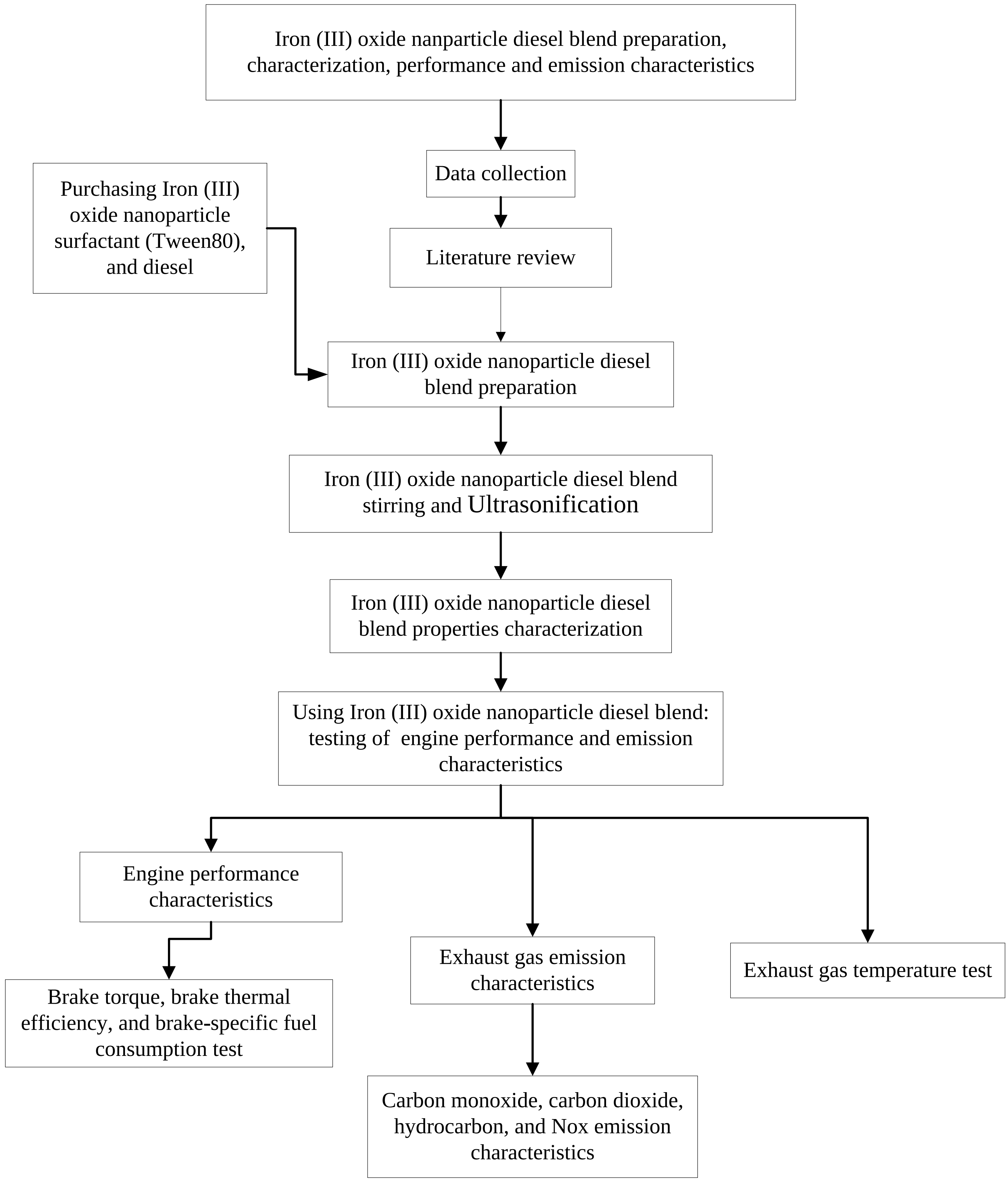

Figure 3. 6. Schematic diagram of preparation, characterization, performance, and emission characteristics of testing of Fe_2O_3 nano-diesel blend

Performance and emission data collection and analysis

a. Appropriate measurement techniques such as exhaust gas analyzers, thermocouples, pressure transducers, and combustion analyzers to collect data during engine operation.
b. Analysed the collected data to evaluate the effect of iron (III) oxide nanoparticles on engine performance, combustion efficiency, emissions reduction, and other relevant parameters.
c. Compared the results obtained from tests with nanoparticle-blended fuels to those from baseline tests to assess the impact of nanoparticle addition.

3.4.1. Nano-enhanced fuel Preparation

Preparing Iron (III) oxide (Fe_2O_3) nanoparticles in the lab typically involves a synthesis method such as chemical reduction, thermal decomposition, or green synthesis. Here's a general procedure for prepared Iron (III) oxide (Fe_2O_3) nanoparticles using a chemical reduction method:

Materials required to prepare nano-diesel fuel:

1. Iron (III) oxide (Fe_2O_3) nanoparticle: additives that improve thermal properties of the diesel
2. Diesel fuel: the base fuel
3. Surfactant (Tween 80): to prevent nanoparticles agglomeration and to maintain the stability of the nano-diesel fuel (nanofluid)

Devices/ apparatus/ instruments required to prepare nano-diesel blend fuel:

1. Iron oxide nanoparticle (Fe_2O_3) weight measurement
2. Magnetic or mechanical stirrer: to dispersed the nanoparticle properly
3. Ultrasonic agitation: to dispersed the nanoparticle properly
4. Mixing chamber: to mix nanoparticles and diesel

Devices/ apparatus/ instruments required to characterize properties of nano-diesel blend fuel:

- ✓ **Particle Size Analyzer**: This is the device to measure the size distribution of nanoparticles in diesel fuel. Techniques include dynamic light scattering (DLS), or scanning electron microscopy (SEM)
- ✓ **Zeta Potential Analyzer**: Zeta potential analysis provides information about the surface charge of nanoparticles dispersed in diesel fuel. This helps assess the stability of the nanoparticle dispersion and predict its behaviours over time.
- ✓ **Spectroscopy Systems**: UV-Vis spectroscopy or infrared spectroscopy (FTIR) can be used to investigate the chemical composition of the nano-enhanced diesel fuel and verify the presence of nanoparticles.

Table 3. 2. Nanoparticle, surfactant, and diesel specification

Discerptions	Diesel	Iron (III) oxide (Fe_2O_3) nanoparticle	Surfactant (Tween 80)
Density	0.85 g/ ml	5.24 g/ml	1.08 g/ml
Size and shape	-	30 nm diameter with spherical shape	-
Supplier	-	Alibaba	-
Model	-	SKU: PO1901	-

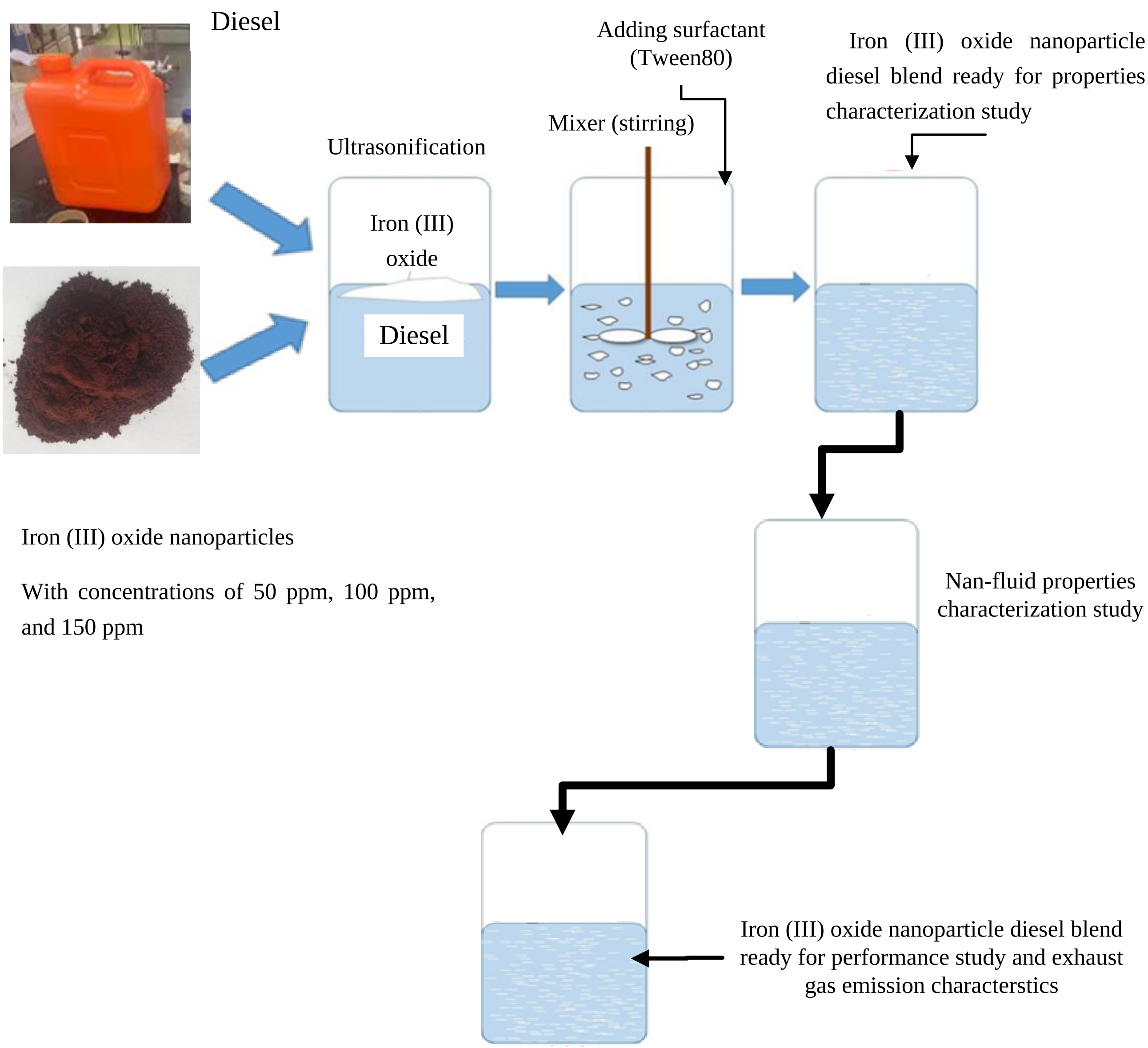

Figure 3. 7. Schematic diagram of performance and emission characteristics of testing of Fe_2O_3 nano-diesel blend

Nanoparticles concentration can be converted in to ppm as follows:

To convert nanoparticle concentrations from percentage (%) to parts per million (ppm) in diesel, the density of the diesel fuel and the density of the nanoparticles must be known. Once finding this information, the concentration in (ppm) can be calculate as using the following formula:

$$Concentration\ (ppm) = \frac{concentration\ (\%) * 10{,}000}{\text{density of the nanoparticles } \left(\frac{\text{g}}{\text{mL}}\right) * \text{density of the nanoparticles } \left(\frac{\text{g}}{\text{mL}}\right)} \ldots.[3.1]$$

Where,

- ✓ Density of iron (III) oxide nanoparticles is approximately 5.24 g/mL
- ✓ Density of pure diesel is approximately 0.85 g/mL

The quantity of nanoparticles in diesel in terms of concentration (%) can be calculate as follows:

$$Concentration\ \% = \frac{concentration\ (ppm) * \text{density of diesel } \left(\frac{\text{g}}{\text{mL}}\right) * \text{density of nanoparticles } \left(\frac{\text{g}}{\text{mL}}\right)}{10{,}000} ..[3.2]$$

The concentration of nanoparticles in terms of % for 50ppm, 100ppm, and 150ppm becomes:

$$Concentration\ \% = \frac{50\ ppm * 0.85\ \text{g/mL} * 5.24\ \text{g/mL}}{10{,}000} = 0.02227\ \%$$

$$Concentration\ \% = \frac{100\ ppm * 0.85\ \text{g/mL} * 5.24\ \text{g/mL}}{10{,}000} = 0.04454\ \%$$

$$Concentration\ \% = \frac{150\ ppm * 0.85\ \text{g/mL} * 5.24\ \text{g/mL}}{10{,}000} = 0.06681\ \%$$

The quantity of nanoparticles in diesel in terms of gram:

Mass of nanoparticle in gram can be found from its density and volume as follows:

$$\rho_{nao} = \frac{Mass_{nano}}{Volume_{nano}} \quad \rightarrow \quad Mass_{nao}(gram) = \rho_{nano*Volume_{nano}} \ldots \ldots \ldots [3.3]$$

The experimental test would be conducted by using 400 ml nanoparticles-diesel blend. From this, 0.02227%, 0.04454%, and 0.06681% would be nanoparticles:

Mass of nanoparticles in diesel with 0.02227%

$$Mass_{nao}(gram) = 5.24\frac{\text{g}}{\text{mL}} * 0.02227\% \text{ of } 400\text{ml} = 5.24\frac{\text{g}}{\text{mL}} * 0.0891\text{ml}$$

$$Mass_{nao}(gram) = 0.5 \text{ gram}$$

Mass of nanoparticles in diesel with 0.04454%

$$Mass_{nao}(gram) = 5.24\frac{\text{g}}{\text{mL}} * 0.04454\% \text{ of } 400\text{ml} = 5.24\frac{\text{g}}{\text{mL}} * 0.178\text{ml}$$

$$Mass_{nao}(gram) = 1 \text{ gram}$$

Mass of nanoparticles in diesel with 0.06681%

$$Mass_{nao}(gram) = 5.24\frac{\text{g}}{\text{mL}} * 0.06681\% \text{ of } 400\text{ml} = 5.24\frac{\text{g}}{\text{mL}} * 0.267$$

$$Mass_{nao}(gram) = 1.5 \text{ gram}$$

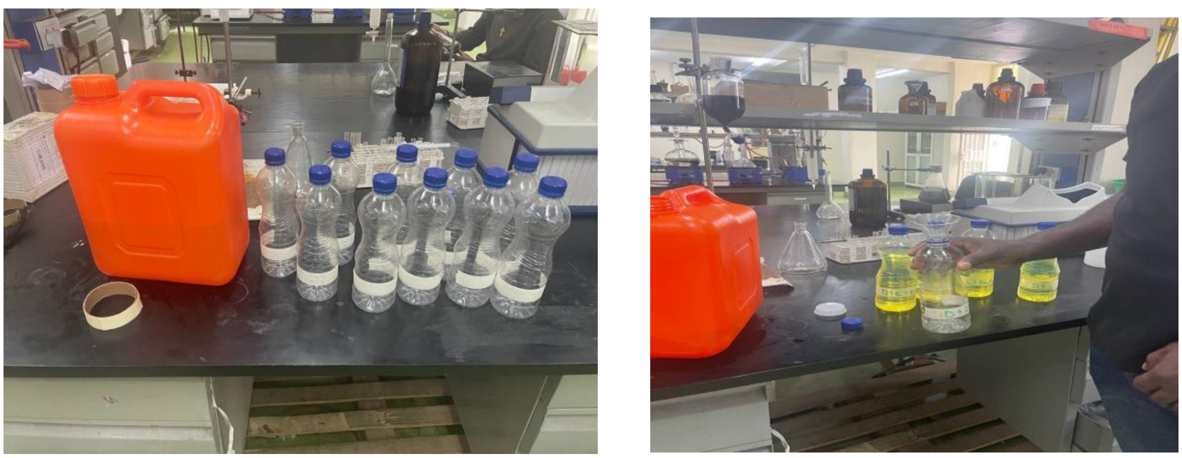

Figure 3. 8. Prepared fuel

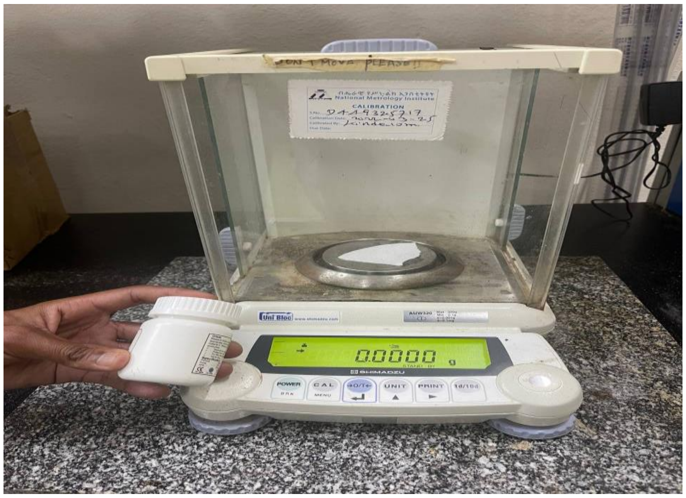

Figure 3. 9. Iron (III) oxide (Fe_2O_3) nanoparticle mass measuring device

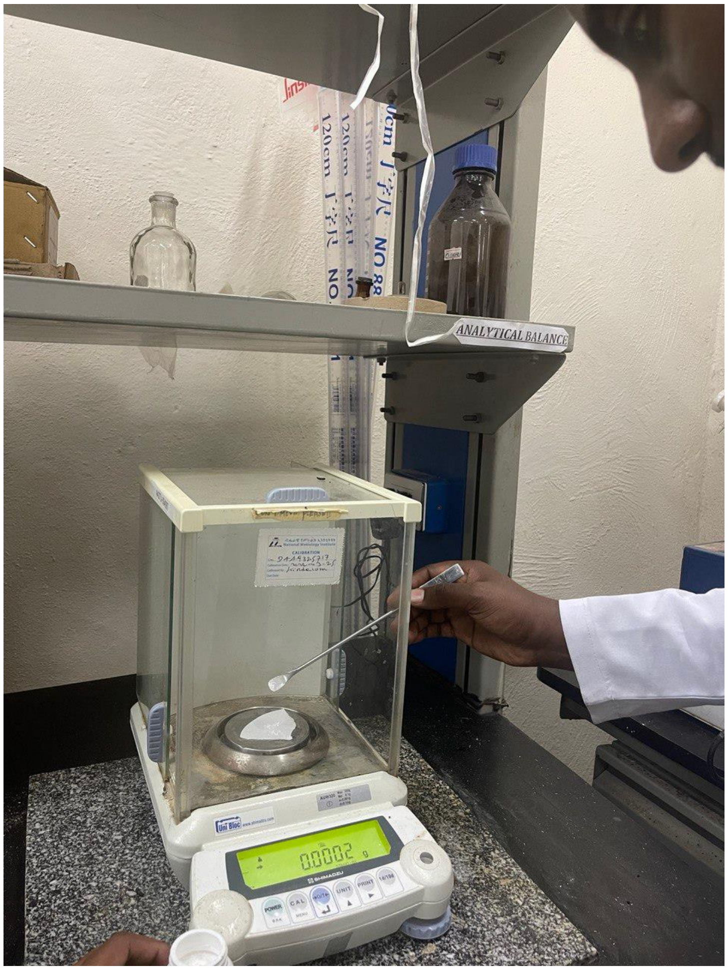

Figure 3. 10. Prepared Iron (III) oxide (Fe_2O_3) nanoparticle with different masses

Figure 3. 11. Made dissolve with fuel and Iron (III) oxide **(Fe_2O_3)** nanoparticle

3.4.2. Engine performance testing using Nano-enhanced fuel

Testing procedure

Firstly, the experiments were conducted on the diesel fuel powered engine with diesel to investigate optimum cooling rate and further all the experiments conduct on the engine by keeping this optimum rate of engine cooling. The performance test was conducted by using diesel as fuel. The following step by step procedures were adopted for the test: -

1. Check the level of lubricating oil in the diesel engine.
2. Give the required electrical networks to the system.
3. Allow water flowing to the engine and the calorimeter and adjust the flow rate.
4. See the level of fuel in the diesel tank.
5. Open the diesel fuel flow raise so that diesel fuel flows to the engine.
6. Release the engine load if any on the dynamometer
7. Allow the diesel engine to run under idling condition for 10 minutes
8. Start the diesel engine by cranking.
9. Repeat the experiment test for different loads and note down the readings.
10. Record all the necessary thermal performance parameters for no load condition
11. After the end of the tests release the load and then switch off the engine.

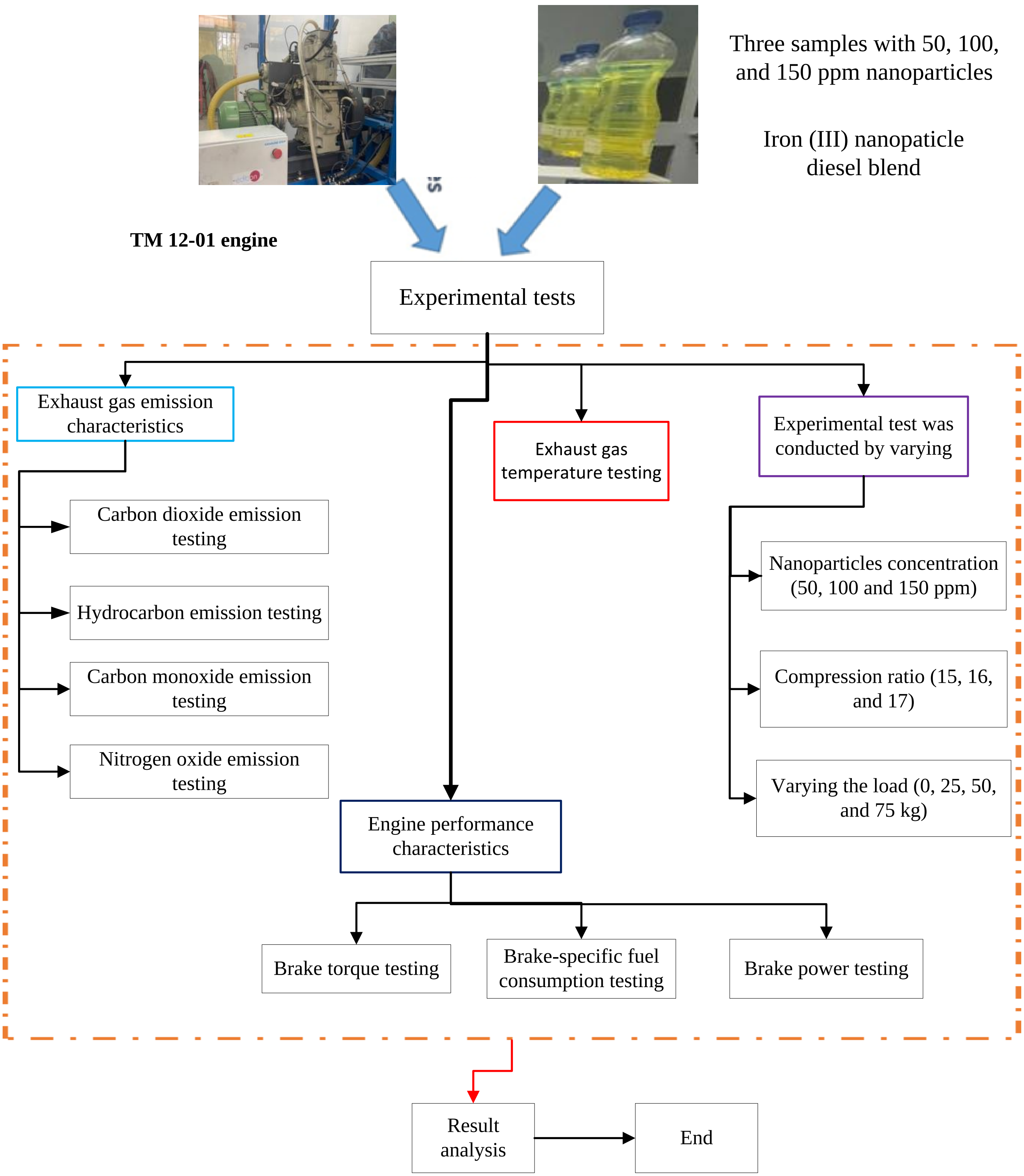

Figure 3. 12. Schematic of emission and performance characterization process of nano-diesel fuel

3.5. Engine test matrix

The engine tested matrixes, including variations in nanoparticle concentration, fuel blend ratios, and operating conditions. And also, the engine operating conditions such as load and compression ratio for each test points are listed below.

Table 3. 3. Engine test matrix for diesel fuel

Fuel	Load (%)	Compression ratio	Fuel	Load (%)	Compression ratio
Diesel	0		Diesel	0	
	25			25	17
	50	15		50	
	75			75	
Diesel	0				
	25				
	50	16			
	75				

Table 3. 4. Engine test matrix for 0.5% Iron (III) oxide (Fe_2O_3) nanoparticles blended with diesel

Nano-Fuel	Load (%)	Compression ratio	Nano-Fuel	Load (%)	Compression ratio
Diesel +0.5%INP	0		Diesel +0.5%INP	0	
	25			25	
	50	15		50	17
	75			75	
Diesel +0.5%INP	0				
	25				
	50	16			
	75				

Table 3. 5. Engine test matrix for 1.0% Iron (III) oxide (Fe_2O_3) nanoparticle blended with diesel fuel

Nano-fuel	Load (%)	Compression ratio	Nano-fuel	Load (%)	Compression ratio
Diesel +1.0% $\mathbf{Fe_2O_3}$	0		Diesel +1.0% Fe_2O_3	0	
	25	**15**		25	
	50			50	17
	75			75	
Diesel +1.0% $\mathbf{Fe_2O_3}$	0				
	25	16			
	50				
	75				

Table 3. 6. Engine test matrix for 1.5% Iron (III) oxide (Fe_2O_3) nanoparticles blended with diesel

Fuel	Load (%)	Compression ratio			
Diesel +1.5% $\mathbf{Fe_2O_3}$	0		Diesel +1.5% Fe_2O_3	0	
	25			25	
	50	15		50	17
	75			75	
Diesel +1.5% $\mathbf{Fe_2O_3}$	0				
	25				
	50	16			
	75				

CHAPTER FOUR
RESULT AND DISCUSSION

4.1. Emission and performance characteristics

In this study, the emission and performance characteristics of CI engine powered with diesel fuel were investigated using Iron (III) oxide (Fe_2O_3) nanoparticles and diesel blended diesel. In this study, the experimental test is divided into two phases: in the first phase, varying the Iron (III) oxide (Fe_2O_3) nanoparticles in the diesel with 50, 100, and 150 ppm, and in the second phase, varying the compression ratio with 15, 16, and 17. Increasing the engine compression ratio can increase the performance of the engine. However, by further increasing the compression ratio above the optimum value, the engine's performance decreased. In this study, three compression ratios were used: 15, 16, and 17, and at the 16-compression ratio, the engine showed better performance. Thus, the discussion is based on the engine compression ratio at 16.

4.1.1. Engine performance testing using Fe_2O_3 nano-diesel blend fuel

The performance of the engine includes brake-specific fuel consumption (SFC), brake thermal efficiency (BTE), brake torque (BT), and exhaust gas temperature (EGT). The experiment is conducted based on variation in Fe_2O_3 nanoparticle concentration (50, 100, and 150 ppm), load, and compression ratio. When introducing nanoparticles into diesel engines, particularly in the context of enhancing engine performance, several factors need consideration, including combustion efficiency, emissions, and durability.

The effect of compression ratio on engine performance

The impact on engine performance at different compression ratios can vary based on the specific nanoparticles used, their concentration, and how they interact with the diesel fuel. At higher compression ratios, diesel engines typically achieve better thermal efficiency due to more complete combustion of the air-fuel mixture. However, extremely high compression ratios can lead to increased temperatures and pressures that may cause knocking or pre-ignition, potentially damaging the engine.

Thus, increasing the engine compression ratio can increase the performance of the engine. However, by further increasing the compression ratio above the optimum value, the engine's performance decreased. In this study, three compression ratios were used: 15, 16, and 17, and at the 16-compression ratio, the engine showed better performance. Thus, the discussion is based on the engine compression ratio at 16.

The effect of the compression ratio on the engine performance is plotted at a load of a load of 25 kg. At 25 kg of load, brake torque and brake power showed the highest performance, and the specific fuel consumption and exhaust gas temperature showed the minimum. Thus, the effect of the compression ratio was analyzed at this load. As shown in Figs. 4.1 and 4.2, the engine performance demonstrated the highest performance. The comparative results using compression ratios 15, 16, and 17 revealed that compression ratios 15 and 17 showed almost similar results, while compression ratio 16 showed the highest performance. The brake torque and brake power increased by increasing the compression ratio from 15 to 16, and decreased by increasing it from 16 to 17. Additionally, the SFC and the outlet gas temperature decreased by decreasing the compression ratio from 15 to 16 and increased by increasing it from 16 to 17.

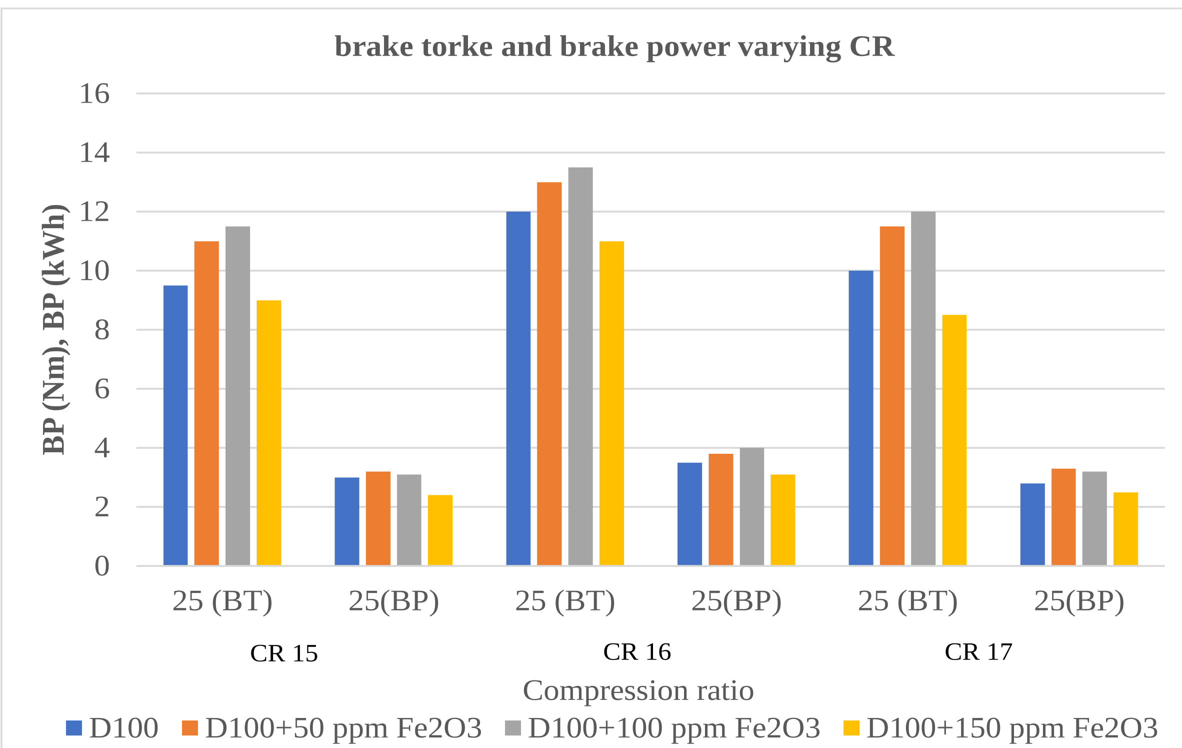

Figure 4. 1. BT and BP with respect to compression ratio at load 25 for (Fe_2O_3) diesel blend

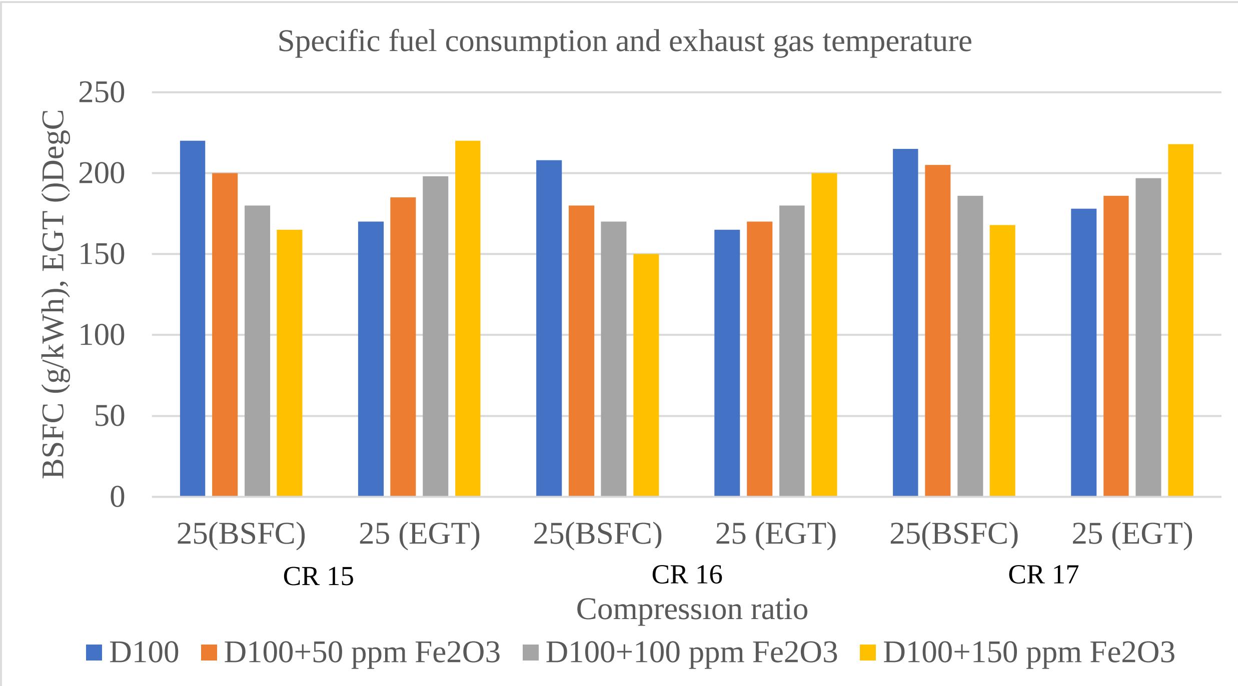

Figure 4. 2. BSFC and EGT with respect to compression ratio at load 25 for (Fe_2O_3) diesel blend fuel

The effect of nano-sized particle concentration on performance of diesel fuel operated engine, including SFC, brake torque, brake power, and outlet gas temperature, was analyzed at compression ratio 16, which demonstrated the highest engine performance as shown in Figs. 4.1 and 4.2.

A. Effect of Fe_2O_3 nanoparticles on specific fuel consumption (SFC)

In order to provide the necessary mechanical power on the engine shaft, the amount of fuel required per unit of time is known as the specific fuel consumption. Fuel qualities, including viscosity, density, and caloric value, are all connected with fuel consumption. As shown in Fig. 4.3, by increasing the load from 0 to 30 kg, the specific fuel consumption gradually decreased, while by further increasing the load from 30 to 75 kg, the specific fuel consumption gradually increased.

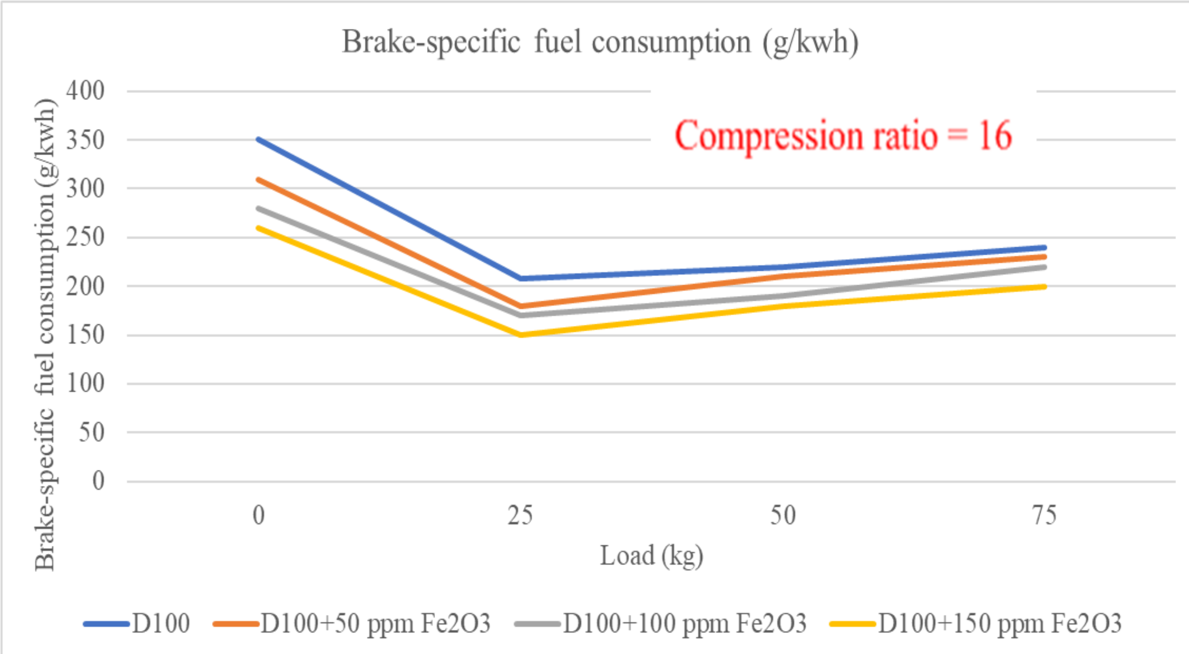

Figure 4. 3. Specific fuel consumption with respect to load for (Fe_2O_3) nano-diesel blend fuel

By adding nanoparticles into diesel fuel, can augment combustion efficiency, leading to the reduction in specific fuel consumption. Metal nanoparticles may enhance fuel atomization, promote more complete combustion, and reduce heat losses, resulting in improved engine efficiency and lower fuel consumption. By increasing the volume fraction of nanoparticles in the diesel, the ignition delay would considerably decrease, resulting in a lower specific fuel consumption. Reduced ignition delay times would result in an improvement in engine output even with the same fuel usage since combustion gases are used up during the engine's exhaust stroke. Diesel fuel + 150 ppm Fe_2O_3 has a shorter ignition delay, hence the lowest value of specific fuel consumption at all loads compared to pure diesel fuel. The dispersion of 150 ppm Fe_2O_3 to pure diesel led to a 27.88% reduction in the SFC value at 25 kg load compared to that in the case of the base diesel fuel alone.

The specific fuel consumption is preferred at 150 ppm Fe_2O_3 nanoparticle concentration. This is because the combustion inside the engine is at its maximum at optimum concentration. At optimum concentration, the thermophysical properties of the nano-diesel blend fuel were improved due to improved thermal conductivity, which had an insignificant effect on the viscosity that affected convection heat transfer by increasing the convection heat transfer coefficient.

B. Effect of Fe_2O_3 nanoparticles on brake power (BP)

Brake power in a diesel engine refers to the mechanical power output of the engine's crankshaft. It represents the useful power delivered by the engine to perform work, such as driving a vehicle or operating machinery. Brake power is typically measured using a dynamometer, which applies a load to the engine's crankshaft to simulate the resistance encountered during actual operation. By measuring the torque applied by the engine and the rotational speed of the crankshaft, the brake power can be calculated using the formula:

$$Brake\ power\ (BP) = \frac{2 * \pi * torque * engine\ speed}{60} \ldots \ldots \ldots ..3.1$$

The maximum brake power is generated at a load of 25 kg. As shown in Fig. 4.4, by increasing the load from 0 to 25 kg, the brake power gradually increased, while by further increasing the load from 25 to 75 kg, the brake power gradually decreased.

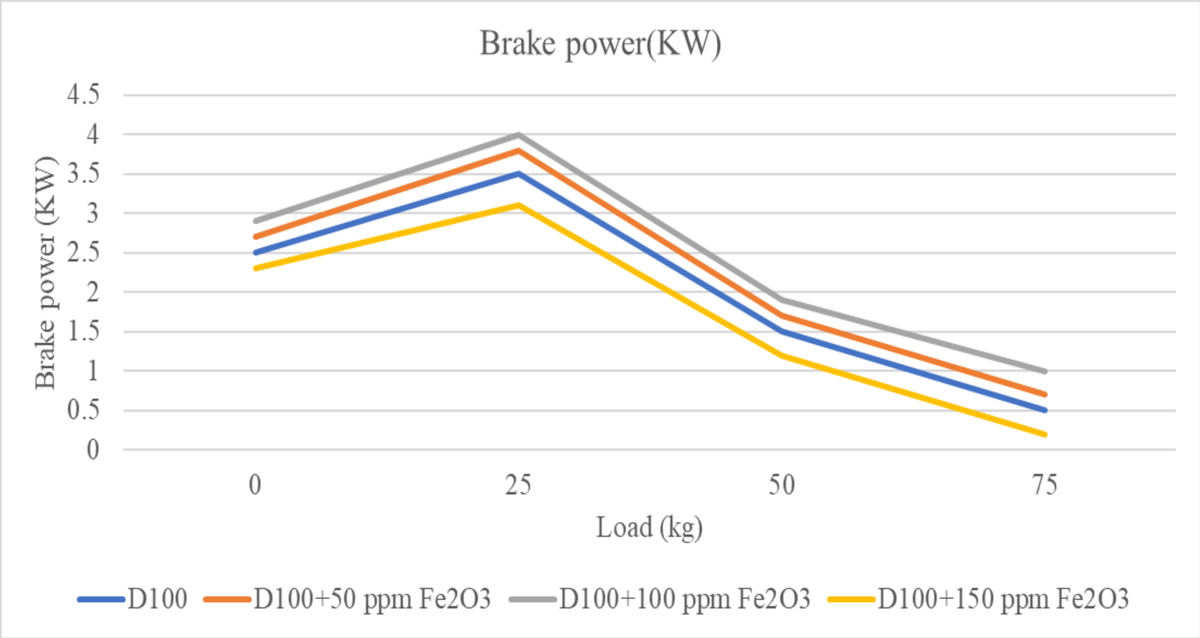

Figure 4. 4. Engine brake power with respect to load for (Fe_2O_3) nano-diesel blend fuel

Adding nanoparticles into diesel fuel can augment combustion efficiency, leading to an increase in brake power. Metal nanoparticles may enhance fuel atomization, promote more complete combustion, and reduce heat losses, resulting in improved engine efficiency. By increasing the volume fraction of nano-sized particles in the diesel, fuel combustion significantly increased, leading to increased engine efficiency. By increasing the concentration of Iron (III) oxide (Fe_2O_3) nanoparticles in the diesel fuel to its optimum level, the brake power increased, while by further increasing the concentration, the brake power decreased. Diesel fuel + 1.0 100 ppm Fe_2O_3 has the highest engine efficiency, hence the highest brake power generation at all loads compared to pure diesel fuel. The addition of 100 ppm Fe_2O_3 to pure diesel led to a 24.0% improvement in the brake power value at 25 kg load compared to that in the case of diesel fuel alone.

As the nanoparticle concentration increased above the optimum level, the thermophysical properties related to brake power decreased. This is because as the concentration increased, the thermal conductivity increased while the calorific value and convection heat transfer rate decreased. Thus, the major problems associated with increasing nanoparticle concentration above its optimum level are that it increases the viscosity, leading to an increased convection heat transfer coefficient and causing incomplete combustion. Additionally, the engine performance can be decreased due to the decreased calorific value of the nano-diesel blend fuel. The calorific value of nanoparticles is lower than that of diesel fuel.

C. Effect of (Fe_2O_3) nanoparticles on brake torque (BT)

The maximum brake torque is generated at a load of 25 kg. As shown in Fig. 4.5, by increasing the load from 0 to 25 kg, the brake torque gradually increased, while by further increasing the load from 25 to 75 kg, the brake torque gradually decreased.

Adding nanoparticles into pure diesel fuel can increase combustion efficiency, leading to an increase in brake power. Metal nanoparticles may enhance fuel atomization, promote more complete combustion, and reduce heat losses, resulting in improved engine efficiency. By increasing the volume fraction of nano-sized particles in the diesel, fuel combustion significantly increased, leading to increased engine efficiency. By increasing the concentration of Iron (III) oxide (Fe_2O_3) nanoparticles in the diesel fuel to its optimum level, the brake torque increased, while by further increasing the concentration, the brake torque decreased. Diesel fuel + 100 ppm Fe_2O_3 has the highest engine efficiency, hence the highest brake torque generation at all loads compared with pure diesel fuel. The dispersion of 100ppm Fe_2O_3 to pure diesel led to a 30.0% increment in the brake torque value at 75 kg load compared to that in the case of pure diesel fuel alone.

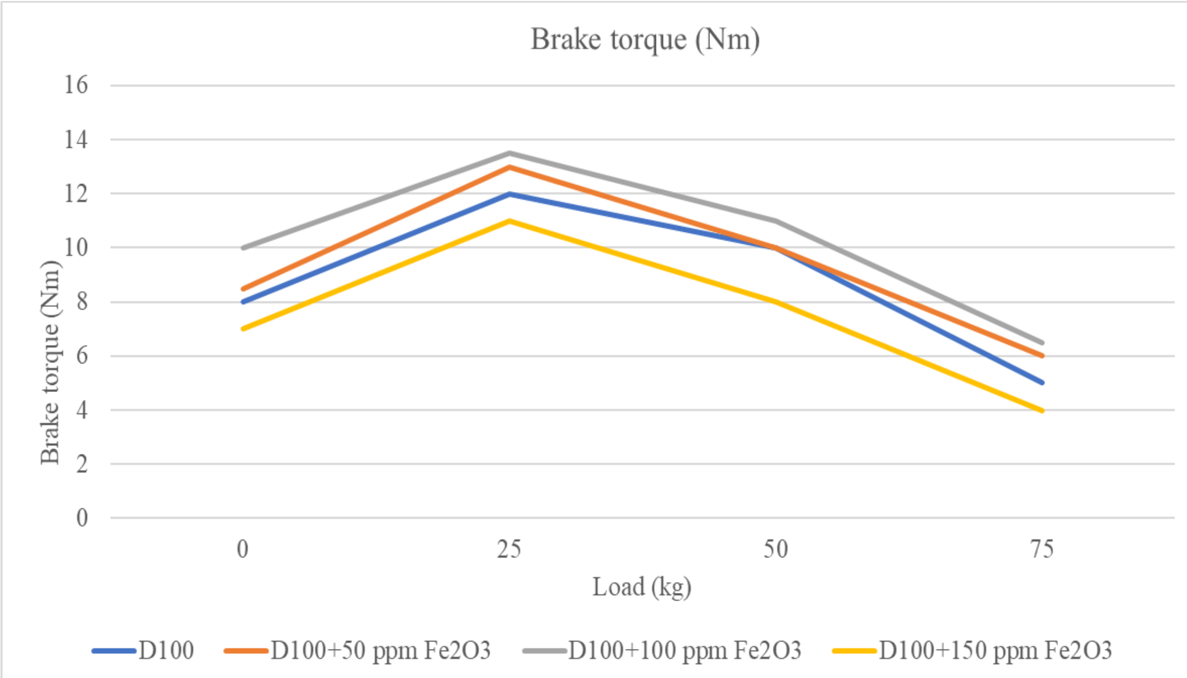

Figure 4. 5. Engine brake torque with respect to load for Fe_2O_3 nano-diesel blend fuel

The influences of nanoparticles on the diesel-powered engine performance of brake torque and brake power showed a similar influence. This is because both parameters are closely dependent on the combustion and calorific value of the fuel. As the nanoparticle volume fraction increases above the optimum level, the thermophysical properties related to brake torque decreased. This is because as the concentration increased, the thermal conductivity increased while the calorific value and convection heat transfer rate decreased. Thus, brake torque increases up to the optimum concentration and decreases above the optimum value due to the decrease in calorific value and convection heat transfer rate caused by the increased fluid viscosity.

D. Effect of Fe_2O_3 nanoparticles on exhaust gas temperature (EGT)

The exhaust gas temperature (EGT) indicates how much fuel energy is used efficiently. Heat loss in the exhaust pipe or an increase in the exhaust temperature are the main causes of reduced heat energy conversion to work. Reduced thermal efficiency is implied by higher exhaust gas temperature data, which is the result of the engine using less heat energy. The exhaust gas temperature is maximum at a load of 0 kg. As shown in Fig. 4.6, by increasing the load from 0 to 75 kg, the exhaust gas temperature gradually decreased.

Adding nanoparticles into pure diesel fuel can increase combustion efficiency, leading to an increase in outlet gas temperature. As the volume fraction of nanoparticles in the diesel increased, fuel combustion significantly increased, leading to increased engine exhaust gas temperature. Diesel fuel + 150 ppm Fe_2O_3 has the highest engine combustion efficiency, hence the highest exhaust gas temperature at all loads compared to pure diesel fuel. The dispersion of 150 ppm Fe_2O_3 to pure diesel led to a 36.0% increment in the outlet gas temperature value at 50 kg load compared to that in the case of pure diesel fuel alone.

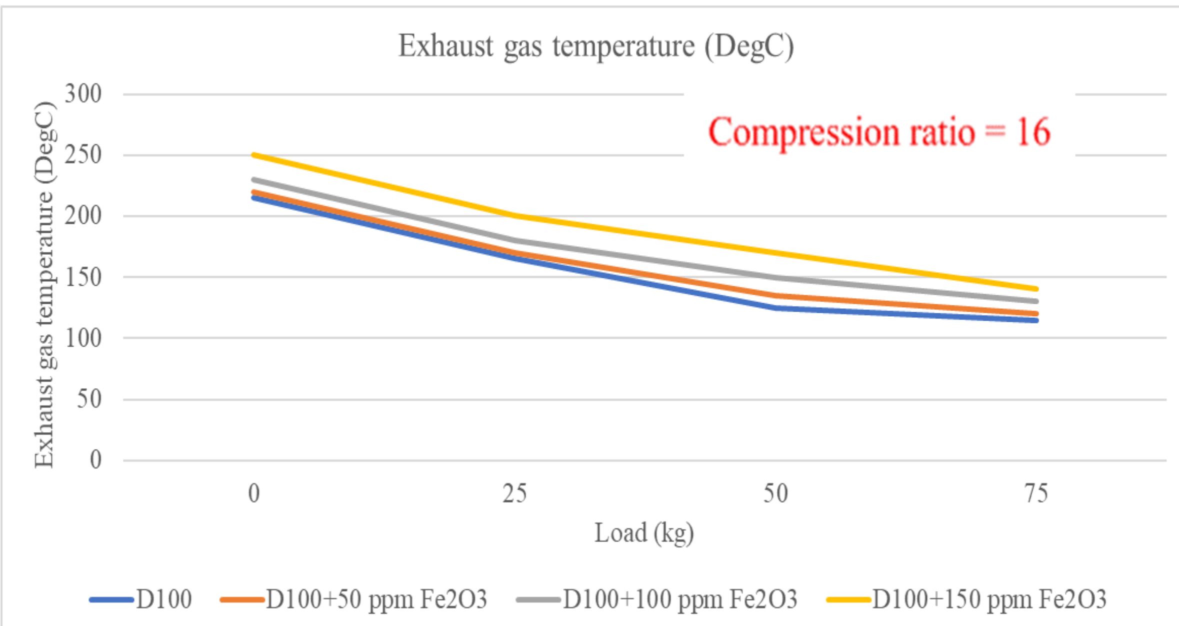

Figure 4. 6. Exhaust gas temperature with respect to load for Fe_2O_3 nano-diesel blend fuel

As the iron (III) oxide nano-sized particle volume fraction increases above the optimum level, the thermophysical properties related to brake power decreased. This is because as the concentration increased, the thermal conductivity increased while the calorific value and convection heat transfer rate decreased. Thus, the major problems associated with increasing nanoparticle concentration above its optimum level are that it increases the viscosity, leading to an increased convection heat transfer coefficient and causing incomplete combustion. Additionally, the engine performance can be decreased due to the decreased calorific value of the nano-diesel blend fuel. The calorific values of nanoparticles particularly, iron (III) oxide is lower than that of pure diesel fuel.

4.1.2. Emission characteristics of diesel engine using nano-enhanced diesel

The emission characteristics of the engine include carbon monoxide exhaust gas emission, carbon dioxide outlet gas emission, unburned hydrocarbon outlet gas emission, and nitrogen oxide emissions.

A. Effect of Fe_2O_3 nanoparticles on carbon monoxide emission

Unburned fuel and CO are produced when there is not enough oxygen present to convert carbon to CO2. The main causes of carbon monoxide formation include incomplete combustion, inadequate oxygen, poor mixing, and locally rich regions. If the combustion cycle is not sufficiently oxygenated and there is sufficient fuel in the fuel-air mixture for the engine to burn, the engine will release carbon monoxide. The carbon monoxide emission of the test engine is maximum at a load of 75 kg. As shown in Fig. 4.7, by increasing the load from 0 to 25 kg, the carbon monoxide emission gradually decreased, while by further increasing the load from 25 to 75 kg, the carbon monoxide outlet gas emissions gradually increased.

Adding nanoparticles to diesel fuel can improve combustion efficiency, leading to increase complete combustion. In the complete combustion process, the amount of carbon monoxide within the exhaust gas is limited. As the volume fraction of nanoparticles in the diesel increased, fuel combustion significantly increased, leading to decreased harmful carbon monoxide emission. This is because the nanoparticles can effectively oxidize the fuel. Diesel fuel + 100 ppm Fe_2O_3 has the lowest engine combustion efficiency, hence reduced harmful carbon monoxide emission at all loads compared with pure diesel fuel. The dispersion of 100 Fe_2O_3 to pure diesel led to a 37.5% reduction in the harmful carbon monoxide emission at 0 kg load compared to that in the case of diesel fuel alone. Adding 50 ppm Fe_2O_3 nanoparticles to diesel can reduce harmful carbon monoxide emissions by 25% at a 75 kg load compared to pure diesel. However, adding 150 ppm Fe_2O_3 nanoparticles to diesel can reduce harmful carbon monoxide emissions by 25% at a 0 kg load compared to pure diesel.

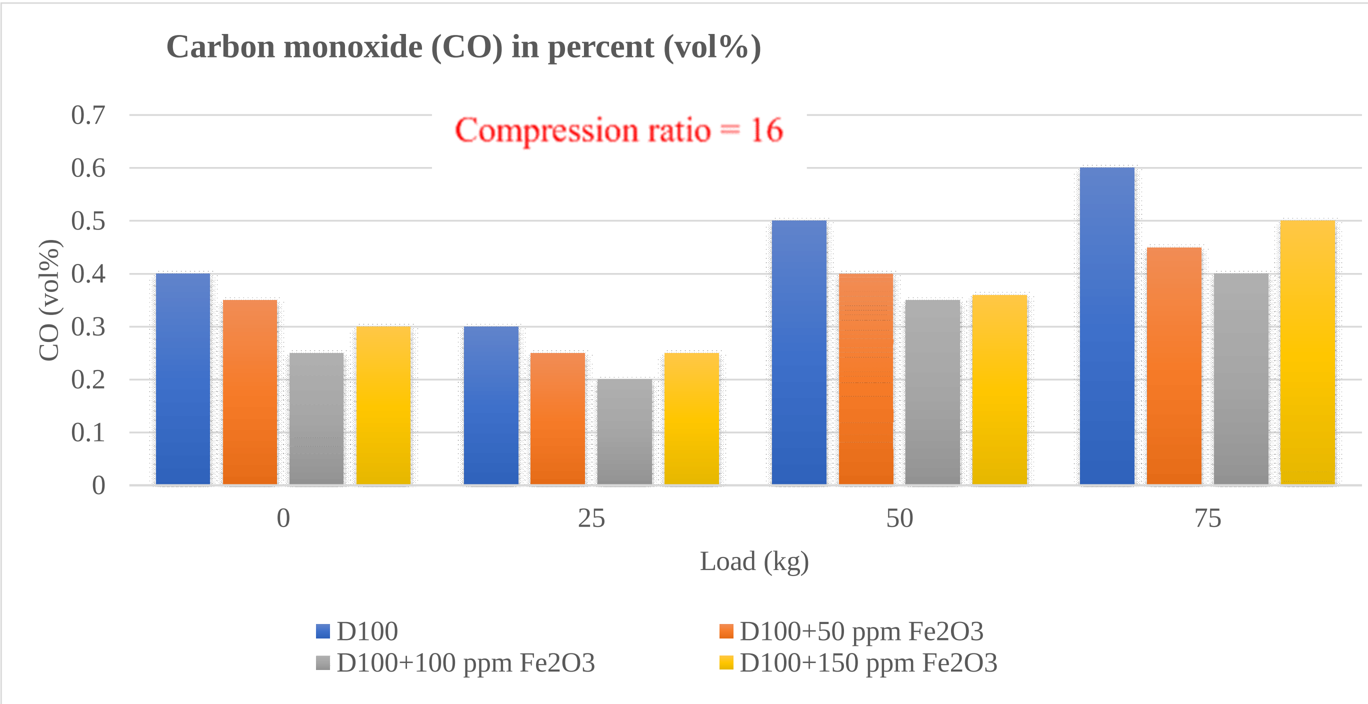

Figure 4. 7. CO emission with respect to load for Fe_2O_3 nano-diesel blend fuel

The reasons that the CO emission reduction demonstrated a maximum at 100 ppm nanoparticle concentration and increased emission above the optimum level are due to the decrease in convection mode of heat transfer rate as a result of increased fluid viscosity. As the nano-sized particle volume fraction increases above the optimum level, the thermophysical properties related to convection heat transfer rate decreased. As the convection heat transfer rate decreases, the combustion performance decreases, causing incomplete combustion; hence, the exhaust gas contains more CO.

B. Effect of Fe_2O_3 nanoparticles on carbon dioxide emission

In a diesel engine, carbon dioxide is one of the primary emissions produced during the burning process of diesel. When diesel fuel burns in the presence of oxygen, it undergoes oxidation, releasing heat energy and producing water vapor and carbon dioxide as byproducts. The carbon dioxide outlet gas emissions of the test engine are maximum at a load of 0 kg. As shown in Fig. 4.8, by increasing the load from 0 to 75 kg, the carbon dioxide emission gradually decreased.

Adding nanoparticles into pure diesel fuel can increase combustion efficiency, leading to increase complete combustion. In the complete combustion process, the amount of carbon dioxide within the outlet or exhaust gas is increased. As the volume fraction of nanoparticles in the diesel increased, fuel combustion significantly increased, leading to decreased engine carbon dioxide emission. Diesel fuel + 100 ppm Fe_2O_3 has the highest engine combustion efficiency, hence the highest carbon dioxide emission at all loads compared with pure diesel fuel. The addition of 100 ppm Fe_2O_3 to pure diesel led to a 33.0% reduction in the carbon dioxide emission value at 75 kg load compared to that in the case of pure diesel fuel alone. Adding 50 ppm Fe_2O_3 nanoparticles to diesel can increase carbon dioxide emissions by 16.67% at a 75 kg load compared to pure diesel. Adding 150 ppm Fe_2O_3 nanoparticles to diesel can also increase carbon dioxide emissions by 25% at a 75 kg load compared to pure diesel.

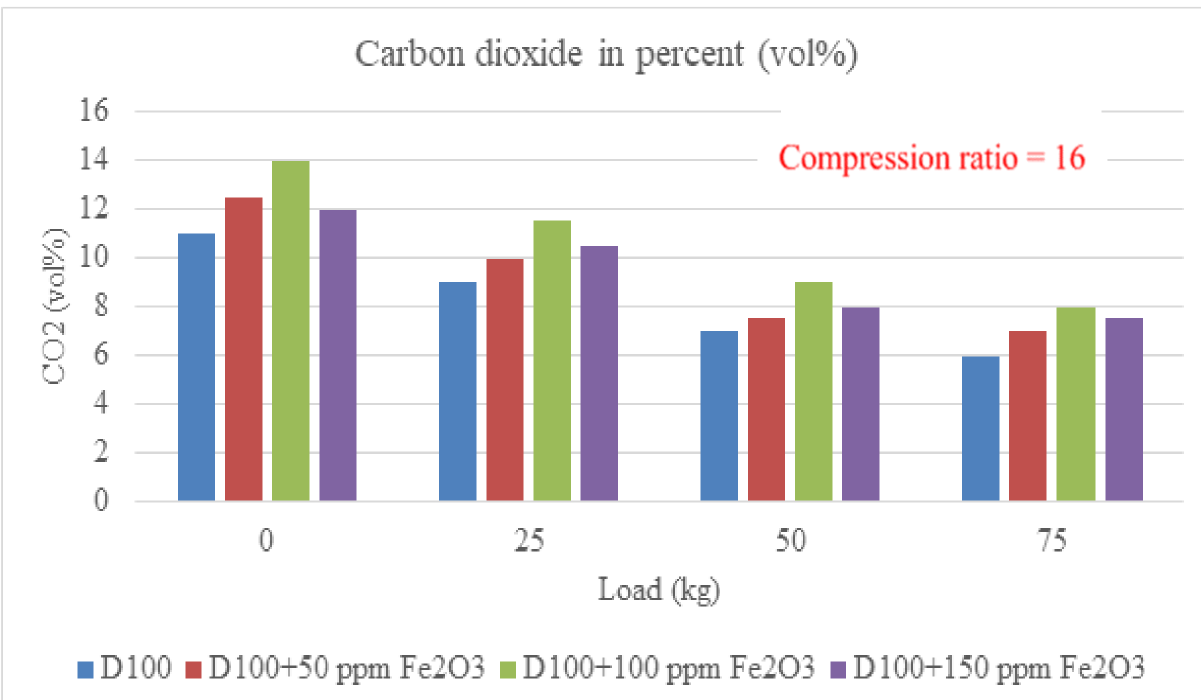

Figure 4. 8. C_2O emission with respect to load for Fe_2O_3 nano-diesel blend fuel

Carbon dioxide emissions are maximum at optimum nanoparticle concentrations. This is because at optimum concentration, the engine has a shorter ignition delay, and thus complete combustion takes place inside the engine, leading to higher carbon dioxide emissions and lower carbon monoxide emissions. At optimum concentration, the impact on convection heat transfer and sediment formation was insignificant. The reduction in convection heat transfer due to the higher concentration of nanoparticles facilitates more carbon monoxide emissions within the exhaust gas.

C. Effect of Fe_2O_3 nanoparticles Hydrocarbon emission

More fuel will be injected into the diesel burning chamber at higher engine loads in order to create a rich air-fuel combination. This will cause more fuel to come into contact with the heated air, which will slow down the rate at which fuel droplets evaporate, leaving less oxygen available for combustion. More unburned hydrocarbon is produced due to the incomplete burning of fuel particles. The unburned hydrocarbon of the test engine is maximum at a load of 75 kg. As shown in Fig. 4.9, by increasing the load from 0 to 75 kg, the unburned hydrocarbon emission gradually increased.

The dispersion of nanoparticles into pure diesel significantly reduces hydrocarbon emissions due to the complete combustion the engine. In the complete combustion process, the amount of unburned hydrocarbon within the outlet or exhaust gas is decreased. As the volume fraction of nanoparticles in the diesel increased, fuel combustion significantly increased, leading to decreased the amount of unburned hydrocarbon emission. Diesel fuel + 150 ppm Fe_2O_3 has the highest engine combustion efficiency, hence the highest reduction in unburned hydrocarbon emission at all loads compared to pure diesel fuel. The dispersion of 150 ppm Fe_2O_3 to pure diesel led to a 29.20% reduction in the unburned hydrocarbon emission at 0 kg load compared to that in the case of pure diesel fuel alone. Adding 50 ppm Fe_2O_3 nanoparticles to diesel can reduce unburned hydrocarbon emissions by 16.7% at a 0 kg load compared to pure diesel. Adding 100 ppm Fe_2O_3 nanoparticles to diesel can also reduce unburned hydrocarbon emissions by 25% at a 0 kg load compared to pure diesel.

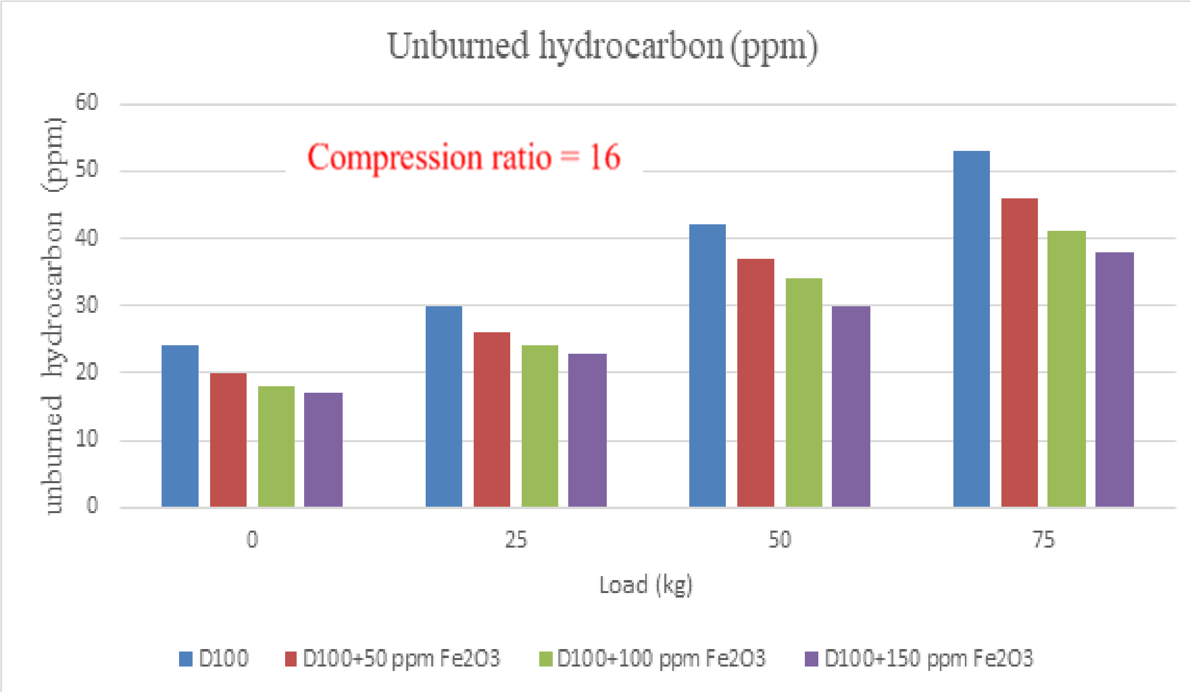

Figure 4. 9. Unburned hydrocarbon emission with respect to load Fe_2O_3 nano-diesel blend fuel

The unburned hydrocarbon reduction is closely dependent on the engine combustion performance. The reduction in convection heat transfer due to the higher volume fraction of nanoparticles facilitates the escape of unburned hydrocarbons within the exhaust gas. Additionally, increasing the volume fraction of nanoparticles above the optimum value increase the ignition delay and hence reduces combustion efficiency.

D. Effect of Fe_2O_3 nanoparticles Nitrogen oxide emission

Due to the high activation energy and temperature during fuel combustion, nitrogen oxide is produced. The unburned hydrocarbon of the test engine is maximum at a load of 0 kg. As shown in Fig. 4.10, by increasing the load from 0 to 75 kg, nitrogen oxide emission gradually decreased. Adding nanoparticles into pure diesel fuel can increase combustion efficiency, leading to increase complete combustion. In the complete combustion process, the amount of nitrogen oxide within the outlet or exhaust gas is decreased. As the volume fraction of nanoparticles in the diesel increased, fuel combustion significantly increased, leading to decreased nitrogen oxide emission. Diesel fuel + 150 ppm Fe_2O_3 has the highest engine combustion efficiency, hence the highest nitrogen oxide emission at all loads compared with pure diesel fuel. The dispersion of 150 ppm Fe_2O_3 to pure diesel led to a 20.80% reduction in the nitrogen oxide emission value at 75 kg load compared to that in the case of pure diesel fuel alone. Adding 50 ppm Fe_2O_3 nanoparticles to diesel can reduce nitrogen oxide emissions by 8.33% at a 75 kg load compared to pure diesel. Adding 100 ppm Fe_2O_3 nanoparticles to diesel can also reduce unburned hydrocarbon emissions by 16.7% at a 75 kg load compared to pure diesel.

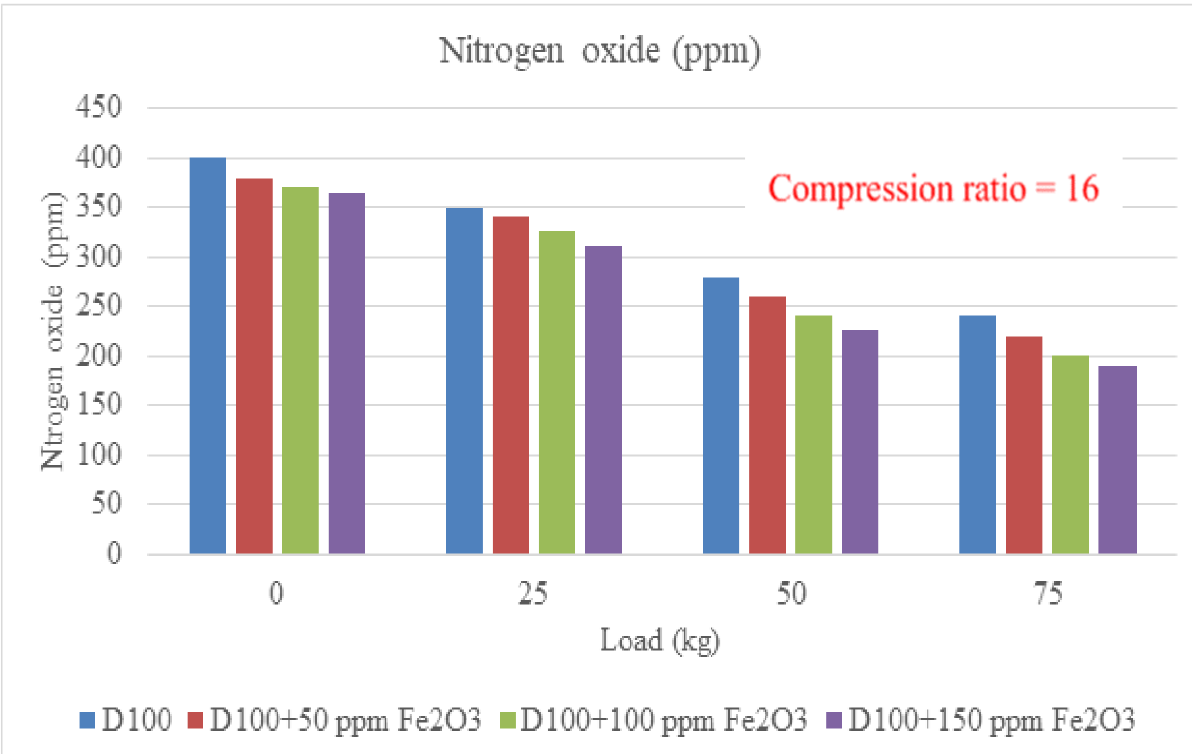

Figure 4. 10. Nitrogen oxide emission with respect to load Fe_2O_3 nano-diesel blend fuel

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Diesel fuel, derived from crude oil, has been a staple in transportation and industry for decades due to its energy density and efficiency. However, concerns over emissions and the environmental effects of fossil fuels have led to research into alternative fuels and additives to increase diesel operated engine performance and reduce emissions. One area of interest is the utilization of nanoparticles as additives in diesel fuel, commonly referred to as nano-enhanced diesel. In this study, the effect of Fe_2O_3 nanoparticles on engine performance and outlet gas emission characteristics were studied. Based on the study analysis and the results obtained, the following important conclusions are drawn:

- ✓ Adding iron (III) oxide nanoparticles to diesel reduced various emissions, including carbon monoxide, nitrogen oxide, and unburned hydrocarbon, while carbon dioxide outlet gas emissions was increased.
- ✓ Adding iron (III) oxide nanoparticles to diesel reduced specific fuel consumption and increased outlet gas temperature. However, brake power and brake torque increased up to the optimum concentration while decreasing above the optimum concentration of nanoparticles.
- ✓ Increasing the load up to 25 kg, brake torque and brake power increased, while those above 25 kg decreased. Additionally, the specific fuel consumption decreased up to a load of 25 kg and decreased above 25 kg. Additionally, the outlet gas temperature linearly decreased as the load increased.
- ✓ The engine performance showed a higher compression ratio of 16 compared with 15 and 17 compression ratios.
- ✓ At 150 ppm Fe_2O_3, nanoparticles diesel blend, reduced unburned hydrocarbon emission by 29.20% at 0 kg load, increased exhaust gas temperature by 36.0% at 50 kg load, reduced specific fuel consumption by 27.88% at 25 kg load, and reduced

nitrogen oxide emission by 20.8% at 75 kg load. compared to that in the case of pure diesel fuel alone.

- ✓ At 100 ppm Fe_2O_3, nanoparticles diesel blend, reduced harmful carbon monoxide emission by 37.5% at 0 kg load, reduced carbon dioxide emission by 33.0% at 75 kg load, increased brake torque by 30.0% at 75 kg load, reduced nitrogen oxide emission by 20.8% at 75 kg load, and increased brake power by 24.0% 25 kg at load compared to that in the case of diesel fuel alone.
- ✓ In conclusion, the optimum concentration of iron (III) oxide nanoparticles is 100 ppm for both emission reduction and performance improvement cases.

5.2. RECOMMENDATIONS

Based on deep understanding of the study in general, the following recommendations and future directions can be taken into consideration as future work:

- ✓ The addition of Iron (III) oxide (Fe_2O_3) nanoparticles can increase engine performance and minimize emissions.
- ✓ The effect of nanoparticle size, shape, and dimensions on the performance of the engine and emission reduction characteristics needs further study.
- ✓ The effect of low-density carbon-based nanoparticles on the performance of the engine and emission reduction characteristics needs further study.
- ✓ The environmental impacts of nanoparticles required a study.
- ✓ Parametric optimization of engine performance using nanoparticles, related to engine performance, emission characteristics, and cost, to find the best nanoparticle type, optimum concentration, optimum particle size, shape and dimension requires a study.

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APPENDICES

Technical specification of Engine test emission and performance chrematistics measured data

Table A- 1. Specific fuel consumption Fe_2O_3 nano-diesel blend fuel

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	350	309	280	260
25	208	180	170	150
50	220	210	190	180
75	240	230	220	200

Table A- 2. Engine brake power of Fe_2O_3 nano-diesel blend fuel (KW)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	2.5	2.7	2.9	2.3
25	3.5	3.8	4	3.1
50	1.5	1.7	1.9	1.2
75	0.5	0.7	1	0.2

Table A- 3. Engine brake torque of Fe_2O_3 nano-diesel blend fuel (Nm)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	8	8.5	10	7
25	12	13	13.5	11
50	10	10	11	8
75	5	6	6.5	4

Table A- 4. Exhaust gas temperature for Fe_2O_3 nano-diesel blend fuel (DegC)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	215	220	230	250
25	165	170	180	200
50	125	135	150	170
75	115	120	130	140

Table A- 5. CO emission of Fe_2O_3 nano-diesel blend fuel (%)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	0.4	0.35	0.25	0.3
25	0.3	0.25	0.2	0.25
50	0.5	0.4	0.35	0.36
75	0.6	0.45	0.4	0.5

Table A- 6. C_2O emission of Fe_2O_3 nano-diesel blend fuel (%)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	11	12.5	14	12
25	9	10	11.5	10.5
50	7	7.5	9	8
75	6	7	8	7.5

Table A- 7. Unburned hydrocarbon emission of Fe_2O_3 nano-diesel blend fuel (ppm)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	24	20	18	17
25	30	26	24	23

50	42	37	34	30
75	53	46	41	38

Table A- 8. Nitrogen oxide emission of Fe_2O_3 nano-diesel blend fuel (ppm)

Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
0	400	380	370	365
25	350	340	325	310
50	280	260	240	225
75	240	220	200	190

Table A- 9. BT, BP, SFC, AND EGT data of Fe_2O_3 nano-diesel blend fuel

Compression ratio	Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
CR 15	25 (BT)	9.5	11	11.5	9
	25(BP)	3	3.2	3.1	2.4
CR16	25 (BT)	12	13	13.5	11
	25(BP)	3.5	3.8	4	3.1
CR17	25 (BT)	10	11.5	12	8.5
	25(BP)	2.8	3.3	3.2	2.5
	Load	D100	D100+50 ppm Fe_2O_3	D100+100 ppm Fe_2O_3	D100+150 ppm Fe_2O_3
CR 15	25(BSFC)	220	200	180	165
	25 (EGT)	170	185	198	220
CR16	25(BSFC)	208	180	170	150

	25 (EGT)	165	170	180	200
CR17	25(BSFC)	215	205	186	168
	25 (EGT)	178	186	197	218