

**Exploring the Impact of Water Port Injection on Performance and  
Emission Characteristics of Diesel-Ethanol Fueled Diesel Engine**



Tadesse Habtamu Andualem

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's in Automotive Engineering**

**Office of Graduate Studies  
Adama Science and Technology University**

May, 2024  
Adama, Ethiopia

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## DECLARATION

First, I hereby declare this thesis entitled “**Exploring the Impact of Water Port Injection on Performance and Emission Characteristics of Diesel-Ethanol Fueled Diesel Engine**” 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.

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I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “**Exploring the Impact of Water Port Injection on Performance and Emission Characteristics of Diesel-Ethanol Fueled Diesel Engine**” prepared under my guidance by Tadesse Habtamu Andualem submitted in partial fulfillment of the requirements for the degree of Masters of Science in Automotive Engineering. Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Getachew Alemayehu (PhD) \_\_\_\_\_

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We, the undersigned, members of the Board of Examiners of the thesis by Tadesse Habtamu Andualem have read and evaluated the thesis entitled “Exploring the Impact of Water Port Injection on Performance and Emission Characteristics of Diesel/Ethanol Fueled Diesel Engine” and examined the candidate during the 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 Automotive Engineering.

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## ACRONYMS AND SYMBOLS

|                   |  |
|-------------------|--|
| AFR               | Air fuel ratio                         |
| ATDC              | After top dead center                  |
| Bp                | Brake-power                            |
| BSFC              | Brake-specific fuel consumptions       |
| BTDC              | Before top dead center                 |
| BTE               | Brake thermal efficiency               |
| °C                | Degree centigrade                      |
| CFD               | Computational fluid dynamics           |
| CI                | Compression ignition                   |
| CNG               | Compressed natural gas                 |
| CO                | Carbon monoxide                        |
| DI                | Direct injection                       |
| DPF               | Diesel particulate filter              |
| DuF               | Dual fuel                              |
| EGR               | Exhaust gas recirculation              |
| EV                | Electric vehicles                      |
| GB                | Gigabyte                               |
| GW                | Giga watt                              |
| HC                | Hydrocarbon                            |
| HCCI              | Homogenous charge compression ignition |
| HP                | Horse power                            |
| HTL               | Hydrothermal liquefaction              |
| kg                | Kilogram                               |
| Kg/m <sup>3</sup> | Kilogram per cubic meters              |
| Kg/h              | Kilogram per hours                     |
| KJ/kg             | kilojoule per kilogram                 |
| KWh               | Kilowatt hour                          |
| LNT               | Lean net temperature                   |
| LPG               | Liquefied petroleum gas                |

|                  |                                   |
|------------------|-----------------------------------|
| LTC              | Lower temperature compositions    |
| MPas             | Mega pascals                      |
| mm               | Millimeter                        |
| NO <sub>x</sub>  | Nitrogen monoxide                 |
| RSM              | Response surface technology       |
| PM               | Particulate matter                |
| RPM              | Revolution per minutes            |
| SCR              | Selective catalytic reductions    |
| SO <sub>2</sub>  | Sulphur dioxide                   |
| STP              | Standard temperature and pressure |
| THC              | Total hydrocarbon                 |
| TiO <sub>2</sub> | Titanium oxide                    |
| TME              | Thumb methyl ester                |
| W/D              | Water diesel emulsifications      |

## ABSTRACT

*The primary focus of this work was exploring water port injections and pre-mixed ethanol injection, which are replaceable, substitutable, and used in diesel engines that didn't require complex engine modifications. The researchers had shown that biodiesel engines discharge NO<sub>x</sub> into the air. Many researchers use emulsions, SCR, fumigations, and other methods to decrease emissions and increase performance and had already found the minimizations of NO<sub>x</sub> emissions but there was trade of emissions and performance loss with complex and used expensive materials. Water and ethanol have lower lubricity compared to diesel fuel, potentially causing engine wear and incomplete combustion; hence, it's crucial to assess injection quantities and engine configurations. The experiments were taken with ethanol content at 5%, 10%, 15%, and 20% with water port additions at a rate of 27g/minute. Port water injection creates space in the combustion chamber because of droplets with the property of viscosity, and high internal pressure, which reduces particulate matter and vibrations. The other property of water is that it lowers peak temperatures and increases the ignition delay to reduce NO<sub>x</sub> emissions while injecting pre-mixed ethanol helps to increase combustion due to its high oxygen content. The experiment on emissions and performance was conducted using a single-cylinder, four-stroke diesel engine equipped with a water port injection system. Four different experimental setups were analyzed: pure diesel, water port injections, pre-mixed ethanol, and a combination of water port injections with pre-mixed ethanol. Measurements included fuel flow rate, brake-specific fuel consumption (BSFC), and emissions. Among the various ethanol blends tested, the mixture of 15% ethanol with water injected at a rate of 27g/minute produced the best results. This blend, combined with water port injections, resulted in a reduction of CO and NO<sub>x</sub> emissions by 17.05% and 17.685%, respectively, while improving combustion efficiency and achieving a 2.29% saves in BSFC. However, it led to a 6.82% rise in HC emissions. The intake manifold water injection system was identified as an effective method for reducing NO<sub>x</sub> emissions, offering a straightforward and cost-effective solution.*

**Keywords:** Direct Injection, Emissions, Performance, Pre-Mixed Ethanol, Single-Cylinder, Water

# CHAPTER ONE

## 1. INTRODUCTION

### 1.1. Back ground

Water injection controls combustion temperatures to reduce NO<sub>x</sub> emissions, and improves thermal efficiency, while ethanol injection introduces ethanol directly into the intake manifold to take more combustion chamber since it has more oxygen content. The constant depletion of fuel resources brought about by the growing demand for energy consumption from industrialization and other sectors propels the development and use of unconventional oil. Biodiesel is one of the available unconventional petroleum oils that receive significant attention globally (Patel *et al.*, 2022).

Alternative fuels can assist to solve the energy issues brought on by the depletion of fossil fuels. A study was also done on the operation and discharge characteristics of different engine types when biodiesel was used (Altarazi *et al.*, 2022).

The pioneer of diesel engines, Rudolf Diesel, explains how vegetable oil was initially used to power compression ignition engines. It was powered by peanut oil. Because of the growing cost of crude oil and the depletion of fossil fuel reserves, vegetable oils are being explored as potential diesel fuel alternatives. Known as alternative fuels, they consist of ethanol and methanol as well as biodiesel, which is essentially vegetable oil (Karimmaslak *et al.*, 2021).

As fossil fuels were rapidly depleted and their environmental implications became apparent, alternative fuels emerged that could meet energy requirements and emission laws. As a result, the need for biofuels and other alternatives to fossil fuels is increasing. Alcohols are easily obtainable, store well, and burn easily, making them one of the biofuels that have proven to be an efficient alternative fuel. Alcohol and ethanol are suitable fuels for spark-ignition engines because of their high cetane and octane values (Morsy, 2015).

By returning a portion of the exhaust gas to the engine's intake manifold, the EGR system warms fuel combustion by introducing fresh air. It affects the emissions and performance of diesel engines. Elevated EGR temperatures negatively impact both the efficiency of the braking system and SO<sub>2</sub> emissions. Engine efficiency can be improved and emissions can be decreased by EGR cooling, or lowering the EGR temperature (Hadhoum *et al.*, 2021).

Post-combustion methods for reducing NO<sub>x</sub> emissions in diesel engines include three-way catalytic converters and selective catalytic reduction (SCR). Three-way catalytic converters utilize expensive materials such as platinum, palladium, and rubidium, which can elevate engine temperatures. SCR involves injecting ammonia in the presence of a catalyst, achieving up to a 90% reduction in NO<sub>x</sub> emissions. However, SCR is mainly used in heavy-duty vehicles and is seldom applied to passenger cars due to the lower temperature of exhaust gases. Water emulsions can also decrease NO<sub>x</sub> emissions by absorbing heat through water vapor, achieving reductions of up to 50%. There are three main methods for incorporating water into diesel engines: adding water-diesel emulsions, fumigating water into the intake manifold, and using a separate injector to directly inject water into the cylinder (Tesfa *et al.*, 2012).

These injection systems are listed in below with their definitions and limitations

**Direct water port injection:** This type of intake manifold injection cools the air and increases air density by introducing water into the engine's intake manifold. Thus, knocking tendencies are addressed, peak combustion temperatures are lowered, NO<sub>x</sub> emissions are reduced, and combustion efficiency is improved. Further water storage components and engine changes are required for this strategy to be implemented effectively. Direct water injection in the intake manifold is a technique that involves directly introducing water into the engine's intake stream in order to maximize engine performance and fuel efficiency. This method's main goals are to enhance the air-fuel mixture's density, reduce the temperature of the intake air, and minimize the unplanned of engine knock. Direct water injection can be applied in two primary manners: direct injection and indirect injection.

In the practice of direct water injection, liquid water is directly introduced into the intake stream. The strategic placement of the water nozzle plays a vital role in ensuring the highest efficiency. A practical amount of water is advised for this technique, accompanied by precise recommendations tailored to various engine categories such as V8 diesel engines.

**Benefits and application:** Direct water injection can lead to improved fuel economy and performance, especially in diesel engines. It is essential to introduce water as a mist into the intake air stream for effective results. This technique can be particularly beneficial for diesel engines, showing documented gains in efficiency.

The theory behind water injection involves utilizing water evaporation to cool the cold side of the heat reservoir, enhancing efficiency without significantly increasing fuel consumption.

Studies have shown that introducing water into the intake manifold can impact combustion time in spark ignition engines and increase fresh mixture density due to vaporization.

**Fumigation water injection method:** Fumigation water injection is a simple process where water is added into the air intake through a carburetor or throttle body injector, enhancing air density and cooling, and potentially reducing NO<sub>x</sub> emissions by reducing peak combustion temperatures. Fumigation water injection is a method that involves introducing water into the intake air of an engine.

This technique is considered one of the simplest ways to add water to the engine. Here is an introduction to fumigation water injection based on the provided search results.

Fumigation water injection is a process where atomized fuel, in this case, water, is introduced into the intake air of an engine. This method offers limited control over injection parameters like timing or spatial coordinates.

However, it is essential to ensure that the cleaned water totally evaporates in the intake air to prevent engine damage.

It is advised to fumigate water vapor rather than liquid water in order to carry out fumigation water injection efficiently. In some situations, steam or engine waste heat can be used to create water vapor. This method requires consideration of logistics for providing a water supply. Fumigation water injection can help reduce NO<sub>x</sub> emissions in diesel engines but may not offer as much control over parameters as other methods like emulsions or direct injection. It is crucial to balance the benefits of reduced emissions with potential challenges such as logistics and ensuring complete evaporation of fumigated water.

**Emulsification water injection method:** is a method of injecting water into diesel fuel, creating a stable emulsion that absorbs thermal energy during combustion. This reduces maximum temperatures, reducing nitrogen oxide emissions and improving fuel efficiency. However, it may require modifications to the fuel system and stability issues. The process of "emulsification water injection," which involves adding water to the combustion chamber, uses emulsified fuel. One of the many benefits of emulsification water injection is that water enters the diesel fuel spray droplets directly. After that, these droplets are introduced into the combustion flame region, which produces emissions:

- **NO<sub>x</sub> reduction:** Emulsions can reduce NO<sub>x</sub> emissions when the required amount of water is applied.

- Emulsions have the effect of improving fuel spray atomization and mixing, which principals to reduced discharges and increased ignition effectiveness.
- **PM emission reduction:** Emulsions can reduce both NO<sub>x</sub> and PM emissions simultaneously; but, in terms of overall reduction, PM reduction may be more effective than NO<sub>x</sub> reduction.

Nevertheless, emulsification water injection has certain restrictions: The injection system's delivery capacity is the limiting factor for water emulsions. If emulsions are to be employed without engine changes, are the maximum water content and NO<sub>x</sub> reduction percentage restricted to approximately less.

When using emulsions, the engine might not be able to reach its full power and might instead operate in a mild condition. When a solution of ethanol and water fumigates into the input air, the emissions from instrumentation on single-cylinder diesel engines are impacted. The fuels consist of ethanol volume combinations of 25%, 50%, 75%, and 100%. For these operating modes, measurements and comparisons are made of the fuel consumption, temperature, and exhaust emissions, including carbon monoxide, nitrogen monoxide, and unprocessed HC. These findings showed that whereas pure ethanol fumigation generally results in a little rise in NO<sub>x</sub> emissions, water helps to reduce them. Each ethanol-water fumigation combination results in CO and HC emissions, low exhaust gas temperatures, and higher fuel consumption. When ethanol-water mixes are fumigated, there is a modest gain in energy and thermal efficiency. The results demonstrated that ethanol-water fumigation reduces NO<sub>x</sub> emissions and improves diesel engine energy efficiency(H. Patil, 2017).

The use of water injection, both as an emulsion and through separate injection methods such as plenary, port, and direct port injection, has shown it to be a cost-effective, adaptable, compact, and efficient solution for modern engines. Various studies have examined port water injection, occasionally mixed with alcohol to prevent freezing in cold weather. While port injection has its benefits, it requires significantly more water than direct injection to achieve similar knock suppression levels. The M-Twin Turbo engine, for instance, demonstrated a 4% increase in fuel efficiency with port water and ethanol injection during the New European Driving Cycle (NEDC). Worm et al. reported that this approach led to a maximum increase of 5% in net mean pressure and a 34% improvement in thermal efficiency.

However, achieving these benefits required water flow rates up to three times the fuel flow rates, underscoring the balance between the method's effectiveness and the necessary water volume (Eshan Singh, Ponnya Hlaing., 2020).

The power plant is equipped with an advanced fuel injection system featuring multiple injectors: two direct injectors and two port-fuel injectors, enabling the simultaneous introduction of different fluids into the cylinder. The secondary direct injectors are positioned on the sides of the cylinder, while the primary direct injector is located towards the center. The two intake valves are situated ahead of the port-fuel injectors, which are mounted on the air intake. Within the combustion chamber, a piezoelectric pressure sensor (AVL GU22CK) is integrated to analyze in-cylinder pressure relative to the crank angle. Additionally, a glow plug within the combustion chamber measures the time-averaged bulk gas temperature. The engine management system uses AVL FI2RE software to control the start and duration of injection as well as the spark timing (ST). Furthermore, AVL IndiCom software is used to log critical in-cylinder data, such as cylinder pressure, glow plug temperature, and combustion timing. The AVLPUMA control station manages testbed parameters, including coolant temperature (80°C), lubrication oil temperature (80°C), and engine speed (2000 rpm), ensuring optimal engine performance and test accuracy (Eshan Singh *et al.*, 2022).

## **1.2. Statement of the problem**

In the area of automotive engineering, particularly concerning diesel engines, there are a significant challenge with emissions and performance loss, especially predominant in certain regions like Ethiopia. Diesel engines, known for their efficiency and power, also produce high levels of nitrogen oxides (NO<sub>x</sub>), hydrocarbons (HC), and carbon monoxide (CO) due to the high internal combustion temperatures and incomplete internal combustions. To diminish these emissions and enhance performance, various methods such as Selective Catalytic Reduction (SCR), Exhaust Gas Recirculation (EGR), Low Temperature Combustion (LTC), emulsifications, fumigations, and the use of biodiesel have been implemented. However, these methods often require additional installations, involve emission trading complexities, utilize expensive materials, and can lead to engine wear and energy loss. A promising research area aims to achieve a clean environment without compromising the performance of diesel engines. Among the innovative solutions, water port injection and pre-mixed ethanol injection have given an attention for their potential to improve combustion characteristics and reduce pollutant emissions. These injection mechanisms are advantageous as they do not necessitate

complex installations or expensive materials, thereby offering a more practical and cost-effective approach to reducing NO<sub>x</sub> emissions and other pollutants while maintaining engine performance. This focus on simpler yet effective injection strategies represents a significant advancement in the way for cleaner diesel engine technology.

### **1.3.1. General objective**

The main objectives of this thesis study were to evaluate the effects of pre-mixed ethanol and water port injection system on the performance and emission characteristics of a dual-fuel diesel engine.

### **1.3.2. Specific objectives**

- To investigate the effect of water port injection on engine emissions and performance,
- To determine the effect of pre-mixing ethanol on engine performance of diesel engine and emissions,
- To evaluate and compare the emissions and performance of the conventional diesel engines with and without water port injections and ethanol pre-mixing,

### **1.3. Significance of the study**

- Environmental sustainability: biodiesel helps to various natural resources to decrease the dependency on fuels derived from diesel fuel and major contributor to both air pollution and climate change.
- Fuel efficiency and performance enhancement: engine power output and efficiency can be significant change through the use of water port injection.
- Alternative fuel development: It investigates the effects of water port injection and advantages of combining such a pre-mixed ethanol with water port injections systems.
- Combustion stability: water port injection promotes more stable combustion by maintaining a more controlled and uniform burn rate, resulting in smoother engine operation, reduced engine vibration, and enhanced drivability.
- Cooling effect: lowering the peak combustion temperature, this cooling affect contributes to decrease in NO<sub>x</sub> production.
- Reduce importing of diesel fuels.
- To describe local produced fuel on a small scale using various natural resources which decrease dependency on fuels derived from diesel.

## **1.4. Scope of the research**

The scope of this study was to investigate the impact of water port injection on the performance and emission characteristics of a diesel engine fueled with diesel-ethanol blends. It encompasses a detailed analysis of engine performance metrics such as power output, torque, and Brake Specific Fuel Consumption (BSFC), alongside a comprehensive examination of pollutant emissions including nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and hydrocarbons (HC). The experimental setup involves a modified diesel engine equipped with a water port injection system, utilizing various proportions of diesel-ethanol blends to identify the optimal configuration for enhanced performance and reduced emissions. Data analysis was conducted using software tools such as Microsoft Excel for data management and Anaconda for advanced statistical analysis and comparisons. This study aims to provide insights into the effectiveness of water port injection as a practical and cost-effective solution for improving diesel engine performance and emission characteristics.

## **1.5. Benefit of the study**

### **1.5.1. Environmental benefits**

There are various possible environmental advantages to investigating how cooling temperature affects the operation and emission properties of a diesel/ethanol-fueled diesel engine. These are just a few of the main advantages that the environment might get from this technology. Here, according to (Gu *et al.*, 2020), they enter the combustion chamber. Because of its well-known benefits, it is a desirable substitute for diesel fuel. Using a sustainable resource offers a major opportunity to reduce reliance on crude oil and lower greenhouse gas emissions due to its closed-loop system. This resource also has a lower combustion emission profile and the potential to boost rural economies. With minimal engine modifications, it can be used efficiently, enhancing engine performance and combustion efficiency due to its high oxygen content. Additionally, this resource has low toxicity and can be easily blended with conventional diesel fuel, making it a versatile and eco-friendly alternative.

### **1.5.2. Energy security benefits**

Exploring the impact of water port injection on diesel/ethanol engines could enhance energy security by diversifying fuel sources, utilizing renewable resources, promoting local economies, and reducing dependence on imported fuels. These benefits contribute to a more strong and sustainable energy system, ensuring a stable and secure energy supply for the future. It is evident that further efforts could be made to capitalize on domestic surpluses of sugarcane, maize, wheat, and oils, thereby enhancing energy security. This is especially relevant given the rising fuel prices and the declining prices of agricultural commodities. Ethanol, which can be produced using existing industrial capacity and utilized with conventional equipment, presents a viable solution; it offers a significant chance to address our energy security concerns right away. Exploring the impact of water port injection on diesel/ethanol engines can enhance energy security by diversifying fuel sources, utilizing renewable resources, promoting local economies, and reducing dependence on imported fuels. These benefits contribute to a more resilient and sustainable energy system, ensuring a stable and secure energy supply for the future.

1. Diversification of fuel sources
2. Utilization of renewable resources
3. Promotion of local and regional economies
4. Energy independence
5. Potential for decentralized fuel production

### **1.5.3. Economic benefits**

The expanded use of renewable fuels provides substantial benefits for both urban and rural areas, while also positively influencing the trade balance. Ethanol and water, in particular, demonstrate favorable performance characteristics, such as improved cetane levels, superior fuel lubricity, and higher oxygen content. These qualities make them attractive blending agents for future ultra-clean diesel formulations. Additionally, they serve as locally generated, renewable alternative fuels for diesel engines, further enhancing their appeal. The adoption of such renewable fuels not only promotes energy independence but also supports local economies and contributes to environmental sustainability. It's important to note that the economic benefits may vary depending on factors such as the availability and cost of ethanol, government policies and incentives, and the scale of implementation. Realizing the full economic potential of exploring water port injection in diesel/ethanol engines requires

collaboration between industries, government support, and the establishment of favorable market conditions. These are a few of the technology's main financial advantages.

1. Job creation and economic growth
2. Technology development and innovation
3. Market opportunities for ethanol producers

### **1.6. Limitation of the research**

The measurement of tractive effort and power was conducted using a framework computer controlled dynamo meter, as the engine computer controlled dynamo meter, these typically used to directly measure brake power and torque from the engine, was not operational ASTU. Unfortunately, due to budget constraints, a comprehensive characterization ethanol and its blends was not viable. In additions to get better results it takes many tests but since the lab unable to get enough time was very great challenges for the thesis work since it requires many samples up to the desired values are get.

### **1.7. Organization of the thesis**

This document is structured into five sections. Standing from chapter one and chapter two also includes introduction to this chapter, focusing on ethanol and water, along with relevant literature that covers an overview of ethanol, the characteristics of water, venture effect, and necessary materials such as experimental apparatus. This chapter also discusses the blending of fuels and its effects on performance, fuel additives, and concludes with conclusions of the literature review and identification of research gaps. Chapter three details the materials and methodology used in this dissertation, including an introduction, a description of the materials, the methodology, and the blending procedures, supported by evidence. Chapter four examines the results of water port injection on emissions of HC, CO, and NO<sub>x</sub>, effects of water port injection combined with pre-mixed ethanol on engine performance, and emissions of NO<sub>x</sub>, HC, and CO. The final chapter presents conclusions, recommendations, and suggestions for future work. The document concludes with references and appendixes.

## CHAPTER TWO

### 2. LITRATURE RIVIEW

#### 2.1. Introduction

Port water injection, also known as direct water injection or intake manifold water injection, is a technique that can increase the productivity and efficiency of internal combustion engines. It involves carefully injecting water into the intake manifold of an engine. Port water injection involves adding water to the engine's intake port. This port water injection has a number of significant advantages in ethanol-diesel dual fuel injection systems, including knock suppression, fuel flexibility, emission reduction, system design control strategy, and performance trade-off. Water port injection is a valuable performance-enhancing tool that can increase power, improve engine durability, and reduce emissions. It requires a relatively higher water quantity to achieve similar knock suppression as with a direct injection (Fan *et al.*, 2021).

#### 2.2. Ethanol and water

Fuel extraction starts with technological advancements. The early years of 2000 saw a sharp increase in the price of petroleum products, which affected all countries, including Ethiopia (Robinson, 2000). This effect is still present in many developing countries. So it is now necessary to create cars with high fuel efficiency, and laws governing various emission gases have been developed (Johnson, 2016). The advantages of ethanol as a fuel for various applications and the long-term impacts of alternative fuels on society are being examined.

Water injection or water-ethanol injection systems can be employed to optimize diesel engine performance. This helps to lower the combustion temperature, improving engine efficiency, increasing power output, reducing exhaust emissions, and preventing engine knocking. Water-methanol injection, which combines water with methanol, can increase engine performance (Demirbas, 2005).

To make ethanol locally, a variety of materials classified as containing starch, sugar, or cellulose can be utilized (Fernando Santos, Aluízio Borém, 2015). The low cost of production and abundant availability of raw materials give ethanol a competitive edge over other fuels.

A diesel engine doesn't produce a pumping loss, has a high compression ratio thermodynamically, and has greater updraft efficiency. Its drawbacks are the emissions of PM

and NO<sub>x</sub> that are released as a result of the depleted smoke produced during the combustion process. Several investigations, like ignition (HCCI) and low-temperature combustions, are investigated in addition to novel combustion, post-treatment, alternative fuel, and component optimization technologies (Amorim *et al.*, 2017; Putrasari *et al.*, 2017). They have a number of issues, such as a small operating range and challenging combustion control, which prevents them from being used in real engines.

Two common NO<sub>x</sub> reduction techniques used in exhaust gas post-treatment for diesel engines are lean NO<sub>x</sub> trap (LNT) and selective catalytic reduction. Among them, one of the most widely utilized techniques for lowering PM is diesel particulate filter (DPF) technology. Lean NO<sub>x</sub> trap and selective catalytic reduction, on the other hand, require separate systems and have a variety of issues that need to be resolved, including low fuel efficiency and expensive maintenance. So compensation for the commercialization of passenger diesel is required (Oesterle *et al.*, 2008).

Biodiesel burns oxygen fuel, it can lower particulate matter emissions, but it also produces more NO<sub>x</sub> (Shamun *et al.*, 2018). Furthermore, studies on mixed fuel, control, and piston shape optimization are ongoing; however, it is challenging to meet regulations and improve exhaust emission performance (Belgiorno *et al.*, .. 2020; Blasio, 2019).

One of the new combustion technologies for diesel engines is homogenous charge compression. It is possible to improve combustion and boost pollutant emissions by adding moisture to the intake manifold in a variety of ways. But the corrosion issue is the problem of using this technology in a practical way (Nour *et al.*, 201; Farag *et al.*, 2017).

Fuel additives can increase engine efficiency; however, doing so requires a solution and mechanisms to the raw material supply issue (Nour *et al.*, 2021; El-Seesy *et al.*, 2021).

Water emulsion fuels that consist of a combination of fuel, water, and surfactants have been adopted as a viable substitute for conventional fuel sources. These particular fuels are employed in a state where water is dispersed within the oil, resulting in a reduction of NO<sub>x</sub> and PM emissions, enhancement of spray atomization properties, and a decrease in combustion levels. Moreover, it is worth noting that they can be utilized in diesel engines without necessitating any additional apparatus within the fuel system (Perumal Venkatesan *et al.*, 2019; Vigneswaran *et al.*, 2018).

Around, three decades ago, the concept of emulsion fuel emerged as a potential solution for mitigating the levels of NO<sub>x</sub> and PM. However, the advancement of this technology has faced

significant obstacles; primarily standing from limitations in manufacturing techniques such as stability, homogeneity, miniaturization, and production cost (Kim *et al.*, 2018).

The impact of adding water to diesel fuel, revealing that it causes extend a period of ignition delay and increases the rate at which heat is realized during the phase of premixed combustion. It also shows that ethanol-water addition reduces emissions of soot and NO<sub>x</sub> when compared to the utilization of pure ethanol and combustion process of any additives (Nour *et al.*, 2017).

A water-cooled single-cylinder direct injection (DI) diesel engine was used in the experiments, and it was fed mixed fuels containing 0%, 5%, 10%, 15%, and 20% ethanol and diesel. Because of their low heat values, mixed fuels made of ethanol and diesel had a higher BSFC. On the other hand, when the amount of ethanol in the engine increased, its BTE improved. The findings demonstrate that, in comparison to diesel, CO emissions dropped by 16.7% and 5.8% for E10-D and E15-D, NO<sub>x</sub> emissions dropped by 2.2% and 4.2%, while THC increased by up to 40% (Wu-gao *et al.*, 2005).

The effect of incorporating water and a surfactant into a water-in-diesel emulsion fuel on brake torque and exhaust emissions in a four-cylinder diesel engine was examined. To establish the correlation between water addition and engine speed, machine learning techniques, specifically support vector regression and a sea-horse optimizer, were employed. The combined support vector regression and sea-horse optimizer model demonstrated enhanced prediction reliability. It identified that the optimal values were achieved with a water-to-fuel ratio of 0.3, wherein 15% water was added to the fuel. This optimal ratio resulted in significant improvements in engine performance and emissions reduction (Patil *et al.*, 2022).

The impact of ethanol-diesel blends and altitude on turbocharged diesel engines operating under varying atmospheric pressures. This revealed that ethanol-diesel blends exhibited more favorable brake-specific fuel consumption (BSFC) compared to pure diesel. However, it was observed that at lower atmospheric pressure (81 kPa), elevated engine speeds, loads, and the addition of ethanol resulted in higher emissions of hydrocarbons (HC) and carbon monoxide (CO). These effects were relatively insignificant at higher atmospheric pressures of 90 kPa and 100 kPa, indicating that altitude and atmospheric pressure play crucial roles in the emission characteristics of ethanol-diesel blends (Lei *et al.*, 2011).

Water injection in diesel engines is employed for the regulation of combustion and the reduction of emissions. A quantity of 40 mg of water was introduced into both the intake and exhaust manifolds, accompanied by exhaust re-circulation rate 10% and 25%. The outcomes of the study indicate that water injection in the exhaust manifold enhances both engine performance and combustion while simultaneously reducing emissions. The observed enhancements were particularly pronounced at an exhaust re-circulation rate of 25%, resulting in a notable decrease of 5% in brake-specific fuel consumption, as well as an appreciable increase of 3% in thermal efficiency and mean effective pressure (Frag *et al.*, 2018).

The engines running on biodiesel emit more NO<sub>x</sub> into the atmosphere. In order to lower NO<sub>x</sub> emissions in a compression ignition (CI) engine running on biodiesel, this technique used a water injection system. Based on the findings, NO<sub>x</sub> emissions with water were decreased by roughly 50% with water interaction at a rate of 3 kg/h without a change in fuel usage. Additionally, the engine's cylinder pressure and heat release rate can affect the water injection (Tesfa *et al.*, 2012).

The CFD analyze the impact of injection pressure, ambient temperature, and nozzle diameter on diesel spray generation. Results showed that high injection pressure increases penetration length and reduces droplet diameter, while smaller nozzle diameters result in shorter breakup lengths (Kane *et al.*, 2016).

Ethanol from sugarcane and leaves, including ethanol and water blends, can enhance engine performance and emission characteristics. Adjusting feed stock properties can reduce fuel costs and improve combustion. The higher cetane value of pure diesel is compared to optimized engines using ethanol and water (Hadhoun *et al.*, 2021).

Because of emission rules, it is difficult to constantly use fuels for internal combustion engines, such as diesel. The two main issues with current compression ignition engines, NO<sub>x</sub> and PM, can be reduced simultaneously with emulsion fuel technology. Water is used to make emulsion fuel, but its density and kinematic viscosity increase when the fuel's temperature rises. The empirical equation based on hotness and moisture content was proposed based on the measurement results. The empirical equation that was derived has an error rate that is typically less than 5%. Furthermore, the adjusted r-square value was generally greater than 0.95, indicating the reliability of the suggested empirical equation. The emulsion fuel or water blended fuel fundamental data can be obtained from the suggested empirical equation (Woo *et al.*, 2021).

Ethanol combustion and soot oxidation are improved through the addition of water. The endothermic effect eliminates injection into exhaust manifolds. A higher water content of ethanol is advised for improved engine combustion. 50% less soot was present, and fewer NO<sub>x</sub> emissions were produced (Altarazi *et al.*, 2022).

For a single injection strategy, the ideal water injection timing is close to 108 °CA ATDC, and for a double injection strategy, it is 8–200 °CA prior to the diesel injection. When using no exhaust gas (EGR), the critical parameters for water mass and optimal water mass are 10–35% and 29–51% of fuel mass, respectively. Until the water mass reaches 50% of the fuel mass, the main advantage of water injection over EGR is reduced NO<sub>x</sub> emissions without sacrificing fuel efficiency. When using a double injection method, the dilution impact becomes important, whereas with a single injection approach, the cooling effect of the water injection is the main element (Chen *et al.*, 2022).

Thumb methyl ester (TME) in compression ignition (CI) engines using the B<sub>20</sub> biodiesel blend exhibits the best performance and emission characteristics. This is because of the better break-through thermal efficiency and the lower emission composition. In the pre-stage of thumb methyl ester manufacturing, NO<sub>x</sub>, HC, and CO emissions are decreased by using titanium dioxide nanoparticles. The study also found that B<sub>20</sub>'s HC and CO emissions were 13.5 and 12% lower than diesel. TiO<sub>2</sub> nanoparticles are found in pre-stage biodiesel synthesis, resulting in lower emissions and an ecological advantage over conventional catalysts (Patil *et al.*, 2022).

LTC is a type of engine combustion process that occurs at a lower temperature compared to traditional methods. High reactive injection schedule increases cylinder temperature, increasing efficiency and output power while reducing pollutants like NO<sub>x</sub>, CO, and HC. The maximum thermal energy release and minimum emissions occur at an injection angle 62.5° CA (Patil *et al.*, 2022).

Port water injection techniques enhance internal combustion engine performance by suppressing engine knock and reducing cylinder temperature. It uses a three-cylinder engine and analyzes various parameters. Results show that with knock minimization, water can improve BTE by 3.4%-16.7% under different engine conditions of gasoline engine. Proper water injection can reduce particulate emissions by up to 96.0% (Fan *et al.*, 2021).

The influence of biodiesel, ethanol, and water on a dual-fuel diesel engine utilizing natural gas has concluded that a mixture of biodiesel and dual-fuel can yield favorable environmental outcomes. Throughout the DuF combustion process, it employed ethanol, biodiesel, and water as pilot fuel while replacing 80% of natural gas. The most optimal performance point of the engine was achieved by employing a fuel sample consisting of 1.57% biodiesel, 4.38% ethanol, 1.1% water, and 80% NG. The most effective combination of fuel was NG+B1.5E4.3W1.1. Biodiesel, as a renewable biofuel, possesses the capability to decrease engine emissions and enhance combustion efficiency (Hashemi-Nejhad *et al.*, 2023).

Nitrogen oxides (NO<sub>x</sub>) are major pollutants generated mainly from atmospheric nitrogen during combustion processes at high temperatures and pressures. These pollutants contribute significantly to ozone formation and photochemical smog, rising environmental and health concerns, especially from diesel engines. The air-fuel ratio during combustion is a key factor influencing NO<sub>x</sub> levels, with optimized ratios being crucial for effective emission control. However, efforts to reduce NO<sub>x</sub> emissions often result in increased fuel consumption related to braking systems. The cetane number, which measures the auto-ignition quality of diesel fuel also, impacts diesel engine performance and emissions of the engine. Understanding and mitigating the formation of NO<sub>x</sub> is essential for enhancing air quality and minimizing environmental impact (Gowthaman & Velmurugan, 2012).

The incorporating ethanol into diesel fuel affects various physical-chemical properties, generally decreasing viscosity, flashpoint, and cetane number while slightly increasing density at lower temperatures. These changes have implications for the fuel's performance and safety characteristics in table 2.1.

Table 2.1 : shows physical-chemical properties of water-in-diesel fuel emulsions (Selim *et al.*, 2015).

| S no | Properties                           | Test method ASTM | Test results |         |                 |                  |                  |                  |
|------|--------------------------------------|------------------|--------------|---------|-----------------|------------------|------------------|------------------|
|      |                                      |                  | Diesel       | Ethanol | Diesel with E5% | Diesel with E10% | Diesel with E15% | Diesel with E20% |
| 1    | Density at 15 °C(kg/m <sup>3</sup> ) | D4052            | 836          | 788     | 850             | 857              | 861              | 866              |
| 2    | Density at 20 °C(kg/m <sup>3</sup> ) | D445             | 842.5        | 796.3   | 837.1           | 834.8            | 832.6            | 831.5            |
| 3    | Kinematic viscosity, at 40 °c        | D440             | 2.500        | 1.12    | 3.125           | 3.065            | 2.5              | 2.4              |
| 4    | Dynamic Viscosity(MPas)              | (Pa s)           | 2.321        | 0.868   | 2.223           | 2.084            | 2.05             | 2.002            |
| 5    | Flashpoint °c                        | D93              | 78           | 13.5    | 20              | 18               | 16               | 14               |
| 8    | Cetane number                        | D976             | 51.1         | 8.4     | 48.7            | 46.8             | 44.9             | 42.4             |

Diesel fuel that had been mixed with water lowers particle and NOx pollution levels. 0.2% surfactant material is required for a stable W/D emulsion. The heating value, pour point, flash point, density, viscosity, estimated cetane index, total acid number, sulfur content, and distillation data were all measured as part of the physical and chemical characteristics of W/D emulsions. In comparison to diesel, water emulsions have less favorable viscosity, density, and heating value. They do, however, have benefits such as sulfur content, total acid number, flash point, and beginning and final boiling points. More research and process optimization for the emulsion production could lead to improvements (Selim *et al.*, 2015, Benea, 2022).

The impacts of introducing water and a surfactant into a four-cylinder, four-stroke diesel engine on both exhaust emissions and braking torque (BT). The investigation utilizes a seahorse optimizer (SHO) and support vector regression (SVR) based on machine learning to

pinpoint the most effective engine speed and water dosage for enhancing BT and diminishing exhaust emissions. The results indicate that the inclusion of 15% water leads to a reduction of CO and UHC emissions by 15.63% and 9.57% correspondingly, whereas the addition of 5% water results in a 3.34% increase in BT. The SVR-SHO model, with optimized values of 49.5 N.m., 0.5%, 57 ppm, and 369 ppm, demonstrates enhanced predictive accuracy (Alahmer *et al.*, 2023).

The engine performance and emission characteristics are affected by varying diesel and ethanol fuel mixture ratios. Using a four-stroke engine diesel, the study used a simulation model to simulator the combustion process of diesel engines operating on pure diesel as well as diesel-ethanol mixtures. The findings showed that while raising the fuel blend's ethanol concentration greatly improved emission characteristics; it had a negative impact on engine performance. On the other hand, increased brake specific fuel consumption, improved brake thermal efficiency, and lower soot and carbon monoxide emissions were the outcomes of a higher ethanol percentage in the combination. There is significant relationship between cylinder pressure and nitrogen oxide emissions, as well as between engine power and fuel consumption related to the brakes (Zhang *et al.*, 2021).

Dual fuel can operates on a combination of diesel fuels and other fuels, such as water, natural gas, ethanol or hydrogen. The use of dual fuel systems are improved fuel efficiency, reduced emissions and increased in fuel choice. Water injection improves the combustion process by reducing peak temperatures and decreasing the formation (NO<sub>x</sub>). Ethanol, on the other hand, has a high octane rating for the combustion efficiency and emissions. Water injection in dual-fuel diesel engines using an ethanol diesel the outline includes: experimental setup, fuel preparation and test procedures (Damyantov & Hofmann, 2019).

The system of intake manifold pressure, also referred to as forced induction, elevates the air pressure within an engine by utilizing techniques such as turbocharging or supercharging. This elevation in air mass results in a heightened power and torque output. Furthermore, it enhances the efficiency of combustion by aiding in the improved atomization and blending of fuel, thereby leading to a more comprehensive combustion process and decreased emissions. The incorporation of this system is frequently observed in diesel engines to enhance performance across various operating conditions. The utilization of port water injection systems within the intake manifold can bring about a multitude of advantages, which include lowering the combustion temperature, preventing knocking, increasing air density, mitigating

emissions, improving thermal regulation, improving power output, and enhancing the stability of combustion. These systems are characterized by easier installation procedures and lower maintenance requirements when compared with direct water injection systems (Decheng *et al.*, 2021).

### 2.3. Water port injections specifications

During the initial testing phase, the intake manifold's water port injection system was employed, distinct from the central and side injector fuel supply systems. Instead of supplying fuel, this system delivers drinkable water through a Bosch EV14 conventional port fuel injector into the air intake. This injector features four nozzles, each with an average diameter of 0.3 mm, creating spray plumes with a  $16^\circ$  separation between them and an  $8^\circ$  bend angle. The injector is strategically positioned 130 mm upstream of the intake valve and operates at a pressure of 6 bars. This configuration ensures precise water delivery to the intake air stream, aiding in the optimization of combustion and engine performance during testing ( Ponnya *et al.*, 2021).

The results showed that the engine achieved optimal performance with a 15% mass of water injection combined with fuel. This improvement is due to the increased indicated mean effective pressure and efficiency, which can be attributed to the cooling effect on specific engine components (Mingrui *et al.*, 2015).

### 2.4. Venturi effect

The term "venturi effect" describes the drop in fluid pressure that happens as a fluid speeds through a pipe's choke, or confined section. The venturi effect has several uses in engineering since it can be used to quantify fluid flow and move other fluids (as in a vacuum ejector) by reducing pressure inside the constriction (Latif & Macdonald, 2018).

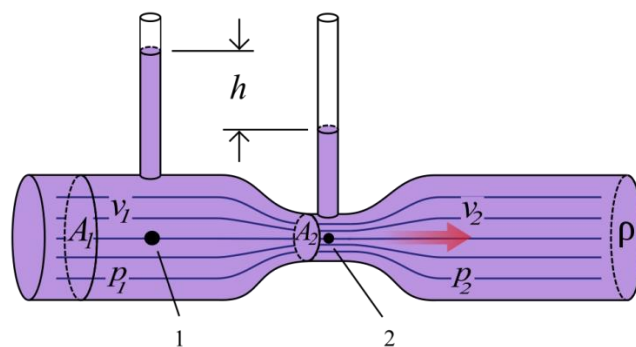


Figure 2.1: Venturi effect shows the flow of fluid

$$P_1 - P_2 = \frac{\rho}{2} (v_2^2 - v_1^2) \dots\dots\dots 1$$

Figure 2.1 shows where the fluid's density is represented by  $\rho$ .  $V_1$  is the fluid velocity in broader pipes and  $V_2$  is the fluid velocity in narrower pipes. The larger cross-sectional area at "1" compared to "2" causes the fluid velocity there to be lower than at "2," and the upstream static pressure (1) is higher than the constriction (2). The equation essentially states that the difference in pressure between two points in a fluid flow is related to the change in kinetic energy per unit volume of the fluid. When fluid flows from a region of high pressure to a region of low pressure, it accelerates, and thus its velocity increases. This is why  $v_2$ , (velocity at the narrower section) is higher than  $v_1$  (velocity at the broader section).

$$Q = V_1 A_1 = V_2 A_2 \dots\dots\dots 2$$

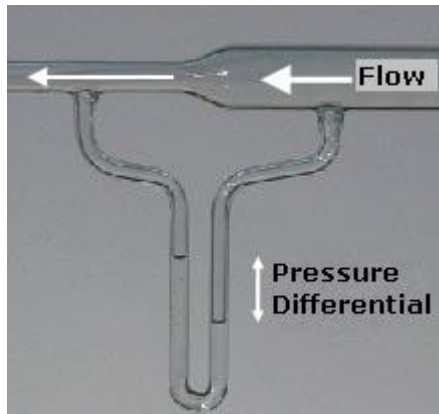


Figure 2.2 : Venture effect shows the flow of fluid

A flow of air via a Pitot tube venture meter in fig 2.2, where the columns are connected in a manometer and partially filled with water, can be measured as a pressure differential in inches or centimeters of water. The continuity equation states that the product of the cross-sectional area and the fluid velocity is constant along the pipe. This means that if the cross-sectional area decreases (as it does at the narrower section), the velocity must increase to keep the flow rate  $Q$  constant.

## 2.5. Experimental apparatus

### 2.5.1. Venture tubes

A venture tube, also referred to as a venture, is a fundamental device consisting of a series of tubes through which fluid flows. These tubes feature varying diameters along their length. To minimize excessive aerodynamic drag, a typical venture tube is designed with an exit cone

angled at 5 degrees and an entering cone angled at 30 degrees. This configuration facilitates efficient fluid flow within the tube, making venturuses essential components in various fluid systems and applications (Nasr, G. G. Connor, 2014). Venture tubes are widely used in procedures where maximum accuracy is needed while handling extremely viscous liquids and when experiencing continuous pressure loss is not acceptable.

### **2.5.2. Orifice plate**

Venture tubes, although functioning on the same principle as normal orifice plates, are typically more costly to construct. This increased expense is attributed to their more complex design and construction requirements. Despite the similarities in operation, venture tubes tend to induce less permanent energy loss compared to orifice plates when subjected to a given differential pressure. This reduced energy loss makes venture tubes advantageous in certain applications where efficiency and energy conservation are prioritized (Retrieved, 2019).

## **2.6. Blending of fuels and its effect on performance**

The blending of ethanol with diesel fuel and water injecting effectively reduce emissions up to 50% and improve engine performance 3.4-16.7% (Chen *et al.*, 2022); (Altarazi *et al.*, 2022); ( Tesfa *et al.*, 2012); (Fan *et al.*, 2021); (Woo *et al.*, 2021). Different ethanol to control solidity trains and informed that the use of raw corn, sugarcane, wheat, cellulosic feedstocks fuels can lead to premature engine failure (Tribak *et al.*, 2012).

Mixing ethanol with fuel has been identified as a technique to alleviate choking and prolong engine lifespan. Similar findings were documented by Bartholomew(Dr.B.Karunanithi<sup>1</sup>, K.Bogeshwaran<sup>2</sup>, 2012). The port fuel injector features four nozzles, each with an average diameter of 0.3 mm. These nozzles emit spray plumes spaced 16° apart, with each plume having an 8° bend angle. Operating at a pressure of 6 bars, the injector is positioned 130 mm upstream of the intake valve, ensuring precise delivery of the fuel mixture into the engine's air intake system.

## **2.7. Fuel additive**

Their numerous advantages include lower pollutant emissions, protection against abrasion and wax buildup on the motor, improved ignition and combustion efficiency, and fuel mixture stabilization. Two fundamental transformations that have been gaining significance are the gradual reduction of sulfur content and the rising adoption of biofuels. Various additive

combinations may be employed, provided that the core chemical functionalities remain operational (Rudi Dungani *et al.*, 2014).

The use of biofuel blends had some serious drawbacks, though, such as increased NO<sub>x</sub> tendencies, less frequent replacement intervals for motor parts like fuel filters, and deterioration from varnish deposits exposed to the elements over time.

Here, fuel additives play a crucial role in both mitigating these adverse impacts and facilitating the fuel trade by manufacturing specialized commodities that meet thirty regional and international standards, including EN, ASTM, and DIN EN.

### **2.7.1. Oxygenated additives**

Oxygenated additives in diesel engines offer advantages by potentially limiting and decreasing emissions through modifying the fuel's chemical composition. These additives can improve engine performance and reduce emissions when added at appropriate proportions, enhancing combustion efficiency and reducing particulate emissions. However, it is crucial to note that modern high-technology diesel engines may not require additional additives, as good quality commercial fuels already contain necessary additive. The use of oxygenated additives can be beneficial in improving engine performance and reducing emissions, but careful research and adherence to recommendations from additive suppliers and engine manufacturers are essential to avoid adverse effects on the engine and warranties (Mahmudul *et al.*, 2016).

### **2.7.2. Ethanol-diesel blends**

Ethanol, a cost-effective oxygenated substance containing a substantial proportion of 34.8%, is frequently derived from biomass sources. E-diesel mixtures, recognized as oxygenated diesel, amalgamate conventional diesel fuel with a maximum of 15% ethanol by incorporating an additive mixture to ensure stability and enhance properties( Madiwale *et al.*, 2017).

Diesel engines can also run on ethanol, which comes in additive packages ranging from 0.2% to 5.0%. The application of ethanol additions into intake port is restricted and necessitates engine modifications. To promote fuel vaporization, aftermarket dual fuel kits with an integrated heat exchanger have been created to feed ethanol into the engine. Ethanol may be produced from a variety of feedstocks and has 34% greater oxygen content by weight. Heat release rate, viscosity, exhaust smoke, and brake thermal efficiency are all increased when

ethanol is added to biodiesel blends. Diethyl is a colorless fuel with high volatility and flammability that is added with oxygen (McCormick & Parish, 2001).

The incorporation of diethyl ether into blends of diesel and biodiesel leads to enhancements in properties, performance, and a reduction in pollutants emitted by the engine. The utilization of N-butanol, derived from the fermentation of biomass, is gaining recognition as an additive owing to its elevated oxygen content, favorable solubility characteristics, and increased calorific value (Nord *et al.*, 2017).

The biodiesel-diesel blend exhibits poor cold flow properties, rendering it unsuitable for use in colder climates unless additives are incorporated. Ethanol emerges as a potential alternative with its higher oxygen content and faster combustion rate within the cylinder. Anhydrous ethanol, boasting a purity level of 99.8%, proves particularly suitable for analytical purposes. Ethiopia, with its abundance of sugar factories capable of producing and distributing ethanol, presents a readily accessible source of this fuel. Given its advantageous properties and easy availability, ethanol becomes a formidable contender when blended with diesel and biodiesel combinations, offering promising prospects for various applications (Verma *et al.*, 2019).

## 2.8. Conclusions of literature review

To summarize the data, SCR, emulsifications, direct water injecting effectively reduce emissions up to 50% and improve engine performance 3.4-16.7%. These summary investigations and limitations are discussed in the following table 2.3.

Table 2.2: Conclusions of literature review

| Author                          | Findings   | Limitations   |
|---------------------------------|--|---|
| (Chen <i>et al.</i> , 2022)     | Water combined with exhaust gas recirculation reduces NOx emissions until the water mass reaches half of the fuel mass   | It increases PM emissions and results in power loss   |
| (Altarazi <i>et al.</i> , 2022) | Water enhances combustion and soot oxidation, eliminating injection into exhaust manifolds. Higher ethanol content improves engine combustion, reduces soot, and reduces up to 50% NOx and soot. | But there is vibration due to high content ethanol and decrease performance since ethanol has higher octane rating. |

|                                |   |  |
|--------------------------------|---|--|
| (Woo <i>et al.</i> , 2021).    | Emulsion fuel technology can reduce NOx and PM issues. A proposed empirical equation, utilizing temperature and water content, was introduced with an error margin below 5% and a reliability exceeding 0.95. | However, these methods have limitations like varying engine performance and require advanced infrastructure. There is also corrosion   |
| ( Tesfa <i>et al.</i> , 2012); | NOx emissions can be reduced using three-way catalytic converter. (SCR) injects ammonia in the presence of a catalyst, resulting in up to 90% NOx reduction.  | However, expensive materials and lean diesel engines make converters less effective. Selective catalytic reduction (SCR) is effective in heavy vehicles but not light duty vehicles. |
| ( Tesfa <i>et al.</i> , 2012); | The rate of water injection at 3 kg/h reduced NOx emissions by 50% without affecting fuel consumption.  | Results show water injection reduces NOx emissions by 50% but increases CO emissions by 40%.   |

SO, integrating a water injection system into the intake manifold alongside ethanol injection offers a practical and cost-effective solution for minimizing emissions and enhancing performance in diesel engines. Water injection cools the combustion chamber, reducing peak temperatures and consequently lowering nitrogen oxides formation, while also smoothing engine vibrations and stabilizing combustion. Ethanol injection, with its high oxygen content, promotes more complete fuel combustion, reducing emissions of hydrocarbons, carbon monoxide, and particulate matter. This combined method increases internal pressure and extends ignition delay, improving combustion efficiency without the need for widespread additional installations or expensive materials, as existing intake manifold systems can be adapted. This method not only reduces costs associated with advanced emission control technologies but also supports environmental sustainability by lowering emissions and improving fuel efficiency, making it a balanced and effective strategy for cleaner and more efficient diesel engine operation ( Tesfa *et al.*, 2012), ( Tesfa *et al.*, 2012).

## 2.9. Research gap

Various methods like direct injection, fumigation, emulsion, SCR, and biodiesel are employed to reduce emissions and improve performance, particularly for NO<sub>x</sub>; however, these methods need extra installation, have emission trading with expensive materials. But water and ethanol injection in diesel engines increases engine performance and minimizes emissions by increasing internal pressure and ignition delay easily (Chen *et al.*, 2022); (Altarazi *et al.*, 2022); ( Tesfa *et al.*, 2012); (Fan *et al.*, 2021); (Woo *et al.*, 2021). Since water has low viscosity and high internal pressure, it smooths the vibration and increases engine performance, respectively. The properties of diesel engine with a cetane number and lower with an octane number also help to manage performance and emissions. The considerable parameters include combustion impact assessment, long-term durability, water quality additives, system integrations and control strategies, and also other parameters like spray characteristics, injection timing, rate, engine load, and sensor control mechanisms. These are considerable and warrantable parameters to minimize NO<sub>x</sub>, HC, CO, and other particulate matter emissions. So by changing the injections methods by using an intake manifold water port injection system in the form of fumigations to see the effect of water and ethanol on engines' performance and emissions is valuable work since it doesn't require any additional installation and easily available.

## CHAPTER THREE

### 3. MATERIALS AND METHODS

#### 3.1. Description of the study

Engine can be greatly influenced by water injection; therefore, a mix of techniques and tests are needed. Common methods include vibration analysis, temperature analysis, combustion analysis, and engine performance testing. While engine performance testing uses dynamometers to monitor various parameters, vibration sensors can be used to quantify and investigate vibrations. Ionization probes and pressure transducers are used in combustion studies to examine the properties of combustion. Thermal analysis measures engine temperatures using temperature sensors or thermal imaging cameras, which can be used to assess how well water injection. This field of study was carried out at AASTU.

#### 3.2. Materials

From the literature review, a suitable engine model and the required materials within the best fuels have been chosen in order to support the study's efforts to maximize performance and reduce emissions. The materials for the thesis work are listed in table 3.1.

Table 3.1: Materials

| Material name           | Use   |
|-------------------------|---|
| Fluid reservoir         | To store an adequate amount of fluid                        |
| Injector/Atomize        | Typically a liquid, into a system in the form of fine mist. |
| Interconnecting hoses   | Pipes used to connect different components                  |
| Computer                | For documentations  |
| Water injection system  | Inject water into the intake manifold                       |
| Data acquisition system | To collect and record data from the engine                  |
| Ball valve              | To control the flow of fluids through a pipeline or system  |
| Exhaust gas analyzer    | Helps to measure exhaust                                    |
| Safety Equipment        | Ensures safety during experiments                           |
| Dynamometer             | To measure the power, torque, and speed                     |
| Engine sensors          | It can measure torque, power output, and emissions.         |

|   |  |
|---|--|
| Anaconda software, excel software, Anova software | For analysis and comparisons of the experimental results |
|---|--|

### 3.3. Methods

The Mechanical Engineering Department at Addis Ababa Science and Technology University (AASTU) helps to conduct experiments to assess emissions and engine performance using ethanol-diesel blends and waters. Four different ethanol mixtures were prepared by varying the ethanol percentage by volume. The tests were carried out on a single-cylinder, four-stroke diesel engine in a lab environment, utilizing a water injection system in the intake manifold for diesel fuel injection. Separate performance and emissions tests were conducted for water and ethanol injections.

1. Gathering and selecting enough information about enhancing engine performance and emission characteristics by using pre-mixed ethanol and water port injections.
2. Identifying the equipment's and lab setup to conduct the experiment.
3. Arranging the lab setups in the conventional and newly modified setups
  1. Calibrating the water port injection volume.
  2. Preparing the ethanol-diesel biofuels with different ratios: E5, E10, E15, and E20.
  3. Arranging and fixing the required measuring instruments on the test engine for measuring performance and emissions and having the water injection setups.
4. Initially, the engine was run for 25 minutes to reach operating temperature,
5. Before testing each ethanol blend, the fuel system was completely drained,
6. The engine was operated for another 25 minutes to ensure the previous fuel was fully cleared.
7. This procedure was repeated for all fuel samples to ensure consistent and accurate test results, and the desired values were obtained over a series of tests.
8. Taking data from the computer-controlled engine test dynamometer.
9. Analyzing data and drawing conclusion

These ideas are expressed in figure 3.1 in precise and systematic ways of experimental work.

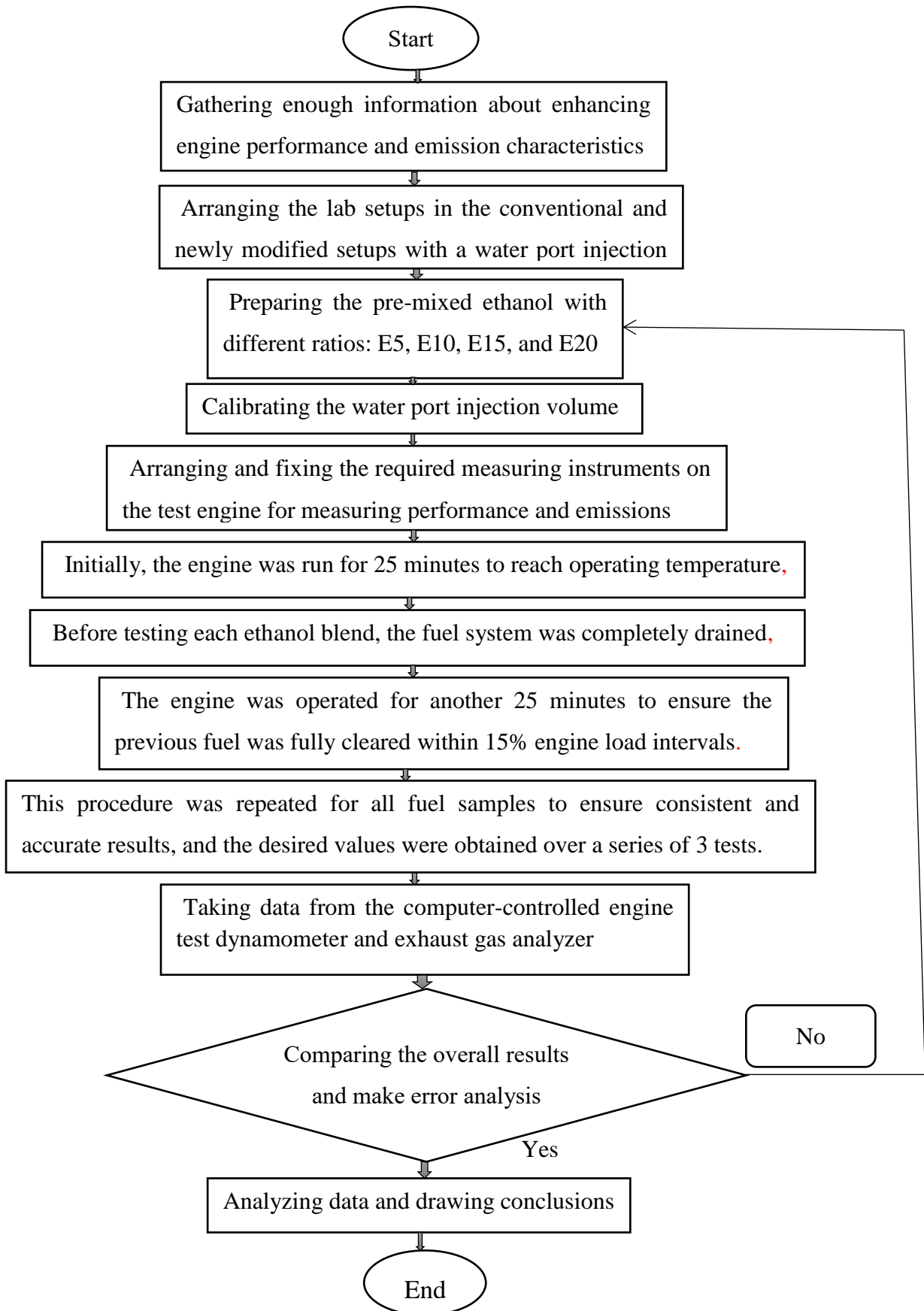


Figure 3.1: The flow chart of method to conduct experiment

Figure 3.1 focuses on evaluating the effects of pre-mixed ethanol and water port injections on diesel engine performance and emissions. The process begins with gathering comprehensive information on these enhancement methods. The necessary equipment and lab setups, both conventional and modified, are identified and arranged. The water port injection volume is calibrated, and ethanol-diesel biofuels are prepared in various ratios (E5, E10, E15, and E20). Measuring instruments are installed on the test engine, which is initially run for 25 minutes to reach operating temperature. Each ethanol blend is tested after fully draining the previous fuel and running the engine for another 25 minutes to ensure clearance. This procedure was repeated for all samples to ensure consistency until three consequent tests for one sample. Data is collected using a computer-controlled engine test dynamometer, followed by thorough analysis to draw conclusions about the effectiveness of water port injection in improving engine performance and reducing emissions using ASTM standards.

### **3.3.1. Experimental setups and facilities for the test**

The examination was take place at the automotive laboratory of AASTU utilizing a particular experimental arrangement. The examinations that include the utilization of E5, E10, E15, and E20 along with constant water port injections in diesel fuel engine. Initially, the engine was undergoing testing with the following analysis

1. The addition of only purely diesel fuel,
2. The addition of water port injections,
3. The additions of pre- mixed ethanol within their respective ratios,
4. The addition the combinations of water port injections with pre-mixed ethanol,

In this study, an evaluation was performed on the combustion process, operational effectiveness, and emission of pollutants from a compression-ignition (CI) engine powered by pre-mixed ethanol, both in the presence and absence of water port injection. The engine utilized in this specific inquiry is a water-cooled, port injections, single-cylinder, and four-stroke diesel engine, with port injection of water taking place into the intake manifold in fig. 3.2. The water was injecting through the way of air compressor of port injections with gravity within pre-calibrated of the water at a rate of 27g/minute with a distance of 12 cm the nozzle of the injections as shown in figure 3.2. The experimental procedures were carried out following the outlined steps.

In addition to cleaning and filling the engine fuel tank with the fuel for testing, fuel blends were produced according to volume. To warm up, the engine was first run on diesel fuel for a

short while. Once the dynamometer had warmed up, tests were run at different speeds with pure diesel while other dynamometer characteristics, such as the results of the emission tests, were read and recorded.

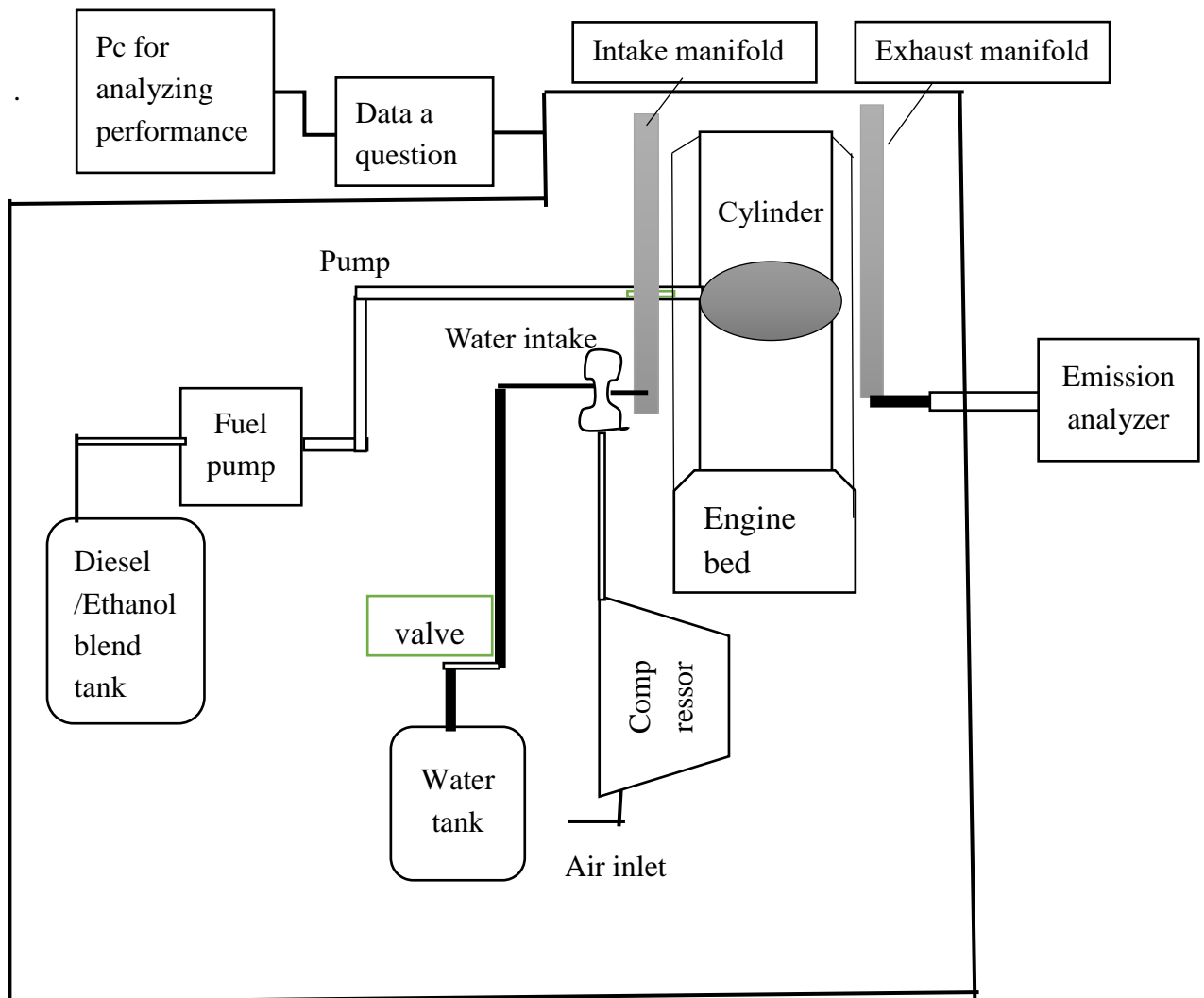


Figure 3.2: Set up of water port injection system in the intake manifold

Figure 3.2 shows a schematic representation of a diesel engine configuration with several parts for modifying and managing the injection system in order to possibly improve performance and lower emissions, especially NO<sub>x</sub>, CO, and HC. The intake manifold diesel engine's water port injection mechanism is sketched out in the diagram. The system uses a constant volume of water injection in the intake manifold and varies the amount of ethanol (E5, E10, E15, and E20) injected into the combustion chamber. The simplest and most direct method for using water injection to achieve the appropriate engine performance and emissions is shown in the sketch.

### 3.3.2. Measuring instruments

The experimental study was conducted using a TM<sub>3</sub>/O<sub>2</sub> air-cooled, single-cylinder, four-stroke diesel engine. The engine features a bore and stroke both measuring 69 mm, and operates at a speed of 3600 rpm. It is capable of delivering a power output of 3.5 kW (4.8 HP) in accordance with the N 80/1269/EEC-ISO 1585 standard. The engine's maximum torque is recorded at 10.4 Nm at 2400 rpm. To facilitate the water port injection system, a port air-blast injection method was employed, delivering ethanol at a pressure of 3 bars. These specifications and experimental conditions provided a robust platform for analyzing the impact of water port injections and ethanol pre-mixing on engine performance and emissions. in table 3.2.

Table 3.2: Specifications of the engine

|  |  |
|--|--|
| TM <sub>3</sub> /O <sub>2</sub> . Air-cooled | Single-cylinder four-stroke diesel         |
| Bore (mm)                                    | 69   |
| Stroke (mm)                                  | 69   |
| Speed (rpm)                                  | 3600                                       |
| Power kW (HP)                                | 3.5(4.8);N 80/1269/EEC-ISO 1585            |
| Maximum torque                               | 10.4 Nm at 2400 rpm                        |
| Water port injection system                  | Port air-blast injection of ethanol (3bar) |

### 3.3.3. Specifications of the exhaust gas analyzer used for the experiment

The characteristics of the exhaust gas analyzer utilized in experimental configurations are delineated. This apparatus was furnished with precise sensors and delivers superior resolution for a variety of parameters such as CO, O<sub>2</sub>, HC, CO<sub>2</sub>, and NO. By offering a resolution as precise as 0.01% for CO and O<sub>2</sub>, and 1 ppm for HC, it guarantees precise measurement within designated ranges. The instrument exhibits rapid response times, with a sensor response time of T95 at 20 seconds, and swift warm-up in under 2 minutes, thereby expediting efficient testing protocols. Moreover, its sturdy design encompasses a durable probe with an insertion depth of 350mm and a 4m lengthy hose for convenient operation. The analyzer is appropriate for a broad ambient operating range from +5°C to +45°C, ensuring versatility in diverse testing conditions. Additionally, it provides data logging functionality for up to 500 tests and can be linked to a PC through an RS 232 port for data interpretation. Measuring at 220mm x 55mm x 120mm and weighing merely 1kg, it is portable and easily manageable. The

apparatus is powered by a rechargeable battery, delivering over 4 hours of uninterrupted operation, and is accompanied by a battery charger compatible with input voltages ranging from 100-240 V. In conclusion, this exhaust gas analyzer furnishes precise and dependable measurements for a thorough scrutiny of exhaust emissions.

#### **3.3.4. Specification of the MQY-200 diesel smoke meter**

The MQY-200 diesel smoke meter had been developed with the purpose of providing precise measurements of opacity (N), light absorption coefficient (k), rotational speed, oil temperature, and exhaust gas temperature, all of which are essential parameters in the evaluation of diesel engine performance and emissions. Its operational capability extends across a broad environmental spectrum ranging from 0°C to 40°C and  $\leq 90\%$  relative humidity, with power supplied at AC220V  $\pm 10\%$  50  $\pm 1$  Hz, ensuring consistent functionality under varied circumstances. The measurement capabilities of the device encompass a broad range from 0 to 99.90% for opacity and 0 to 16.08m<sup>-1</sup> for light absorption coefficient, thereby providing comprehensive insights into exhaust emissions. Noteworthy is the device's high resolution of 0.01% for opacity and 0.01m<sup>-1</sup> for light absorption coefficient, which significantly enhances the precision of measurements conducted.

It maintains minimal indication errors, with absolute errors limited to  $\pm 2.0\%$  for opacity and  $\pm 5^\circ\text{C}$  for oil and exhaust gas temperatures, thus guaranteeing the accuracy of readings. Boasting a power consumption of 250W and an optical channel length of 215mm, the MQY-200 diesel smoke meter effectively combines efficiency and reliability for a thorough analysis of diesel engine exhaust emissions. The specification of the MQY-200 diesel smoke meter or opacimeter used for the experiment listed detailed in table 3.3.

Table 3.3: Specification of the MQY-200 diesel smoke meter

| Parameters                                  |                                  |                          |
|---|----------------------------------|--------------------------|
| Environmental conditions                    | Temperature                      | 0°C ~ 40 °C              |
|   | Relative humidity                | ≤ 90%                    |
|   | Supply voltage                   | AC220V ± 10% 50 ± 1 Hz   |
| Measurement range                           | Opacity (N)                      | 0 ~ 99.90%               |
|   | Light absorption coefficient (k) | 0 ~ 16.08m <sup>-1</sup> |
|   | Speed                            | 300 ~ 9999rpm            |
|   | Oil temp                         | 0 ~ 200°C                |
|   | Exhaust gas temp                 | 0 ~ 150°C                |
| Indicating value error                      | Opacity (Absolute error)         | ±2.0%                    |
|   | Light absorption coefficient (k) | 0.05m <sup>-1</sup>      |
|   | Rotational speed piezo electric  | 50rpm                    |
|   | Oil temp.                        | ± 5°C (Absolute error)   |
|   | Exhaust gas temp                 | ± 5°C (Absolute error)   |
| Resolution                                  | Opacity (N)                      | 0.01%                    |
|   | Light absorption coefficient (k) | 0.01m <sup>-1</sup>      |
|   | Speed                            | 1rpm                     |
|   | Oil temp                         | 1°C                      |
|   | Exhaust gas temp                 | 1°C                      |
| Power consumption                           |                                  | 250W                     |
| The effective length of the optical channel |                                  | 215mm                    |

The MQY-200 diesel smoke meter/opacimeter specifications utilized in the study were detailed. The selection of operating conditions aimed to encompass primary engine speeds and loads in accordance with the New European Driving Cycle (NEDC).

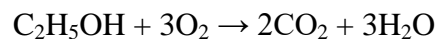
Fuel blends were made according to volume, and previously the engine petroleum tank was filled with the fuel that was going to be tested, it was thoroughly cleaned.

To guarantee adequate warm-up, the engine was driven with diesel fuel for a certain amount of time before the actual testing were conducted. After that, tests were run at different speeds using only pure diesel fuel, and all of the dynamometer's characteristics were carefully read and documented along with the results of the emissions testing. These characteristics included

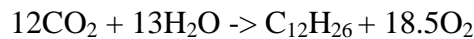
power at the back wheel and tractive force, which were measured at equal intervals between each measurement by methodically recording them at various speeds within the predefined speed range.

### 3.3.5. Lab experimental ratios with their chemical reaction properties

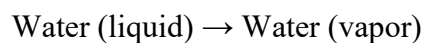
The combustion of ethanol involves the chemical reaction where ethanol reacts with oxygen to generate carbon dioxide and water vapor. Such a process exemplifies a combustion reaction, more precisely an oxidation reaction.



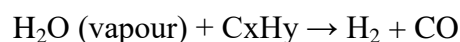
The chemical reaction that occurs during the combustion of diesel fuel between oxygen and the hydrocarbon molecules in the fuel produces carbon dioxide and water vapor. This procedure is an example of an oxidation reaction, which is a type of combustion reaction.



Water can participate in several different chemical processes when it is added to the combustion chamber separately. One of the most important of these processes is the conversion of water from a liquid to a gas due to the high temperatures in the combustion chamber. The transformation of liquid water into water vapor is facilitated by this specific phase transition event.



Furthermore, water has the capability to engage in various reactions, for instance, steam reforming. In this process, water vapor interacts with hydrocarbon compounds found in the fuel, resulting in the generation of hydrogen gas and carbon monoxide.



It is crucial to emphasize that the equations presented correspond to theoretical combustion reactions. In practical engine operations, the combustion mechanism is significantly intricate, involving a range of additional compounds and chemical processes. Moreover, the precise composition of diesel fuel may exhibit variability, characterized by diverse hydrocarbon structures.

A complete combustion scenario is illustrated by the equation:  $C_{13}H_{28} + O_2 = CO_2 + H_2O$  (diesel + oxygen = carbon dioxide and water). The actual combustion of diesel fuel in real-world applications is notably more intricate. The complex reaction is commonly perceived as the emissions produced by a vehicle. Fuel's chemical energy is transformed into mechanical energy by diesel engines. Fuel and airborne oxygen combine to produce a sequence of combustions that release energy. Diesel fuel combustion can be described chemically as follows:  $4C_{12}H_{23} + 71O_2 \rightarrow 48CO_2 + 46H_2O$  (Sadeq, 2024).

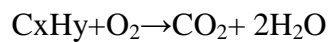
The chemical combustion processes of hydrocarbons, carbon monoxide, and nitrogen oxides in the internal combustion of diesel engines are complex and involve multiple reactions.

➤ **Hydrocarbons (HC)**

Hydrocarbons are unburned or partially burned fuel that results from incomplete combustion. In a diesel engine, the combustion of hydrocarbons follows these general steps:

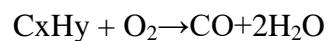
➤ **Complete Combustion**

Ideal Reaction hydrocarbons react with oxygen to produce carbon dioxide and water.



➤ **Incomplete Combustion:**

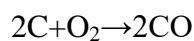
When there isn't enough oxygen or the combustion temperature is too low, incomplete combustion occurs, leading to the formation of carbon monoxide (CO) and various hydrocarbons.



➤ **Carbon monoxide (CO)**

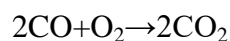
Carbon monoxide is a product of incomplete combustion. It forms when there is insufficient oxygen for the complete combustion of carbon to carbon dioxide.

Incomplete combustion reaction carbon reacts with limited oxygen to form carbon monoxide.



➤ **Conversion to CO<sub>2</sub>:**

In the presence of adequate oxygen and higher temperatures, CO can further oxidize to CO<sub>2</sub>.

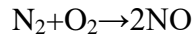


➤ **Nitrogen Oxides (NO<sub>x</sub>)**

Nitrogen oxides are formed during combustion at high temperatures, where nitrogen N<sub>2</sub> and oxygen in the air react. The primary forms of NO<sub>x</sub> are nitric oxide NO and nitrogen dioxide NO<sub>2</sub>.

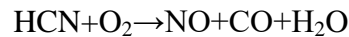
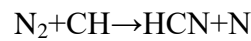
➤ **Thermal NO<sub>x</sub> Formation:**

Occurs at high temperatures



➤ **Quick NO<sub>x</sub>:**

Forms through complex reactions in the flame front



➤ **Fuel NO<sub>x</sub>:**

Results from the oxidation of nitrogen compounds present in the fuel.



Overall combustion process in diesel engines

In a diesel engine, the combustion process involves the following steps:

➤ **Injection**

Diesel fuel is injected into the combustion chamber at high pressure.

➤ **Ignition:**

The high temperature and pressure cause the fuel to ignite spontaneously (auto-ignition).

➤ **Combustion**

The fuel burns, ideally producing CO<sub>2</sub> and H<sub>2</sub>O. However, due to variations in temperature, pressure, and air-fuel mixture, incomplete combustion can occur, leading to the formation of CO, HC, and NO<sub>x</sub>.

➤ **Balancing Emissions**

Controlling the emissions of HC, CO, and NO<sub>x</sub> requires a delicate balance:

➤ **Lean Combustion**

Reduces HC and CO but can increase NO<sub>x</sub> due to higher combustion temperatures.

➤ **Rich Combustion**

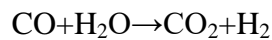
Reduces NO<sub>x</sub> but can increase HC and CO due to incomplete combustion.

➤ **Considering HC and CO Emissions:**

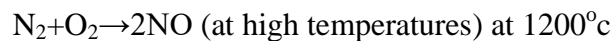
- **HC Emissions:** While increased HC emissions indicate unburned fuel, which is a sign of incomplete combustion, HC emissions are generally more manageable and less immediately toxic compared to CO.
- **CO Emissions:** CO is a poisonous gas that can cause serious health issues even at relatively low concentrations. Its presence is more acutely hazardous in environments where engines operate in enclosed or poorly ventilated spaces.

➤ **Water Injection:**

- Water injection primarily serves to lower combustion temperatures through evaporative cooling.
- The presence of water can facilitate the water-gas shift reaction:



- Additionally, water injection can suppress NO<sub>x</sub> formation by reducing peak temperatures:



➤ **Hydrocarbons (HC) Emissions:**

- Ethanol's presence generally reduces HC emissions due to better combustion efficiency.
- Water injection, if well-controlled, can maintain or slightly increase HC emissions due to cooling effects, but the overall impact can be mitigated by careful tuning.

When weighing the impacts of increased HC versus CO emissions due to water injection, CO emissions are generally more concerning because of their direct toxicity to humans. Therefore, while both HC and CO emissions can increase with water injection, it is typically better to minimize CO emissions due to their immediate health risks.

The experiments were conducted using various combinations of ethanol and diesel fuel to investigate their impact on engine performance and emissions. Four distinct fuel ratios were examined: 5% ethanol with 95% diesel, 10% ethanol with 90% diesel, 15% ethanol with 85% diesel, and 20% ethanol with 80% diesel. Each blend was meticulously prepared, with 475 ml of diesel and 25 ml of ethanol for the 5% mixture, 450 ml of diesel and 50 ml of ethanol for the 10% mixture, 425 ml of diesel and 75 ml of ethanol for the 15% mixture, and 400 ml of diesel and 100 ml of ethanol for the 20% mixture. These specific ratios were selected to evaluate the effects of increasing ethanol content on engine performance and emissions. By methodically varying the ethanol-to-diesel ratio, the experiments aimed to provide valuable insights into the feasibility and effectiveness of ethanol-diesel blends as alternative fuel options, thereby contributing to ongoing efforts to develop more sustainable and environmentally friendly fuels.

The predetermined water volume was precisely measured and quantified, with 250 ml of water administered over 9 minutes and 25 seconds. The total duration for the mixing process was calculated, yielding a flow rate of 27 ml per minute, or 27 g per minute. The water injector has an outer diameter of 3.5 mm, an inner diameter of 0.5 mm, a nozzle length of 12 mm, and an overall length of 28 mm. These specifications were based on real data measurements for the tests conducted.



Figure 3.3 : Pre-mixed ethanol content and their ratios

From figures 3.3 the effort to optimize fuel efficiency and reduce emissions, various ratios of ethanol and diesel fuel were tested, specifically E5 (5% ethanol, 95% diesel), E10 (10%

ethanol, 90% diesel), E15 (15% ethanol, 85% diesel), and E20 (20% ethanol, 80% diesel). Each blend offers distinct advantages and trade-offs. The E5 and E10 blends provide moderate increases in oxygen content, enhancing combustion efficiency and reducing carbon monoxide emissions, while still maintaining the energy density close to that of pure diesel. These lower ethanol ratios are particularly effective in improving fuel lubricity and reducing particulate matter without significantly altering engine performance. The E15 and E20 blends further increase the oxygen content, which can significantly lower CO and hydrocarbon (HC) emissions, thanks to more complete combustion. However, these higher ethanol concentrations may also lead to a slight increase in fuel consumption due to the lower energy density of ethanol compared to diesel. Additionally, the higher ethanol content can raise combustion temperatures, potentially increasing nitrogen oxides emissions, although this can be mitigated with appropriate engine tuning and water injection strategies. Overall, these ethanol-diesel blends present a promising approach to cleaner diesel engine operation, balancing improved emission profiles with manageable changes in fuel properties and engine performance

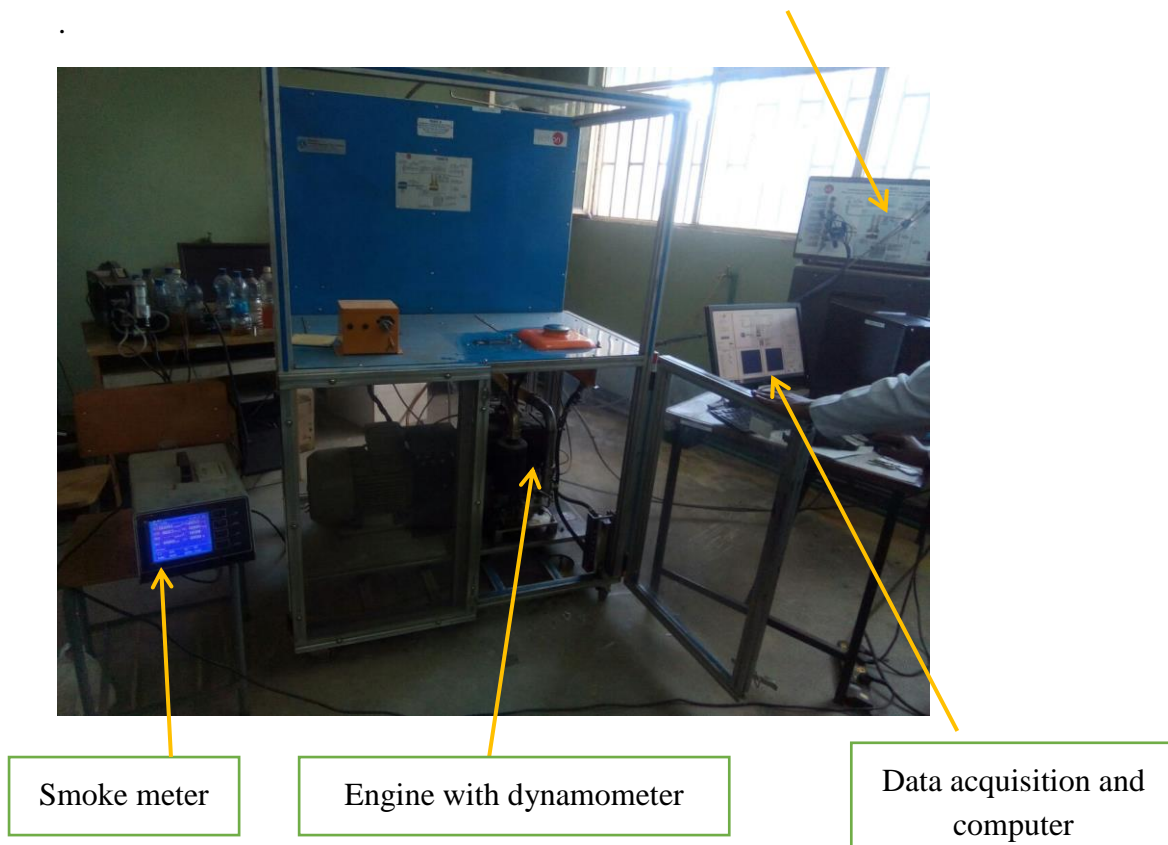


Figure 3.4: Engine setups of the experimental work

The experimental setup of figure 3.4 was developed to systematically investigate the effects of ethanol-diesel blends and water port injection on diesel engine performance and emissions.

By carefully controlling and monitoring engine parameters, the study aimed to identify optimal fuel compositions and injection strategies to improve combustion efficiency and reduce harmful emissions.

### **3.3.6. Lab experimental set ups of port water injections in the intake manifold**

A quantity of crucial actions had been taken in order to include water port injection in the engine testing procedure. First the system had a dedicated water tank that supplies water to a valve that controls the flow. After that, a valve mechanism directs the water, providing exact control over injection rates. Simultaneously, air is injected into the valve, combining with the water prior to its passage into the intake manifold. Through careful blending, the engines combustion dynamics are optimized, improving efficiency and performance. Furthermore, by precisely delivering the water-air mixture into the combustion chamber through the use of port injectors, the combustion process was further enhanced and adjusted changes could be made to obtain desired performance outputs. All things considered, this integrated approach ton water injection was an advanced technique, for enhancing engine performance and reducing emissions two factors that was critical to contemporary automotive engineering and environmental sustainability initiatives.

Figures 3.5 are indicates all the lab experimental setup of water port injections systems



Figure 3.5: Engine setup installations when water port additions

During the engine setup installation of figure 3.5 with water port additions, careful steps are taken to ensure seamless integration of the water injection system. This involves selecting

appropriate water injection components and placing them strategically within the intake manifold or air intake system to facilitate even distribution of water. Integration with the engine management system allows for precise control of injection timing and duration. Testing and calibration procedures verify system functionality, while optimization efforts focus on achieving desired performance and emissions targets. Safety measures are implemented to prevent potential damage, and comprehensive documentation and training ensure proper operation and maintenance. Overall, these steps ensure that the water injection system is effectively integrated into the engine setup, contributing to enhanced performance and reduced emissions.

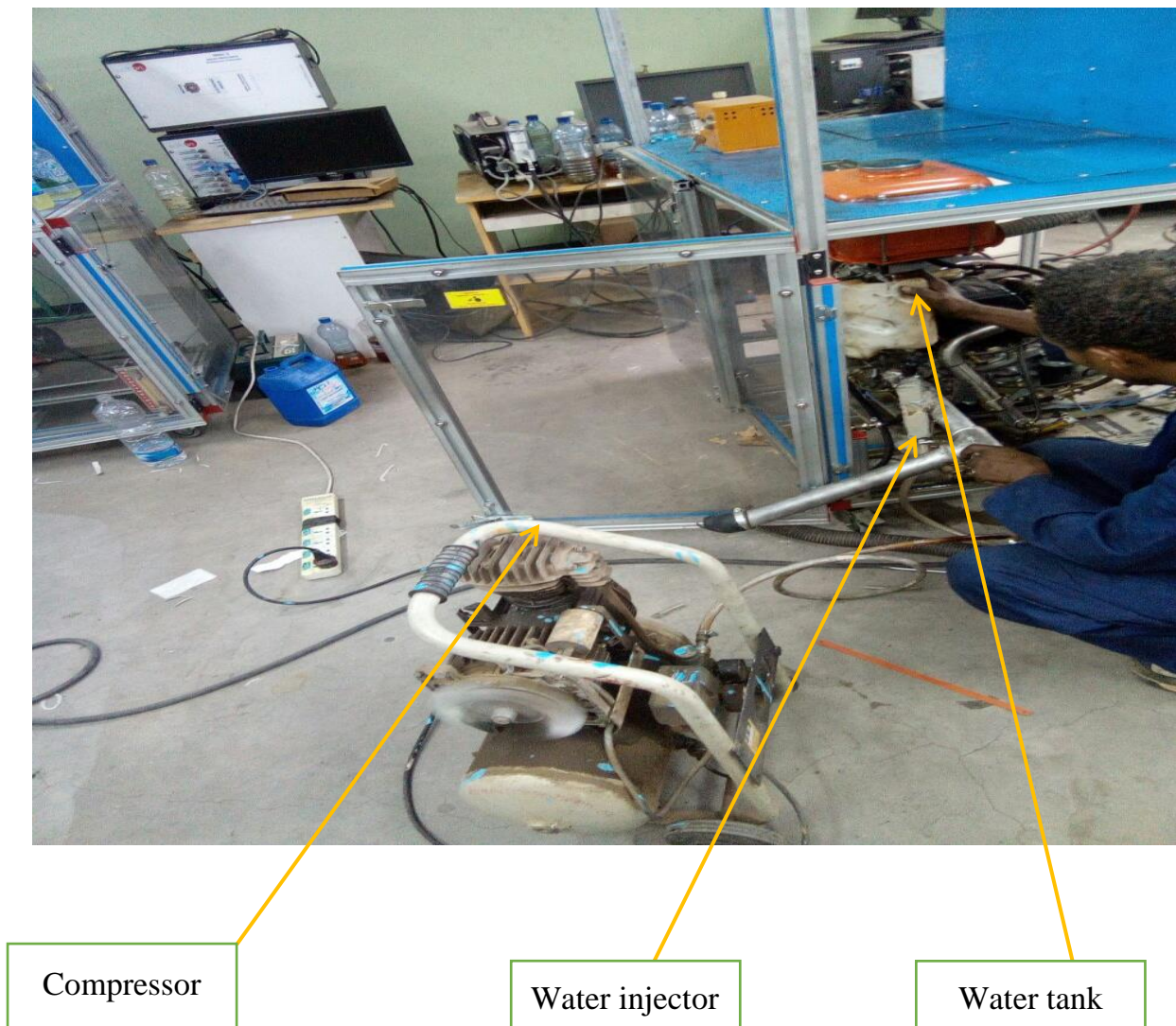


Figure 3.6: When engine starts with the fuel of water port addition

In figure 3.6 each experimental run, the fuel system is thoroughly drained to ensure the accuracy and reliability of subsequent tests. The process begins with shutting down the engine and allowing it to cool. The current fuel blend is then drained from the fuel tank and lines, followed by flushing the system with a small amount of the next fuel blend or a cleaning solvent to remove any residues. This step is repeated to ensure complete removal of any remnants. The system is then refilled with the new fuel blend, and the engine is primed for the next test. Equipment, including exhaust gas analyzers, is recalibrated. Detailed records of the draining and refilling process are maintained to prevent cross-contamination and ensure consistent test conditions. This careful procedure is crucial for maintaining the integrity of the experimental results, allowing for accurate evaluation of different ethanol-diesel blends and water injection strategies.

### 3.3.7. Brake specific fuel consumption

Brake-Specific Fuel Consumption (BSFC) is a critical parameter for evaluating the fuel efficiency of an engine. It is defined as the amount of fuel consumed per unit of power produced and is typically expressed in grams of fuel per kilowatt-hour (g/kWh). Lower BSFC values indicate higher fuel efficiency, meaning the engine produces more power for a given amount of fuel. Specific fuel consumption is one of mostly relate to the fuel efficiency of an engine, particularly in the case of jet engines and aircraft. The fuel consumption rate as a function of thrust or power output is its definition. The conventional units of SFC for jet engines are kilograms per unit of thrust per hour or pounds of fuel per pound of thrust per hour.

- Higher fuel efficiency is indicated by lower SFC values.
  - Specific fuel consumptions (SFC) =  $\frac{\text{mass flow rate}}{\text{power}}$  .....1
- Another way is to calculate how long it takes to burn a certain mass of fuel. The engine performance factors known as brake specific fuel consumptions are what mostly control the engine's fuel consumption and fuel efficiency. They are described as the engine's fuel consumption in kilograms per hour (kg/hr) while maintaining a steady engine speed (N) in revolutions per minute (rpm). BSFC is a precise method for measuring fuel efficiency in internal combustion engines, primarily in automotive and related applications.
- The rate of fuel consumption in relation to engine power output is how it is defined. The engine's braking horsepower (bhp) is referred to as the "brake" in BSFC.

- The units for BSFC are typically grams of fuel per kilowatt-hour (g/(kWh)) or pounds of fuel per horsepower-hour (lb/(hp·h)).
- BSFC indicates how efficiently an engine uses fuel to produce power. Lower BSFC values imply higher fuel efficiency and are desirable.

$$\text{Brake specific fuel consumptions (BSFC)} = \frac{\text{mass flow rate}}{\text{power}} \text{ in kg/kWh} \dots\dots\dots 2$$

Brake specific fuel consumptions can be computed by utilizing the following formula after the fuel's mass flow rate has been established using the following.

$$M_f = \rho * v \dots\dots\dots 3$$

$$\text{BSFC} = \frac{mf\left(\frac{\text{gm}}{\text{minute}}\right)}{\text{brake power}} \left(\frac{\text{gm}}{\text{kWh}}\right)$$

Density for each fuel can be calculated with the following formulas,

$$\text{Density of each blended fuel} = \text{Volume of diesel} * \text{density of diesel} + \text{volume of ethanol} * \text{density of ethanol}$$

And the density of pure diesel which has been used in laboratory is 0.85g/ml and density of pure ethanol (99.8%) is 0.788g/ml, water also has 1g/ml.

Standing from the above calculations the results obtained from each blend fuel is,

$$E5\% = 0.842 \text{ g/ml,}$$

$$E10\% = 0.834 \text{ g/ml}$$

$$E15\% = 0.826 \text{ g/ml,}$$

$$E20\% = 0.818 \text{ g/ml}$$

### 3.4. Error analysis

The experiments cannot be measured with 100% accuracy due to various factors such as calibration, test conditions, instrument selection, readings, material homogeneity, ambient conditions, measurement device range, and connection points and locations of measurements. To mitigate these effects, it is recommended that experiments be performed at least three times to ensure the reliability and repeatability of the results under the same conditions. The averages of these three measurements are then reported. Error and uncertainty analysis is crucial for evaluating and validating experimental results. Therefore, the accuracy rates of all measurement devices used in this study are provided. The total error rate is calculated using a specific equation designed for this purpose.

$$\text{Error} = [(0.78)^2 + (1.2)^2 + (0.75)^2 + (1.3)^2 + (0.98)^2 + (1)^2]^{1/2} = (11.02\%)^{1/2} \approx 3.32 \%$$

$$\text{Confidence level} = 96.68 \%$$

## CHAPTER FOUR

### 4. RESULT AND DISCUSSION

#### 4.1. INTRODUCTION

The primary aim of the continuing analysis was to assess the influences of introducing water at a flow rate of 27g/minute into a compression-ignition engines fueled with pre-mixed ethanol on the operational appearances of the engine. The injection rate 27g/minute is calibrated was takes place before starting the experiment. Subsequently, the findings explained, encompassing all the evaluated test scenarios, with a particular on the combustion process. The mixture diesel and pre-mixed ethanol with pure diesel affects HC and CO emissions improves at lower engine loads and decreases at higher engine loads, where NO<sub>x</sub> levels increase with higher engine loads. Diesel engines, due to their superior efficiency, definitely generate lower CO<sub>2</sub> emissions compared to gasoline engines. Diesel fuel contains higher energy than regular gasoline and more energy than pre-mixed ethanol-blended gasoline. In essence, diesel engines generate lower CO<sub>2</sub> emissions compared to gasoline engines primarily due to their higher thermal efficiency, which results in less fuel being burned for the same amount of work. This efficient use of fuel translates directly into fewer CO<sub>2</sub> emissions. CO levels in diesel engines decreased, except at maximum power, the amount of fuel injected was significantly less than the volume of air supplied, ensuring an excess of oxygen levels that results in increased CO production. The unburned hydrocarbons (HC) present in diesel exhaust consist of original fuel molecules, breakdown products of fuel compounds, and partially oxidized hydrocarbons. These emissions include approximately 400 organic compounds, ranging from methane to the heaviest components of the fuel. Excessive HC, emissions arise from ignition failures or misfires induced by excessively lean or rich air/fuel mixtures. The experiments were taking load in the intervals of 15% in between 0 and 80%.

#### 4.2. Effect of water port injections on emissions of HC, CO and NO<sub>x</sub>

Water port addition affects deplete smoke temperature of a diesel engine across different engine loads. The exhaust temperature decreases when water port injections enter the diesel engine. These phenomena could explain the ability of the water port injections content in the injected fuel to absorb heat. Moreover, the cooling effect in the engine combustion chamber influences the evaporation process, which utilizes the latent heat of water. Consequently, a

higher water percentage in the fuel injections leads to a lower average temperature after fuel injections but before ignition. The reduction in exhaust gas temperature contributes to finally isolated water droplets in the fuel injections, establishing a standard for heat dissipation.

#### 4.2.1. CO emissions

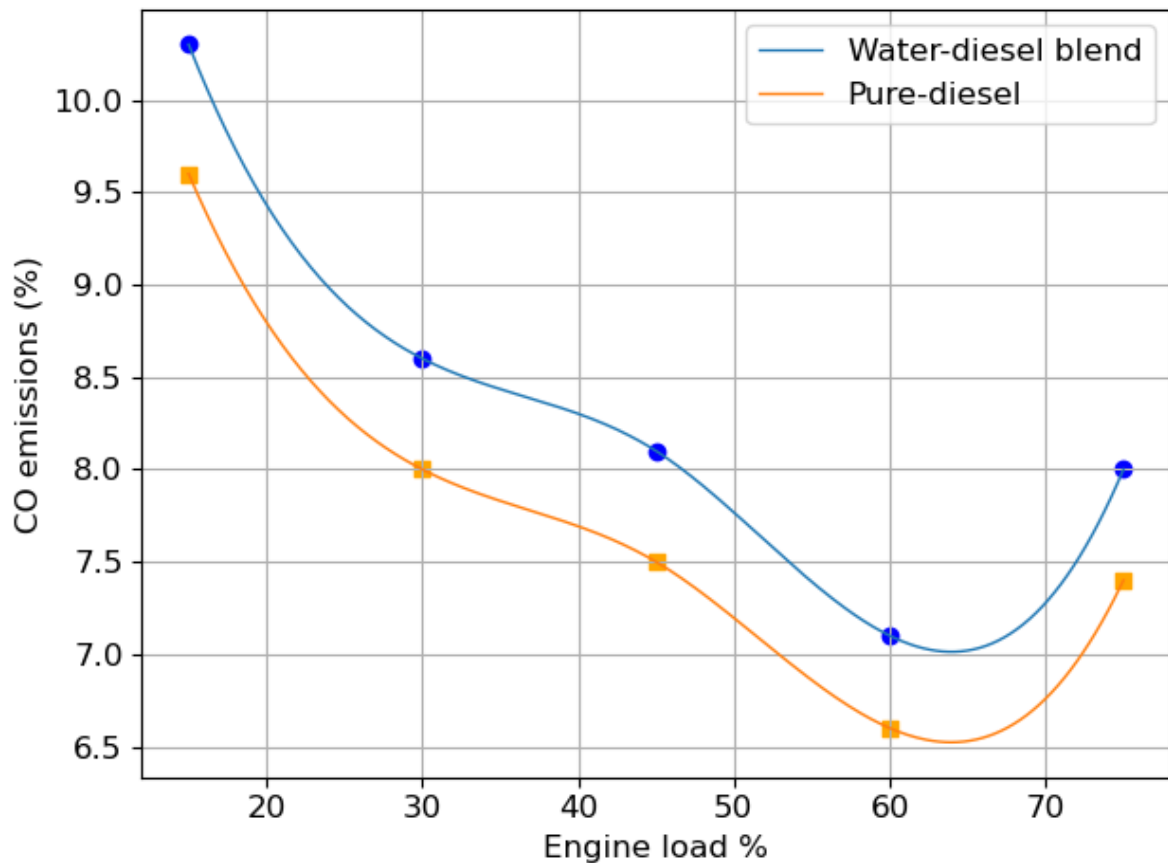


Figure 4.1: CO emissions in pure water port additions in diesel engine

Figure 4.1 examines the impact of water port injections fuel on CO emissions from a diesel engine. It found that the percentage of CO emitted decreased with engine load but increased due to incomplete combustion and ignition timing retardation compared from pure diesel fuel. It has two scenarios, when the engine load increases, CO emissions decrease, but CO emissions increase due to incomplete combustion fuels after it reached maximum limit.

Analyzing the data, the percentage increase in CO emissions ranges from approximately 6.77% to 8.11%, depending on the load. Through the load levels, the overall increase in CO emissions was about 7.59%. It demonstrates that introducing only water port injections into diesel fuel was not effective in reducing harm full emissions of CO. over all CO emissions increase when compared with pure diesel.

#### 4.2.2. HC emissions

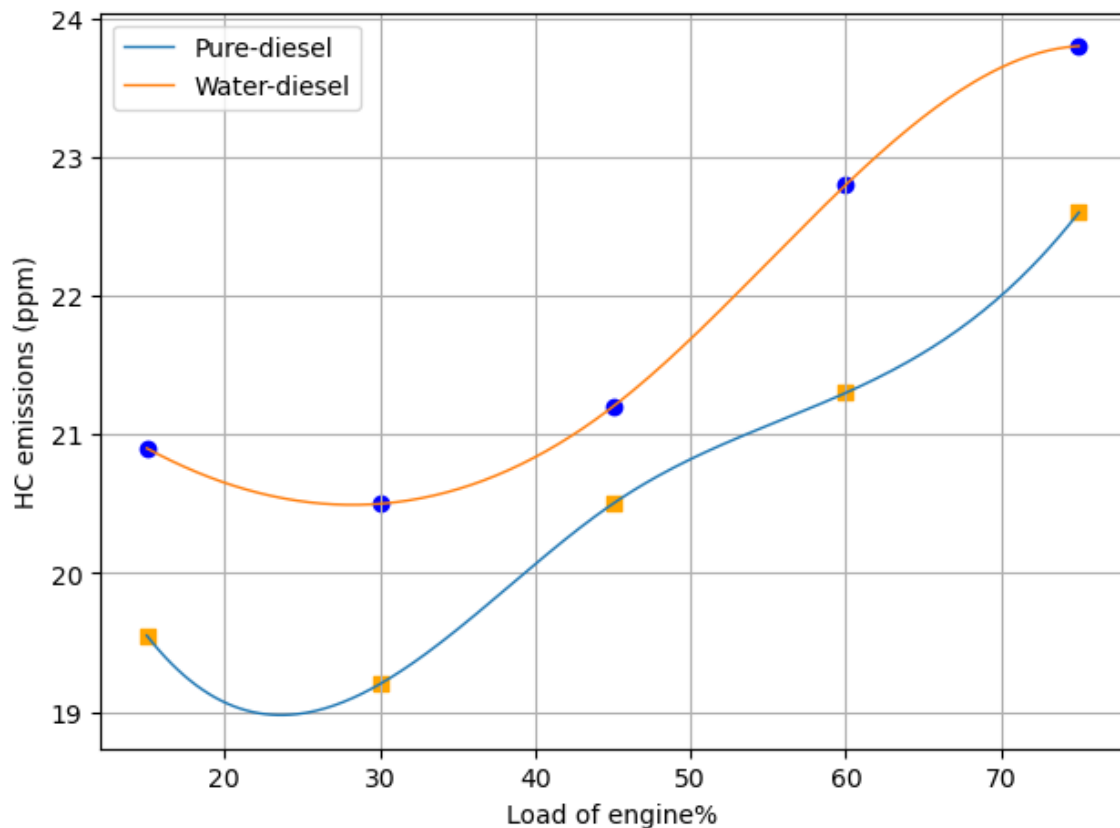


Figure 4.2: HC emissions in water port additions in diesel engine

From figure 4.2 as engine load increases, there is an increase in the instability in the amount of UHC released by diesel engine. The outcome of running a diesel engine on water port derived diesel fuel was increased UHC emissions. In the pure diesel, UHC emissions rise when engine powered by water port injections operates at a higher load. The use of a water port injection method results in incomplete combustion, leading to higher UHC emissions. This increase is attributed to factors such as extended ignition delay, reduced combustion, and lower flame temperatures, all of which negatively impact combustion efficiency. When water enters in diesel engine, there was in HC emissions across various load levels.

Addition of water port injections primes to an increase in HC emissions across varies load levels. The analyzing data concludes, the increase in HC emissions percentage ranges from approximately 3.30% to 8.13%, depending on the load. Through the given or selected load levels, the overall increase in HC emissions was about 7.54%. It demonstrates that introducing only water port injections into diesel fuel was not effective in reducing harm full emissions of HC specially HC bond is more strong than CO.

### 4.2.3. NOx emissions

The figure 4.3 indicates the results of NOx emissions when water port injections take place.

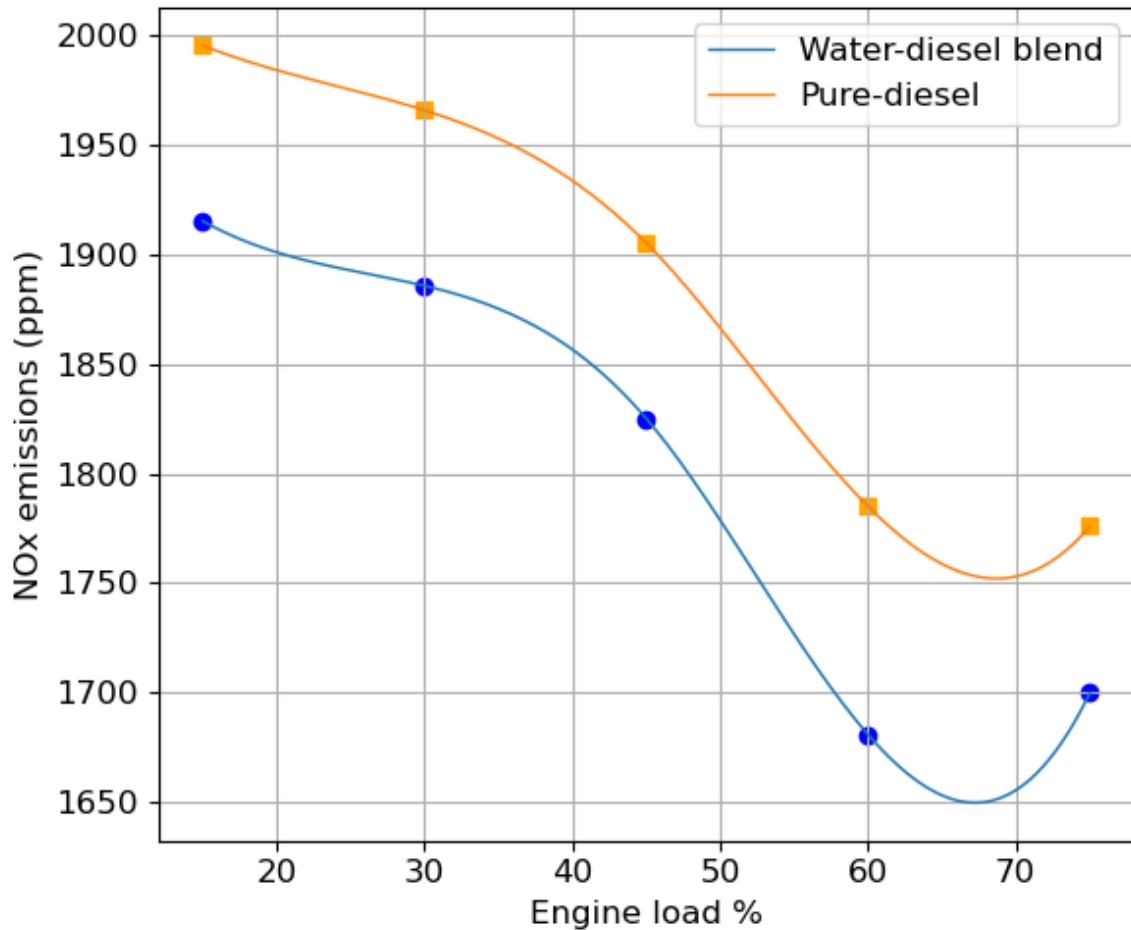


Figure 4.3: NOx emissions in water port additions in diesel engine

When weighed against the fuels water content, the analysis shows that engine speed has effect on NOx emissions. When compared to pure diesel, water port injection fuels had lower NOx emissions. Better combustion follows from a higher load, maintaining a more effective fuel and air combination.

This was mainly because the heat dissipation action lowers the flame temperature. This decrease could be attributed to the significant latent heat generated by the evaporation of water in the water port injections, which efficiently absorbs heat burning. Moreover, the addition of water port injections raises hydroxyl radical levels, which in turn cause a drop in NOx levels.

Figure 4.3 and additions of water port injections to diesel fuel leads to a decrease in NOx emissions across varies load levels. Analyzing the data, the percentage decrease in NOx emissions ranges from approximately 4.01% to 5.83%, depending on the load. Across all load levels, the overall increase in NOx emissions was about 5.83%. It validates that introducing only water port injections into diesel fuel was effective in reducing harm full emissions of NOx.

#### 4.2.4. Water port injections on torque, power and BSFC

The evaluation of the sample fuels performance is conducted through utilizations of an engine test rig. Measurements are taken for brake torque, and brake power. The process involves adjusting the load in increments of 0 to 80% within the intervals of 15%. The detailed analysis of the performance parameters is presented in the subsequent sections.

#### 4.2.5. Torque

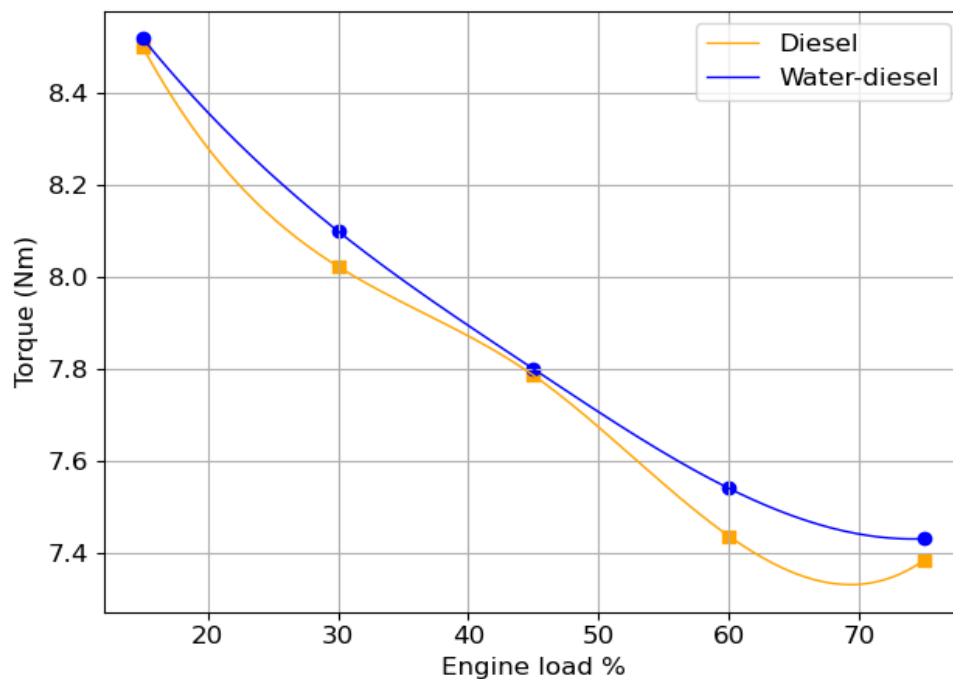


Figure 4.4: Torque in water port additions to diesel engine

The figure 4.4 depicts the influence of the proportions of water additions in port injection systems on the engines brake torque at various loads. The brake torque lowers with the engines loads until reaching an optimal level, beyond which it decline is due to frictional losses and the engines incapacity to fully utilize an air charge at high velocities. Operating the

engine 27g/minute of water added to the port injections results in the engines load being at optimal level, thereby yielding the peak brake torque.

So calculating the percentage change in torque for each load, it found increase or decrease, depending on the load level. The torque increase by about 0.49% compared from pure diesel. The additions, water port injection to diesel fuel not only had the potential to impact emissions but also positively affects engine performance in terms of torque, a key measure of an engine rotational force within a significant change.

#### 4.2.6. Brake power

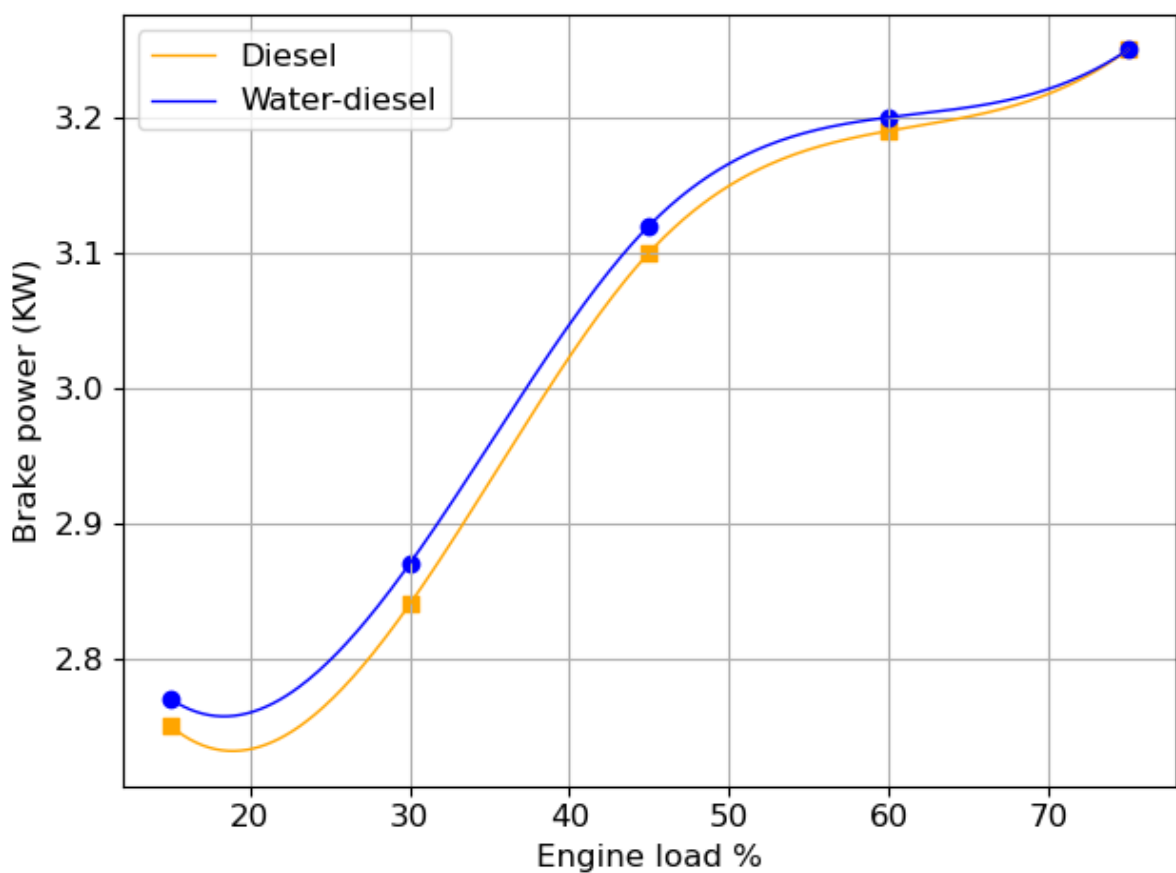


Figure 4.5: Brake power in water port additions in diesel engine

Water was added to diesel engine, the brake power increase across all load conditions as shown in figure 4.5. The percentage change in brake power varies up to 0.58, depending on the load. The brake power results show an increase of about 0.58%. This indicates that water port addition in diesel fuel can lead to an enhancement in brake power; this also improves engine performance and efficiency.

Water port injection in a diesel engine causes a notable reduction in BSFC at all load levels. When water was added, BSFC was much lower than with pure diesel, especially at higher loads. This suggests that water port injection could improve diesel engines' fuel efficiency.

#### 4.2.7. Brake specific consumptions

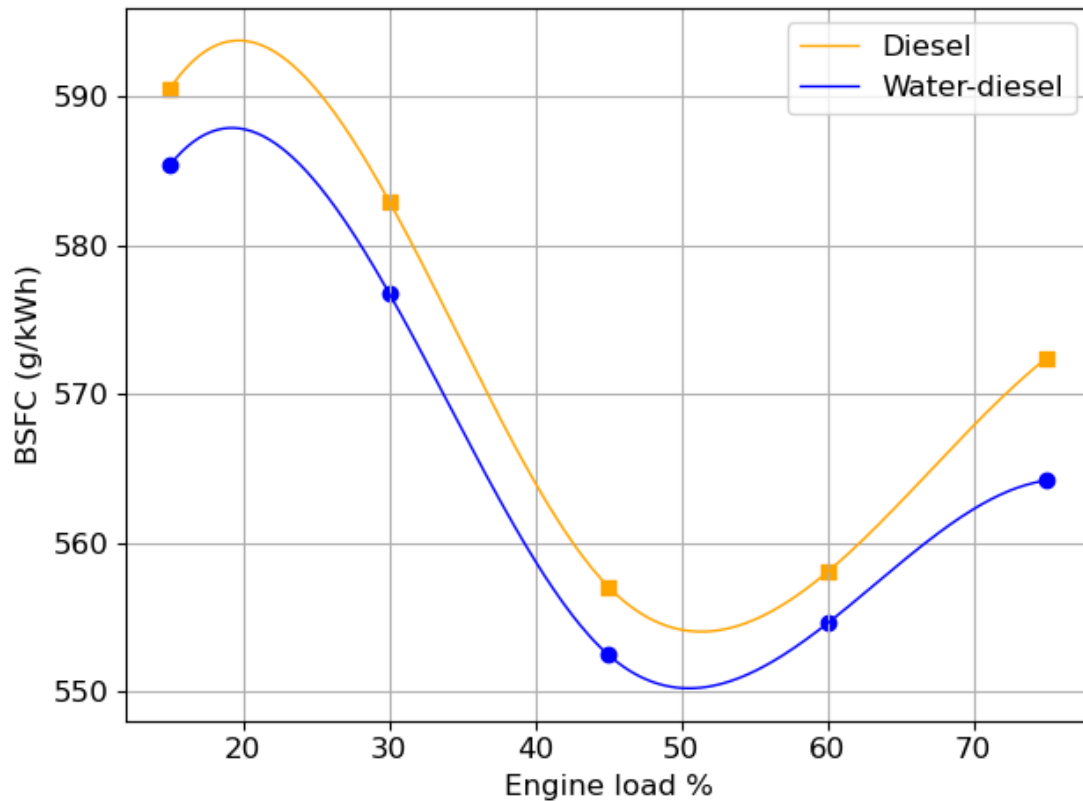


Figure 4.6: BSFC in water port additions in diesel engine

The addition of water port injections to diesel fuel in a diesel engine results in an approximate 1% decrease in BSFC, as shown in figure 4.6. This percentage change signifies that incorporating water into the combustion process can lead to more efficient fuel usage. The improved BSFC indicates that the engine is able to produce the same amount of power while consuming less fuel, highlighting a notable enhancement in fuel efficiency. This efficiency gain can be attributed to the cooling effect of water, which optimizes the combustion process by lowering the peak temperatures and reducing the occurrence of engine knock. Consequently, this more controlled and efficient combustion process allows for better fuel utilization, leading to significant improvements in power output without a proportional increase in fuel consumption. This finding underscores the potential of water port injection as a practical method for boosting the efficiency and performance of diesel engines.

Since water has cooling effect and lower the temperature and decrease the knock of the engine. These results to decrease the vibrations of engine increase the stability and performance of the engine.

### 4.3. Water port injection with pre-mixed ethanol on engine performance

#### 4.3.1. Pre-mixed ethanol additions on engine torque

The following figure 4.7 indicates the amount of torque which produced in the engine at different ethanol contents.

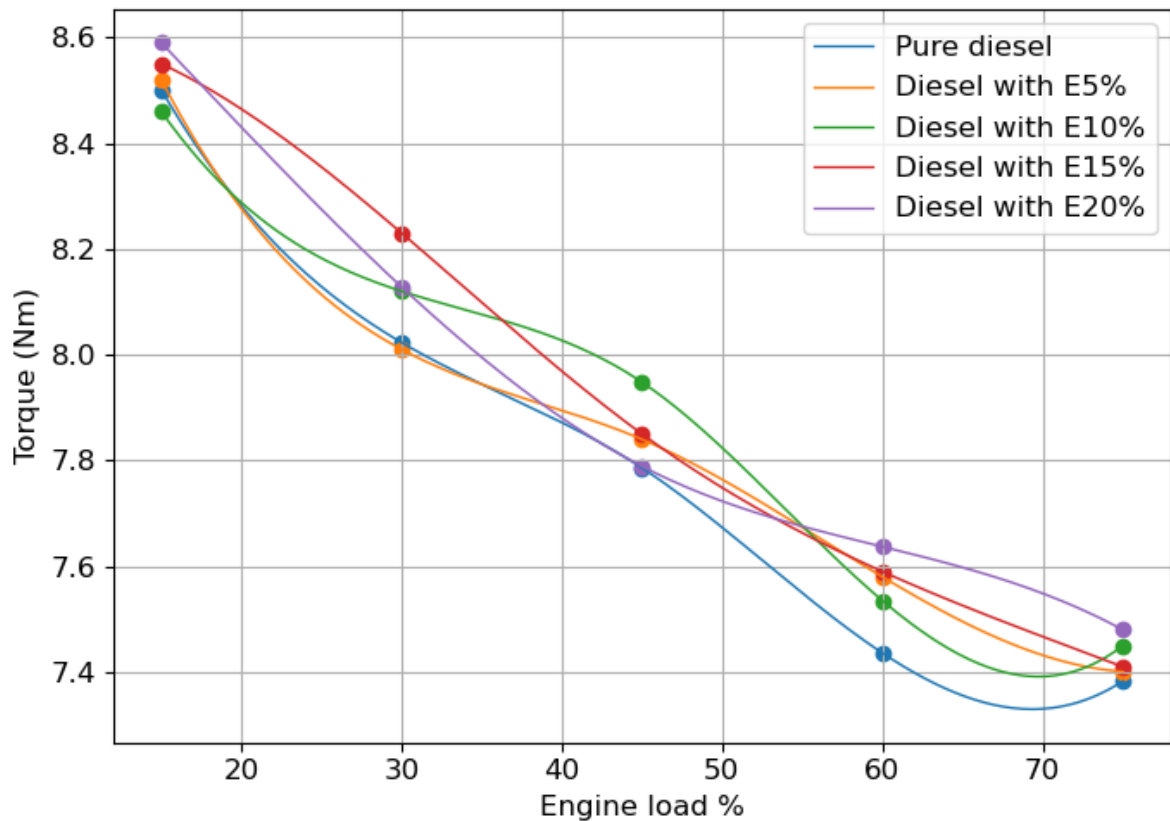


Figure 4.7: Torque in pre-mixed ethanol additions in diesel engine

Figure 4.7 shows that additions of pre-mixed ethanol to diesel fuel in the diesel engine leads to varying changes in torque depending on the ethanol concentration. For E5%, the average increase in torque compared to pure diesel is approximately 3.37%. With E10%, the average increase in in torque is 3.38%, while E15% sees the most significant rise with an average increase of 4.12%, however, when the pre-mixed ethanol concentrations reaches E20%, the average torque gives about 3.834%.

These results indicate that additions of pre-mixed ethanol to diesel fuel give maximum torque, with the most substantial effect observed with E15% the increase 4.12%, in torque observed due to presence of additional oxygen and better combustions. The uneven increases or decreases in torque observed experimentally when adding ethanol to diesel fuel are likely due to the complex interaction of combustion characteristics, engine calibration, fuel properties, experimental conditions, and measurement accuracy. These factors collectively influence how efficiently the engine converts fuel into torque under varying operating conditions and fuel compositions.

#### 4.3.2. Water port injection on engine torque with pre-mixed ethanol

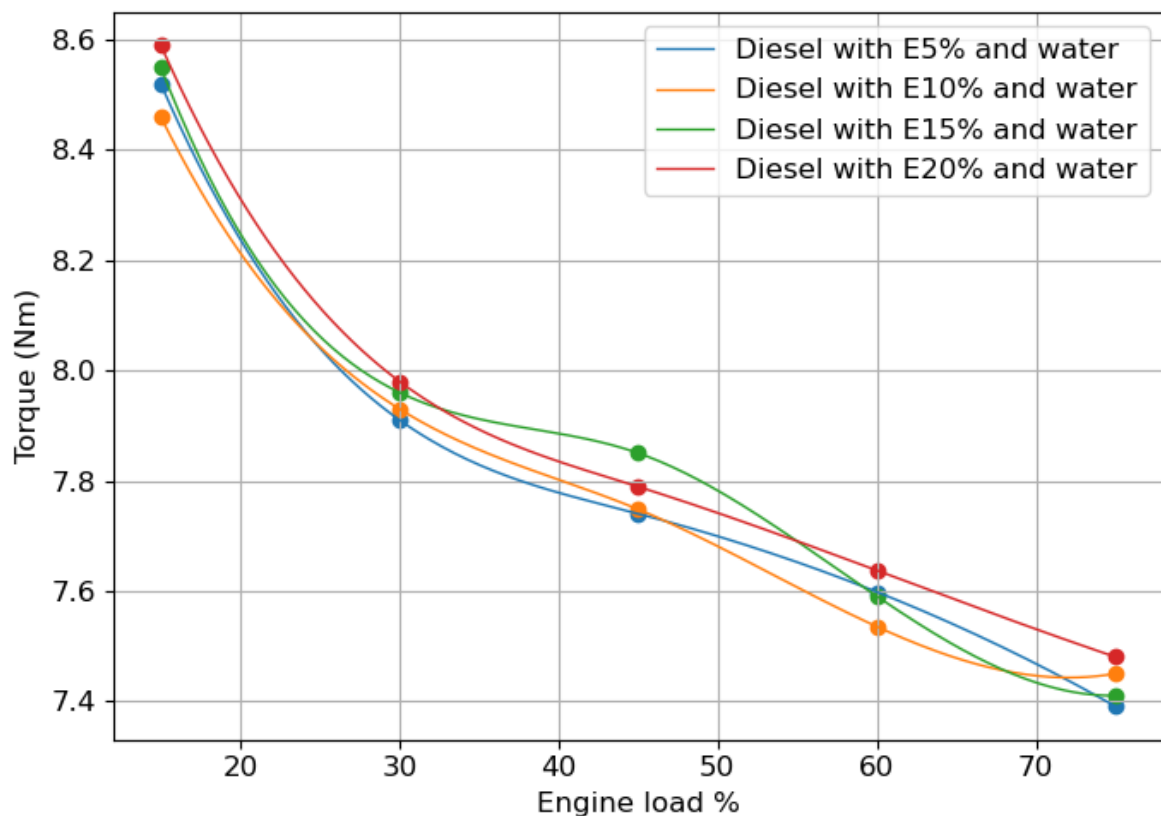


Figure 4.8: Torque in pre-mixed ethanol and water port additions in diesel engine

Figure 4.8 shows that additions of both water port injections and pre-mixed ethanol to diesel fuel in the diesel engine leads to varying changes in torque depending on the ethanol concentration with water port injections. For E5% with water port injections, the average increase in torque compared to pure diesel is approximately 0.1%. With E10% with water port injections, the average increase in in torque is 0.02%, while E15% with water port injections sees the most significant rise with an average increase of 0.92%, however, when the pre-

mixed ethanol concentrations reaches E20% with water port injections, the average torque gives about 0.61%. These results indicate that additions of pre-mixed ethanol with water port injections to diesel fuel give maximum torque, with the most substantial effect observed with E15% and water port injections increase 0.92%, in torque observed due to presence of additional oxygen and better combustions with water.

#### 4.3.3. Pre-mixed ethanol additions on engine brake power

One parameter used to evaluate engine performance was brake power. Brake power refers to engine power measured at the output shaft. Figure 4.9 shows the results of the experiment with the diesel engine.

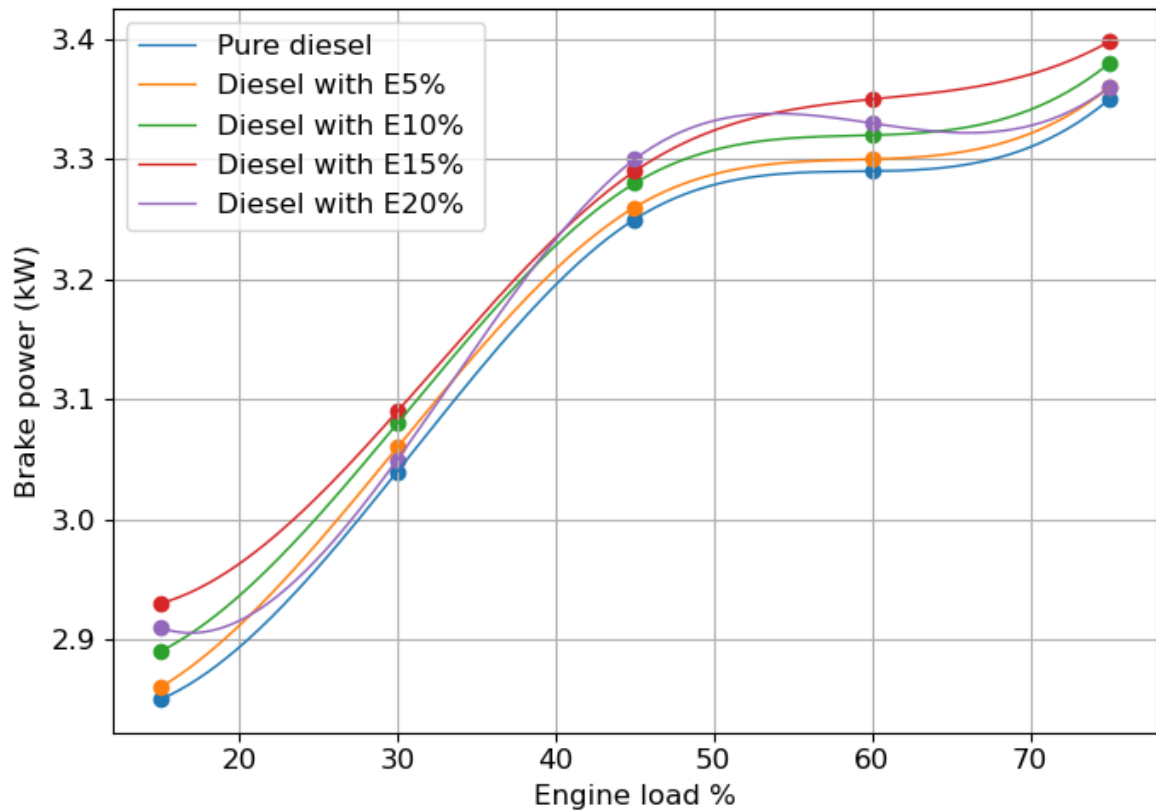


Figure 4.9: Brake power in pre-mixed ethanol additions in diesel engine

Figure 4.9 shows additions of pre-mixed ethanol to diesel fuel in the diesel engine leads to increased brake power across all loads conditions with a significant change. For E5%, the average increase in brake power is approximately 0.36%. For E10%, the average increase rise to about 1.089%. Diesel with E15% shows the most significant rise in brake power, with an average increase of 1.77%, indicating a substantial improvement in engine output. Diesel with E20% sees a similar trend with an average increase of 1.097%.

Overall, the mean average change in brake power across these blends was about 1.77%. This result demonstrates that adding pre-mixed ethanol to diesel fuel in varying concentrations can lead to significant change in brake power. The E15% blend offers the most substantial improvement in brake power.

#### 4.3.4. Water port injection on engine brake-power with pre-mixed ethanol

The decline in engine power is observed when the ethanol content exceeds 15% in fuel blends. This reduction in power can be attributed to inadequate blending of diesel and ethanol at elevated ethanol levels, resulting in a non-uniform mixture.

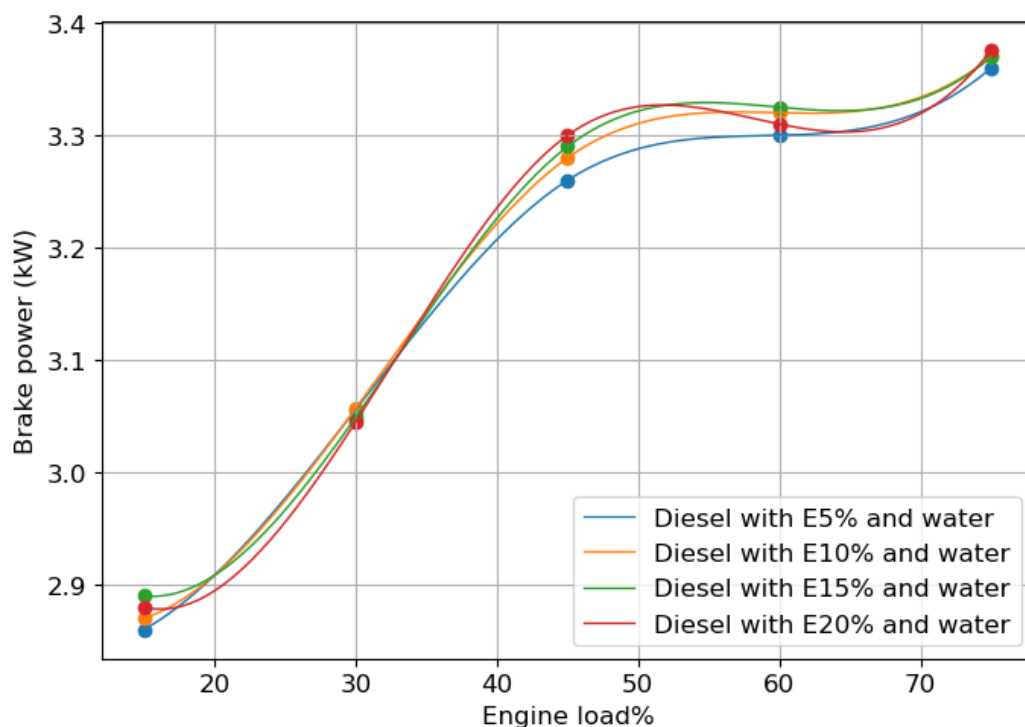


Figure 4.10 : Brake power in water port injections and pre-mixed ethanol additions

Water port injections and pre-mixed ethanol was added in diesel engine shown in figure 4.10, there was an increase in brake power at blended fuels. For the E5% blend with water port additions, the average increase in brake power was about 0.358%. The E10% blend with water port additions had a higher average increase of 0.738%. Diesel with E15% and water port injections shows a significant increase, with an average of 0.848%, indicating a substantial improvement in engine output.

Diesel with E20% and water port injections had an average increase of 0.828%. Overall, the change in brake power across pre-mixed ethanol blends with water port injections was

approximately 0.848%. This result validates that adding water and ethanol to diesel fuel could lead to considerable gains in brake power, suggesting that these blends might be beneficial for applications requiring improved engine performance. The E15% blend with water port injections had the most significant increase, making it potentially optimal for applications where maximum power was desired.

#### **4.3.5. Pre-mixed ethanol additions on engine brake specific fuel consumptions (BSFC)**

The following is a list of findings from the characterizations of blend fuels with water port injection at the intake manifold. Analyze how water port injection affects important performance metrics like power output, torque and BSFC. Examine how engine performance varies with water port injection rates and engine operating parameters. Figure 4.11 the engine's BSFC based on an experimental investigations of emissions characteristics and performance testing rings. Conducting comparison b/n two result's with differing values of BSFC such as 540.04g/kWh with 585g/kWh, the engine that displays the lower BSFC, value (540.04g/kWh) showcase superior fuel efficiency. A decrease in BSFC value indicates that less fuel was needed by the engine to produce a unit of power, highlighting its enhanced fuel efficiency. In the case at hand, the engine including a BSFC of 540.04g/kWh proves to be more effective in converting fuel into power when contrasted with the engine processing a BSFC better the least values. The introduction of pre-mixed of ethanol and water port injections into diesel fuel could have an important influence on engine efficiency, as demonstrated by the values of BSFC. Upon examinations of provided data, it is evident that these blend diverse impacts on BSFC when compared to pure diesel. The addition of pre-mixed ethanol with water port injections in diesel fuel has a significant effect on BSFC in a diesel engine. When comparing BSFC to pure diesel, pre-mixed ethanol and water port injections demonstrates improved fuel efficiency.

The brake-specific fuel consumption decrease with increasing ethanol contents. The load was taken in between 0-80 %, additions of pre-mixed ethanol to diesel results in lower BSFC shows compared to pure diesel this helps to save the fuels of diesel.

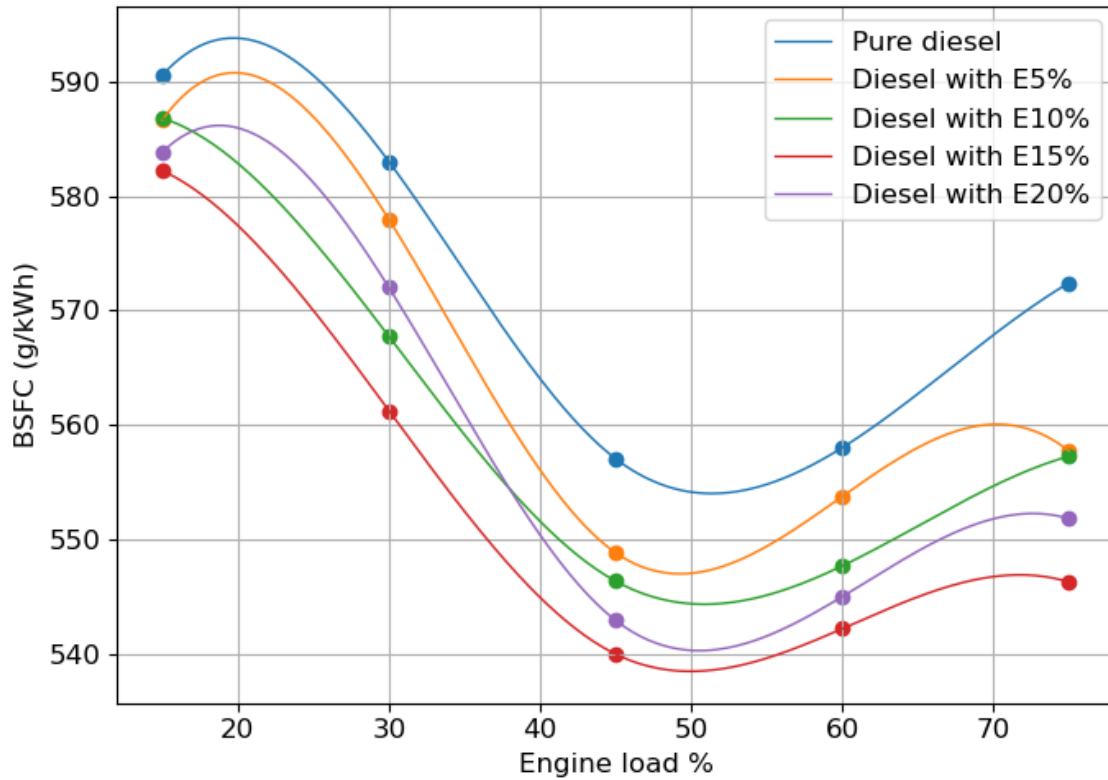


Figure 4.11: BSFC of pre-mixed ethanol additions in diesel engine

Figure 4.11 shows the impact of adding pre-mixed ethanol to diesel fuel on BSFC in diesel engines, indicating significant improvements in fuel efficiency with increasing ethanol content. Diesel blended with E5% ethanol shows a slight decrease in BSFC of 0.374%, while E10% ethanol achieves a more notable reduction of 1.312%. Higher ethanol blends exhibit even greater improvements: E15% ethanol results in a 3.02% decrease in BSFC, and E20% ethanol shows the most substantial improvement with a 6.042% decrease. These improvements in BSFC can be attributed to ethanol's higher oxygen content, which enhances combustion efficiency and promotes more complete fuel combustion. The findings underscore ethanol's potential to enhance engine efficiency by improving fuel utilization and reducing energy losses during combustion, thereby offering the benefits for improving overall fuel economy in diesel engines.

From these entire blended ratio fuels are considered together, the change in BSFC was 6.042%, indicated that pre-mixed ethanol tends to be more fuel-efficient than pure diesel. So the ratio E20% contributes greater overall performance.

#### 4.3.6. Water port injection with pre-mixed ethanol on engine BSFC

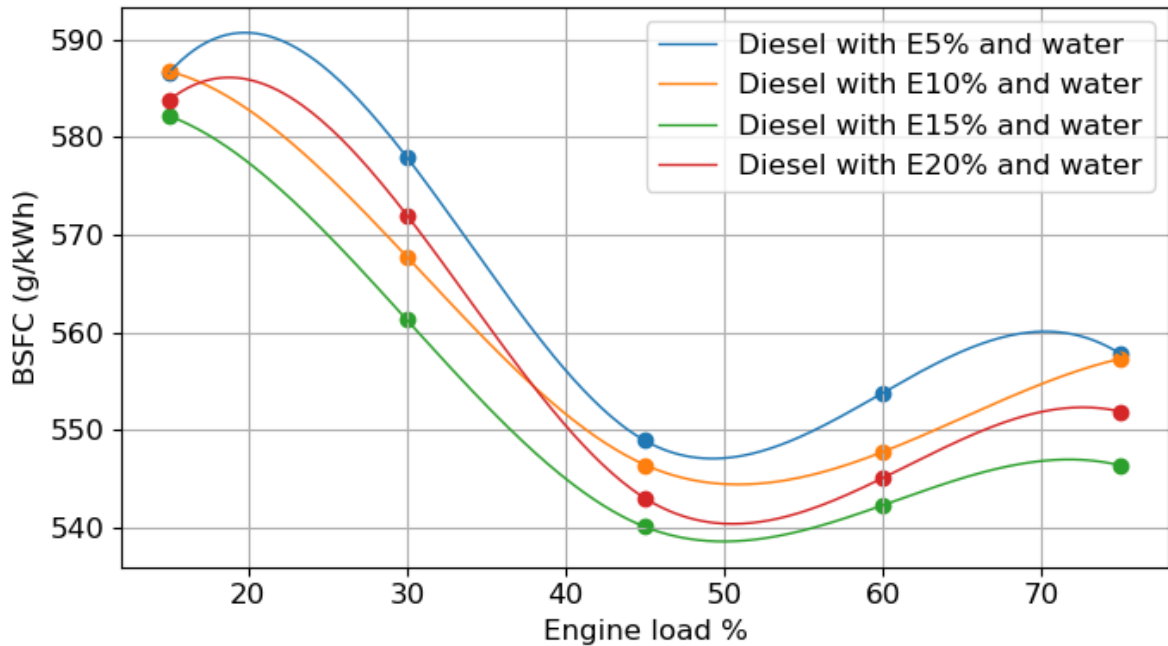


Figure 4.12: BSFC in water port injections and pre-mixed ethanol additions in diesel engine

For diesel fuel at D95% with ethanol at E5% shown in figure 4.12 was pre-mixed and water port injections, the percentage change in BSFC was 0.302%, this was slight decline. As the pre-mixed ethanol percentage rises, it increases the saving amount of fuel. Diesel with pre-mixed ethanol content of 10% and water port injections shows a drop of 1.226%, while diesel with pre-mixed ethanol content of 15% and water port injections shows an increase of 3.16%. The other diesel with pre-mixed ethanol content of 20% and water port injections shows a decline in BSFC of 2.292%, indicating significant fuel efficiency increase. This drop in BSFC shows that pre-mixed ethanol and water port injections help diesel engines run more efficiently and emit fewer emissions.

From these entire blended ratio fuels are considered together, the change in BSFC was 3.16%, indicated that pre-mixed ethanol tends to be more fuel-efficient than pure diesel. So the ratio E15% contributes greater overall performance.

#### 4.4. Water port injection with pre-mixed ethanol on NO<sub>x</sub>, HC, and CO emissions

The effect of injecting water at a rate of 27g/minute on the exhaust emissions of a compression-ignition engine fueled with pre-mixed ethanol has been studied experimentally. The following figures shows the investigation of NO<sub>x</sub> emissions from the engine at different pre-mixed ethanol concentrations, 10Nm torque, and engine speeds, using water port injection

and pre-mixed ethanol injection rates of E5, E10, E15, and E20. Under all operating situations, it was found that NOx emissions produced as engine speed increased. The improvement in gas flow velocity and volumetric efficiency in the combustion chambers at higher engine speeds can explain these phenomena. As result, the air and fuel mix more quickly, this shortens the ignition delay.

#### 4.4.1. Pre-mixed ethanol injections on NOx emissions

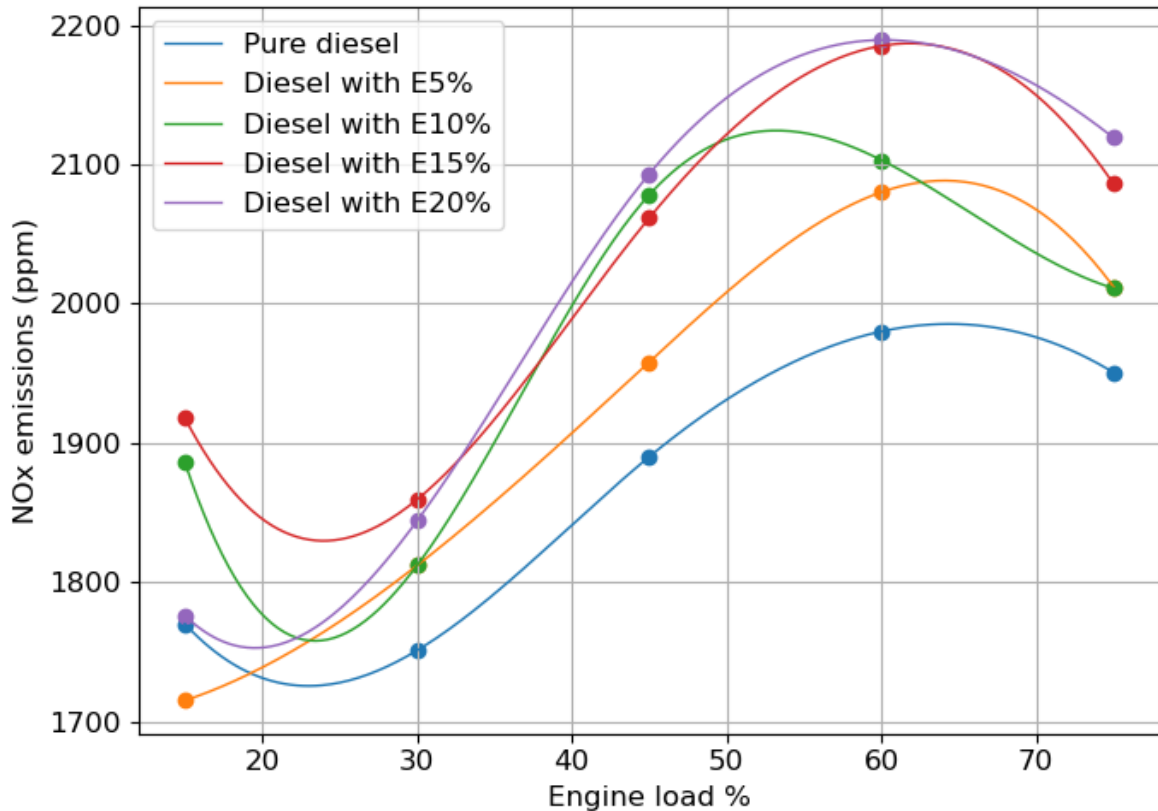


Figure 4.13: NOx emissions in pre-mixed ethanol additions in diesel engine

Adding pre-mixed ethanol to diesel fuel in diesel engines, as shown in figure 4.13, generally results in increased nitrogen oxides emissions across different ethanol blends. Specifically, the data shows that the E5% blend increases NOx emissions by approximately 2.56% compared to pure diesel, while E10% increases by about 5.86%, E15% by 8.19%, and E20% by 7.13%. This increase in NOx emissions with higher ethanol content can be attributed to ethanol's higher oxygen content, which can elevate combustion temperatures and contribute to NOx formation. The varying degrees of increase underscore the complex interaction between ethanol's combustion characteristics, engine experimental limitations, and fuel properties, highlighting the challenges in achieving consistent NOx reductions with ethanol-diesel blends across different blending ratios and engine configurations.

Overall, the percentage change across all pre-mixed ethanol. Addition of pre-mixed ethanol was 8.19%, indicating that adding of pre-mixed ethanol increase NOx emissions from diesel engine. This increase was most disadvantages with the E15% blend, this was increasing NOx emissions in diesel engines. But from the given ratio E5% has least increase in NOx emission which is better.

#### 4.4.2. Water port injection with pre-mixed ethanol on NOx emission

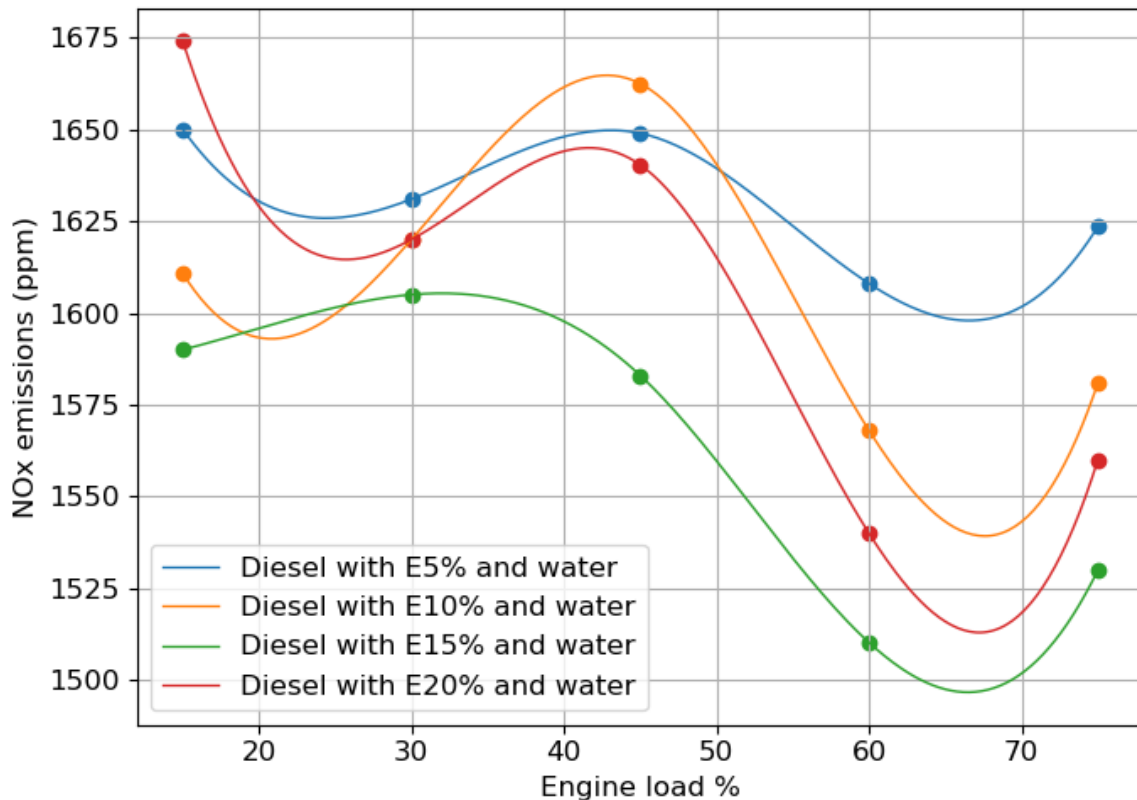


Figure 4.14: NOx emissions pre-mixed ethanol and water port additions in diesel engine

Figure 4.14 shows the combining pre-mixed ethanol and water port injections in diesel engines results in varying reductions in nitrogen oxides emissions across different ethanol contents. Specifically, the data shows an average NOx reduction of about 12.18% with E5% ethanol and water port injections, 13.25% with E10%, 17.68% with E15%, and 13.68% with E20%. These reductions reflect ethanol's oxygen-rich composition, which promotes more complete combustion and can lower peak combustion temperatures, thereby reducing NOx formation. The varying effectiveness of NOx reduction at different ethanol concentrations suggests a complex interaction between ethanol's combustion properties, and operational conditions. Optimal NOx reductions are observed at moderate ethanol blends (E10% to

E15%), highlighting the potential for ethanol-diesel blends to alleviate NOx emissions while considering engine compatibility and performance requirements.

Overall, the percentage change across all pre-mixed ethanol and water port additions was 17.685%, indicating that adding of pre-mixed ethanol and water port injections can significantly reduce NOx emissions from diesel engine. This reductions was most notable with the E15% blend, this was the promising for achieving lower NOx emissions in diesel engines.

#### 4.4.3. Pre-mixed ethanol injections on carbon monoxide emissions

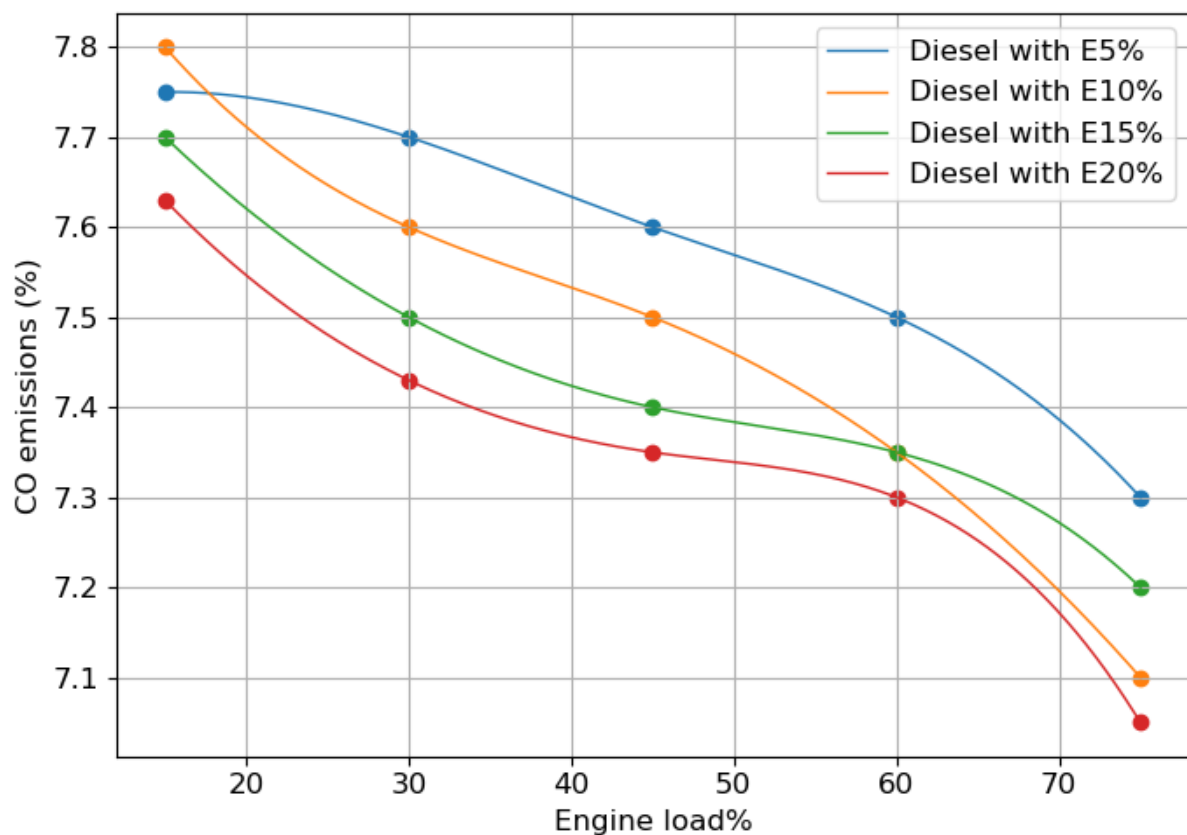


Figure 4.15: CO emissions in pre-mixed ethanol is add in diesel engine

Figure 4.15 illustrates the impact of water port injection on CO emissions at various engine loads to maximum of 10 Nm torque. Factors such as combustion efficiency, air-fuel ratio, and temperature influence CO emissions in diesel engines, especially when ethanol is pre-mixed with the fuel. Because of incomplete combustion and rich circumstances, diesel engines emit more emissions, on the other hand, pre-mixed of ethanol and diesel has fewer emissions because of their cleaner combustion.

The data determines the benefits of adding pre-mixed ethanol to diesel fuel in reducing carbon monoxide emissions across various ethanol contents. Specifically, the analysis exposes a reduction of 15.42% with a blend of E5% ethanol and D95% diesel, 16.58% with E10% and D90%, 16.69% with E15% and D85%, and 17.84% with E20% and D80% compared to using pure diesel alone. These findings underscore that higher ethanol concentrations lead to greater decreases in CO emissions relative to diesel. Ethanol's oxygen content enhances combustion efficiency, facilitating more complete combustion and thereby reducing CO formation. The incremental increase in emission reduction with higher ethanol blends highlights their effectiveness in qualifying CO emissions from diesel engines. However, it's essential to consider engine compatibility and operational parameters to optimize the benefits of ethanol-diesel blends while maintaining overall engine performance and emission profiles within regular limits.

Across all ethanol pre-mixed levels, the overall decrease in CO emissions was about 17.84% for E20. It demonstrates that introducing pre-mixed ethanol injections into diesel fuel was effective in reducing harm full emissions of CO.

#### 4.4.4. Water port injection with pre-mixed ethanol on CO emission

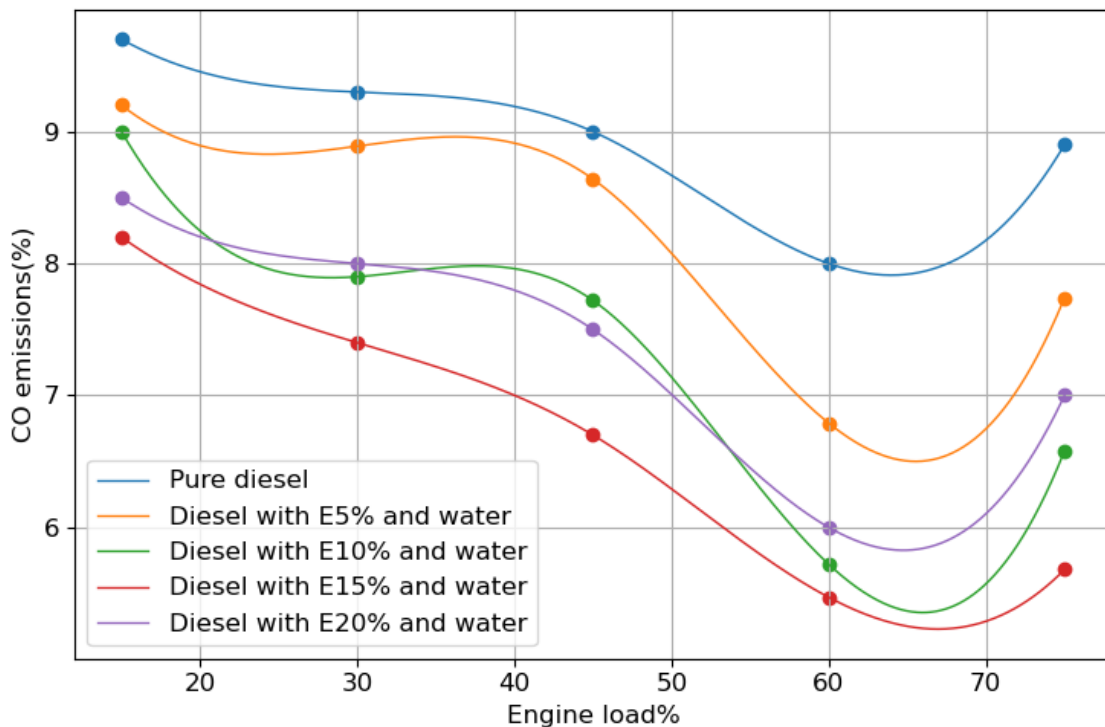


Figure 4.16 : CO emissions in water port injections and pre-mixed ethanol additions

The data from figure 4.16 illustrates the reduction in carbon monoxide emissions achieved by blending pre-mixed ethanol and water port injections with diesel fuel across different ethanol contents. Results show a 12.6% decrease with E5%, 16.59% with E10%, 17.05% with E15%, and 13.35% with E20% ethanol content compared to pure diesel, indicating that higher ethanol concentrations generally lead to greater reductions in CO emissions up to E15%. These reduce emissions from ethanol's oxygen-rich composition, which enhances combustion efficiency and reduces incomplete combustion CO emissions. Among them the slight decrease in reduction observed at E20% recommends potential challenges or optimal blending edges that could influence combustion characteristics and emissions performance. So, ethanol blends show promise in lowering CO emissions from diesel engines, highlighting their role in emission control strategies alongside considerations for engine compatibility and performance optimization.

Across all ethanol pre-mixed and water levels, the overall decrease in CO emissions was about 17.05% for E20. It demonstrates that introducing pre-mixed ethanol and water port injections into diesel fuel was effective in reducing harmful full emissions of CO especially for E20.

#### 4.4.5. Pre-mixed ethanol injections on HC emissions

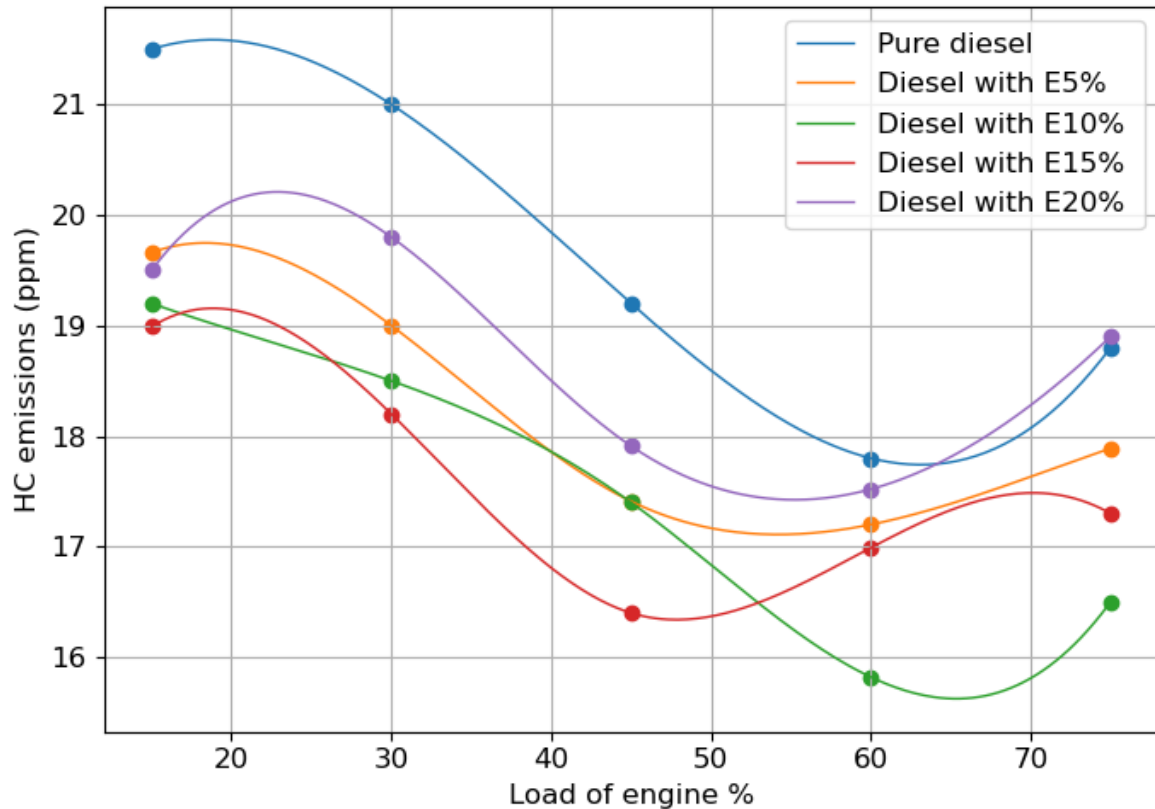


Figure 4.17 : HC emissions in pre-mixed ethanol additions in diesel engine

The data from Figure 4.17 illustrates the varying reductions in hydrocarbon (HC) emissions when using pre-mixed ethanol fuels compared to pure diesel. Specifically, the findings indicate a 7.52% decrease with E5%, 11.06% with E10%, 10.41% with E15%, and 4.55% with E20% ethanol content. These higher ethanol concentrations generally lead to greater reductions in HC emissions up to a point, beyond which the benefits diminish. E10% ethanol appears to offer the optimal reduction in HC emissions among the tested blends. These results highlight the potential of ethanol blends in modifying HC emissions from diesel engines, though the practical benefits should be weighed against factors like engine compatibility and overall emission profiles including nitrogen oxides and particulate matter.

From all ethanol pre-mixed levels, the overall decrease in HC emissions was about 11.06% for E20. It validates that introducing pre-mixed ethanol injections into diesel fuel was effective in reducing harmful emissions of HC.

#### 4.4.6. Water port injection with pre-mixed ethanol on HC emission

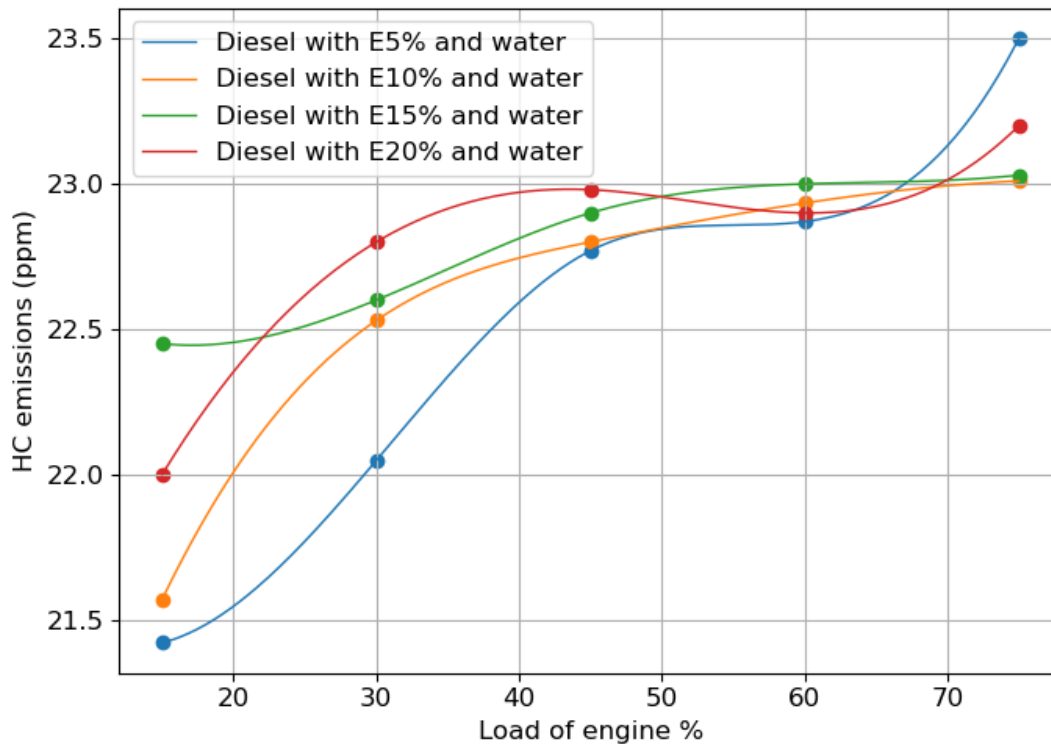


Figure 4.18: HC emissions in water port injection with pre-mixed ethanol

Figure 4.18 indicates additions of pre-mixed ethanol and water port injections to primes increase in HC emissions across varies ethanol contents. Analyzing the data, the percentage increase in HC emissions within an increase of emissions, relative to pure diesel, was found to be 8.18% for a pre-mixed with E5%, 6.99% for E10%, 6.82% for E15%, and 8.57% for E20% depending on the ethanol content.

From all ethanol premixed and water levels, the overall increase in HC emissions was about 8.57% for E20, from the ratios of each fuel E10% was better since the values is less. It indicates that introducing pre-mixed ethanol and water port injections into diesel fuel was not effective in reducing harm full emissions of HC. While water can help reduce NO<sub>x</sub> and soot, it leads to an increase in hydrocarbon (HC) emissions. This is due to the potential cooling effect on the combustion process, where some fuel remains unburned. The main reason for this result is due to HC emissions has greater bonding of carbons and needs more temperatures compared from CO emissions. Even if the experiment was repeated this result also comes due to instrumental or environmental errors was other proposed parameter.

## CHAPTER FIVE

### 5. CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusions

Various tests were accompanied in this thesis work to test the performance of 27g/minutes water port injection systems with pre-mixed ethanol additions in diesel vehicles. The development of the water port injections system was successfully, providing precise and consistent water delivered into the combustion chamber. The findings reveal water port injections alone decreases NOx emissions by 5.83% and slightly enhances torque and brake power by 0.49% and 0.58% respectively, with a 1% saves in BSFC but it increases CO and HC emissions by 7.59% and 7.595% respectively. Overall, water port injections effectively reduced specific NOx pollutants, but trade of emissions for CO and HC emissions.

Pre-mixing ethanol with diesel fuel enhanced combustion efficiency, resulting in more complete combustions and higher cylinder pressure when ethanol is pre-mixed with diesel, CO and HC emissions significantly decrease by 17.84% and 11.06 % respectively, even if NOx emissions increases maximum by 8.19%. This also results in a 4.12% increase in torque, a 1.77% increase in brake power, and a 6.042% rise in BSFC. However, it was observed that higher ethanol concentrations required careful optimization to avoid issues like engine knock and material compatibility concerns.

When comparing conventional diesel engines with those modified to include water port injections and ethanol pre-mixing, the modified engines demonstrated significantly better emission characteristics since diesel engine emits more NOx than HC and CO emissions. Combining water port injection with ethanol pre-mixing results in a 17.055% decrease in CO emissions, substantial 17.68% reductions in nitrogen monoxide emissions and 8.18% increases in HC emissions compared from pure diesel. Torque and brake power increase by 0.92% and 0.82% respectively, with a 2.292% increase in BSFC. Overall, the combined approach of water port injection and ethanol pre-mixing significantly reduces CO and NOx emissions while only slightly increasing HC emissions. This strategy also improves brake-specific fuel consumption (BSFC), making it a promising method for enhancing diesel engine performance and reducing harmful emissions. The synergy of water port injection and ethanol pre-mixing is more effective in cutting emissions than using either method alone, highlighting its benefits.

In summary, the combined approach of water port injections and ethanol pre-mixing specially E15% and water offers a balanced trade-off by significantly increasing BSFC and reducing CO and NO<sub>x</sub> emissions, while slightly increasing HC emissions due to bonding since it needs greater temperatures compared from CO emissions. The peripheral gains in torque and brake power gives this method could enhance engine performance with a manageable increase in fuel consumption. These findings over all support the potential of water port injection and ethanol pre-mixing as effective strategies for reducing harmful emissions and improving diesel engine efficiency within a significant change.

## **5.2. Recommendations**

To optimize and implement water port injections and ethanol pre-mixing in diesel engines, it is recommended to adjust injection parameters for maximum NO<sub>x</sub> reduction and minimal fuel consumptions impact and to determine optimal ethanol blending ratios to enhance efficiency and reduce emissions without causing knock. Developing advanced control mechanisms that adjust injection parameters in real-time based engine conditions and ensuring long-term compatibility and durability of engine components with water and ethanol are crucial. Field testing in various applications should validate laboratory findings. Regular standards should be developed, and policies promoting these technologies should be encouraged. If lab test also is set in ASTU is better to do it easily.

## **5.3. Future work**

The future work should focus on advanced optimization techniques, such as machine learning, to improve water injections parameters, to conduct long-term durability studies to ensure material and component flexibility to water and ethanol content, explore hybrid injection strategies with alternative fuels and advanced combustion methods to examine the effect of varying engine loads and speeds, to extend field testing to diverse real-world applications, perform life cycle environmental impact assessments, conduct economic feasibility analyses, engage which policy makers to develop supportive regulatory frameworks and market incentives. During the study, the injection system of water was taken on the intake manifold. But if the new design of the engine will modify it is possible to inject water directly into the combustion chambers it increase the performance and decrease NO<sub>x</sub> better. The proposed combustion mode involving water port injection could be further studied for heavy-duty diesel engines, potentially enhancing efficiencies and reducing greenhouse gas emissions.

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## APPENDIXES

Table A1: budget for the thesis

| No | Lists                         | Measured in terms of unit                      | Amount in terms of quantity | Single cost(birr) | The quantity of cost (birr) |
|----|-------------------------------|--|-----------------------------|-------------------|-----------------------------|
| 1  | Stationery expense            |  |                             |                   |                             |
|    | Standard print                | Pages  | 400                         | 3                 | 1200                        |
|    | Coloring prints               | Pages  | 14                          | 10                | 140                         |
|    | Service for binding           | Pages  | 4                           | 500               | 2000                        |
|    | Transport cost                | Term   | 12*2                        | 115               | 2760                        |
|    | Labor cost                    | For sample preparation                         | All sample                  |                   | 2000                        |
|    |                               | For test preparation                           | All test                    |                   | 3300                        |
|    | Total lab for all permissions | Getting all lab access                         | All tests                   |                   | 12000                       |
| 2  | Internet                      |  |                             |                   |                             |
|    | Internet package              | GB 32  |                             | 340               | 3400                        |
|    |                               | <b>Sub-total-3</b>                             |                             |                   | 13,160                      |
|    |                               | Total estimated cost                           |                             |                   |                             |
|    |                               | Total cost =subtotal 1 +subtotal 2 +subtotal 3 |                             |                   | 25,000                      |

The results that was taken from the lab test in TM<sub>3</sub>-O<sub>2</sub> diesel engine model are the following,

Table A2: Results of CO emissions in water port addition in diesel engine

|                                  |      |     |     |     |     |
|----------------------------------|------|-----|-----|-----|-----|
| Load in %                        | 15   | 30  | 45  | 60  | 75  |
| CO of pure diesel fuel emissions | 9.6  | 8.0 | 7.5 | 6.6 | 7.4 |
| CO of water ads emissions        | 10.3 | 8.6 | 8.1 | 7.1 | 8.0 |

Table A3: Results of HC emissions in water port addition in diesel engine

|                                  |       |        |        |        |      |
|----------------------------------|-------|--------|--------|--------|------|
| Load in %                        | 15    | 30     | 45     | 60     | 75   |
| HC of pure diesel fuel emissions | 20.9  | 20.5   | 21.2   | 22.8   | 23.8 |
| HC of water add emissions        | 21.88 | 22.032 | 22.338 | 24.786 | 25.5 |

Table A4: Results of NO<sub>x</sub> emissions in water port addition in diesel engine

|  |      |        |      |         |         |
|--|------|--------|------|---------|---------|
| Load in %                                    | 15   | 30     | 45   | 60      | 75      |
| NO <sub>x</sub> of pure diesel fuel emission | 1995 | 1965.5 | 1905 | 1785    | 1775.98 |
| NO <sub>x</sub> of water add emission        | 1915 | 1885.5 | 1825 | 1680.98 | 1700    |

Table A5: Results of brake power (kW) in water port addition in diesel engine

|                               |      |      |      |      |      |
|-------------------------------|------|------|------|------|------|
| Load in %                     | 15   | 30   | 45   | 60   | 75   |
| Bp with diesel fuel emissions | 2.85 | 3.04 | 3.25 | 3.29 | 3.35 |
| Bp of water add emissions     | 2.87 | 3.07 | 3.28 | 3.3  | 3.35 |

Table A6: Results of torque (Nm) in water port addition in diesel engine

|                          |       |       |       |       |       |
|--------------------------|-------|-------|-------|-------|-------|
| Load in %                | 15    | 30    | 45    | 60    | 75    |
| Torque with diesel fuel  | 8.501 | 8.023 | 7.786 | 7.436 | 7.383 |
| Torque of water add fuel | 8.52  | 8.1   | 7.8   | 7.54  | 7.43  |

Table A7: Results of torque (Nm) in pre-mixed ethanol additions in diesel engine

| Load in %        | 15    | 30    | 45    | 60    | 75    |
|------------------|-------|-------|-------|-------|-------|
| Pure diesel      | 8.501 | 8.023 | 7.786 | 7.436 | 7.383 |
| Diesel with E5%  | 8.52  | 8.01  | 7.84  | 7.58  | 7.401 |
| Diesel with E10% | 8.46  | 8.12  | 7.948 | 7.535 | 7.45  |
| Diesel with E15% | 8.55  | 8.23  | 7.85  | 7.59  | 7.41  |
| Diesel with E20% | 8.59  | 8.128 | 7.789 | 7.637 | 7.48  |

Table A8: Results of torque (Nm) in water port addition and pre-mixed ethanol additions

| Load in %                  | 15    | 30    | 45    | 60    | 75     |
|----------------------------|-------|-------|-------|-------|--------|
| Pure diesel                | 8.501 | 8.023 | 7.786 | 7.436 | 7.383  |
| Diesel with E5% and water  | 8.52  | 7.91  | 7.74  | 7.598 | 7.3901 |
| Diesel with E10% and water | 8.46  | 7.93  | 7.748 | 7.535 | 7.45   |
| Diesel with E15% and water | 8.55  | 7.96  | 7.85  | 7.59  | 7.41   |
| Diesel with E20% and water | 8.59  | 7.98  | 7.789 | 7.637 | 7.48   |

Table A9: Results of brake power (kW) at pre-mixed ethanol additions in diesel engine

| Load in %        | 15   | 30   | 45   | 60   | 75    |
|------------------|------|------|------|------|-------|
| Pure diesel      | 2.85 | 3.04 | 3.25 | 3.29 | 3.35  |
| Diesel with E5%  | 2.86 | 3.06 | 3.26 | 3.3  | 3.36  |
| Diesel with E10% | 2.89 | 3.08 | 3.28 | 3.32 | 3.38  |
| Diesel with E15% | 2.93 | 3.09 | 3.29 | 3.35 | 3.398 |
| Diesel with E20% | 2.91 | 3.05 | 3.3  | 3.33 | 3.36  |

Table A10: Results of brake power (kW) in pre-mixed ethanol and water port addition

| Load in %                  | 15   | 30    | 45   | 60    | 75    |
|----------------------------|------|-------|------|-------|-------|
| Pure diesel                | 2.85 | 3.04  | 3.25 | 3.29  | 3.35  |
| Diesel with E5% and water  | 2.86 | 3.056 | 3.26 | 3.3   | 3.36  |
| Diesel with E10% and water | 2.87 | 3.057 | 3.28 | 3.32  | 3.37  |
| Diesel with E15% and water | 2.89 | 3.049 | 3.29 | 3.325 | 3.37  |
| Diesel with E20% and water | 2.88 | 3.045 | 3.3  | 3.31  | 3.376 |

Table A11: Results of CO emissions when pre-mixed ethanol was add in diesel engine

| Load in %        | 15   | 30   | 45   | 60   | 75   |
|------------------|------|------|------|------|------|
| Pure diesel      | 9.70 | 9.30 | 9.00 | 8.00 | 8.90 |
| Diesel with E5%  | 7.75 | 7.70 | 7.60 | 7.50 | 7.30 |
| Diesel with E10% | 7.80 | 7.60 | 7.50 | 7.35 | 7.10 |
| Diesel with E15% | 7.70 | 7.50 | 7.40 | 7.35 | 7.20 |
| Diesel with E20% | 7.63 | 7.43 | 7.35 | 7.30 | 7.05 |

Table A12: Results of CO emissions in water port injection and pre-mixed ethanol injections in diesel engine

| Load in %                  | 15  | 30  | 45  | 60  | 75  |
|----------------------------|-----|-----|-----|-----|-----|
| Pure diesel                | 970 | 930 | 900 | 800 | 890 |
| Diesel with E5% and water  | 820 | 790 | 764 | 750 | 790 |
| Diesel with E10% and water | 800 | 770 | 712 | 700 | 758 |
| Diesel with E15% and water | 820 | 720 | 710 | 690 | 780 |
| Diesel with E20% and water | 850 | 800 | 750 | 700 | 790 |

Table A13: Results of NOx emissions when pre-mixed ethanol additions in diesel engine

| Load in %        | 15      | 30      | 45     | 60     | 75     |
|------------------|---------|---------|--------|--------|--------|
| Pure diesel      | 1770    | 1750.98 | 1890   | 1980   | 1950.5 |
| Diesel with E5%  | 1715    | 1811.96 | 1958   | 2080   | 2012   |
| Diesel with E10% | 1886    | 1811.96 | 2078   | 2103   | 2011   |
| Diesel with E15% | 1917.78 | 1859.28 | 2061.4 | 2185   | 2086   |
| Diesel with E20% | 1776    | 1843.98 | 2093   | 2189.2 | 2119   |

Table A14: Results of NOx emissions at pre-mixed ethanol and water port addition

| Load in %                  | 15     | 30      | 45     | 60     | 75     |
|----------------------------|--------|---------|--------|--------|--------|
| Pure diesel                | 1770   | 1750.98 | 1890   | 1980   | 1950.5 |
| Diesel with E5% and water  | 1650   | 1630.98 | 1648.9 | 1608   | 1623.5 |
| Diesel with E10% and water | 1610.8 | 1605    | 1583   | 1510.3 | 1530.9 |
| Diesel with E15% and water | 1590   | 1605    | 1583   | 1510.3 | 1530   |
| Diesel with E20% and water | 1674   | 1620    | 1640.3 | 1540   | 1560   |

Table15: Results of HC emissions in pre-mixed ethanol additions in diesel engine

| Load in %        | 15    | 30   | 45    | 60    | 75    |
|------------------|-------|------|-------|-------|-------|
| Pure diesel      | 21.5  | 21   | 19.2  | 17.8  | 18.8  |
| Diesel with E5%  | 19.66 | 19   | 17.41 | 17.2  | 17.89 |
| Diesel with E10% | 19.2  | 18.5 | 17.4  | 15.82 | 16.5  |
| Diesel with E15% | 18.99 | 18.2 | 16.41 | 16.99 | 17.3  |
| Diesel with E20% | 19.5  | 19.8 | 17.91 | 17.52 | 18.9  |

Table16: Results of HC emissions water port addition and pre-mixed ethanol additions in diesel engine

| Load in %                  | 15    | 30     | 45    | 60     | 75    |
|----------------------------|-------|--------|-------|--------|-------|
| Pure diesel                | 21.5  | 21     | 19.2  | 17.8   | 18.8  |
| Diesel with E5% and water  | 21.45 | 21.6   | 21.9  | 22.5   | 23.5  |
| Diesel with E10% and water | 21.57 | 21.53  | 20.8  | 19.934 | 21.01 |
| Diesel with E15% and water | 21.42 | 21.048 | 20.77 | 19.87  | 21.5  |
| Diesel with E20% and water | 21    | 21.8   | 21.98 | 20.3   | 21.2  |

Table A18: Results injection rate of pre-mixed ethanol and water port addition

| Load in %                   | 15    | 30    | 45    | 60    | 75    |
|-----------------------------|-------|-------|-------|-------|-------|
| Pure diesel rate ml/min     | 33    | 34.75 | 35.5  | 36    | 37.6  |
| Diesel with E5% rate ml/min | 33.21 | 34.96 | 35.87 | 36.83 | 37.76 |
| Diesel with E10%rate ml/min | 33.65 | 34.68 | 35.81 | 37.2  | 38.23 |
| Diesel with E15%rate ml/min | 33.95 | 34.93 | 35.85 | 36.38 | 37.5  |
| Diesel with E20%rate ml/min | 34.25 | 34.5  | 36.5  | 36.75 | 37.95 |

Table A19: Results injection rate of diesel engine with pre-mixed ethanol content injections

| Load in %                   | 15   | 30    | 45    | 60    | 75    |
|-----------------------------|------|-------|-------|-------|-------|
| Pure diesel rate ml/min     | 33   | 34.75 | 35.5  | 36    | 37.6  |
| Diesel with E5% rate ml/min | 33.2 | 34.95 | 35.85 | 36.8  | 37.75 |
| Diesel with E10%rate ml/min | 34   | 34.68 | 35.8  | 37.1  | 38.2  |
| Diesel with E15%rate ml/min | 34.5 | 34.93 | 35.85 | 36.75 | 37.5  |
| Diesel with E20%rate ml/min | 34.8 | 35.5  | 35.95 | 36.25 | 37.95 |

Table A20: Results injection rate of diesel engine with water port injections

| Load in %                     | 15 | 30    | 45   | 60   | 75   |
|-------------------------------|----|-------|------|------|------|
| Pure diesel rate ml/min       | 33 | 34.75 | 35.5 | 36   | 37.6 |
| Diesel with water rate ml/min | 28 | 29.5  | 30.2 | 30.5 | 31.5 |

Table A21: Results of BSFC g/kWh in water port injections in diesel engine

| Load in %           | 15     | 30     | 45      | 60     | 75     |
|---------------------|--------|--------|---------|--------|--------|
| BSFC of diesel fuel | 590.53 | 582.98 | 557.076 | 558.05 | 572.42 |
| BSFC of water add   | 585.4  | 576.8  | 552.5   | 554.6  | 564.2  |

Table A22: Results of BSFC when pre-mixed ethanol additions in diesel engine

| Load in %                | 15      | 30      | 45      | 60      | 75     |
|--------------------------|---------|---------|---------|---------|--------|
| Pure diesel (g/kWh)      | 590.53  | 582.98  | 557.076 | 558.05  | 572.42 |
| Diesel with E5% (g/kWh)  | 586.456 | 577.017 | 555.57  | 563..37 | 567.6  |
| Diesel with E10% (g/kWh) | 588.776 | 563.5   | 546.23  | 559.25  | 565.6  |
| Diesel with E15% (g/kWh) | 583.6   | 560.24  | 540     | 553.7   | 556.94 |
| Diesel with E20% (g/kWh) | 570.2   | 599.2   | 520     | 549.7   | 549.8  |

Table A23: Result of BSFC in water port injections and pre-mixed ethanol additions

| Load in %                | 15      | 30     | 45      | 60     | 75     |
|--------------------------|---------|--------|---------|--------|--------|
| Pure diesel (g/kWh)      | 590.53  | 582.98 | 557.076 | 558.05 | 572.42 |
| Diesel with E5% (g/kWh)  | 586.63  | 577.94 | 555.88  | 563..8 | 567.75 |
| Diesel with E10% (g/kWh) | 586.776 | 567.74 | 546.4   | 557.74 | 567.3  |
| Diesel with E15% (g/kWh) | 582.2   | 561.26 | 540.04  | 542.26 | 546.33 |
| Diesel with E20% (g/kWh) | 583.82  | 572    | 542.98  | 545.06 | 551.85 |

Table A24: The accuracies of the experimental devices using this study

| Measurements          | Accuracy in this study |
|-----------------------|------------------------|
| Co concentrations (%) | 0.78%                  |
| HC (ppm)              | 1.2ppm                 |
| NOx (ppm)             | 0.75ppm                |
| BSFC                  | 1.3%                   |
| Torque                | 0.98%                  |
| Brake power           | 1%                     |