INFLUENCE OF WATER - DIESEL MICRO-EMULSIFIED MIXTURE ON DIESEL ENGINE PERFORMANCE AND EMISSION

A Thesis submitted to Gujarat Technological University

for the Award of

Doctor of Philosophy

in

Mechanical Engineering

By

Patel Kintu Rajeev
(Enrollment no. 159997119017)

under supervision of

Dr. V. D. Dhiman

GUJARAT TECHNOLOGICAL UNIVERSITY

AHMEDABAD

August - 2022

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ABSTRACT

The diesel engines are utilized for supplying energy for vehicles like marine transportation, road vehicles, industries, etc. The consumption of diesel in internal combustion engines has increased for various applications, leading to the emission of Carbon monoxide (CO), Particulate matters (PM), Carbon dioxide (CO_2), Nitrogen oxides (NOx), Sulphur dioxide (SO_2), which is a matter of concern. Engine modifications and the use of alternative fuels play a significant role in reducing emissions. Using Biodiesel and some types of Nano additives, adding catalytic converters and exhaust gas recirculation (EGR) the engine performance can be upgraded, and the emission of the pollutants can be reduced with minor modifications. Now a days, water emulsion diesel leads to improved engine efficiency and emission control in diesel engines. An attempt is made to study the effect of Water Emulsified Diesel (WED) fuel performance in the traditional diesel engine. In this analysis, water emulsion fuel in three different proportions, such as WD10, WD20, and WD30, are used in a single cylinder four-stroke diesel engine. For each water emulsion, combinations of two surfactants, namely Sorbitan monooleate(Span80) and Polyoxyethylene sorbitan monooleate(Tween80), are used at a concentration of 2%. The electromagnetic and mechanical approaches are used for establishing the emulsified fuel. A parametric study of emulsion fuel is done in the laboratory before use. For prepared emulsion fuel density, kinematic viscosity, flash point, and gross calorific value were tested in different accredited laboratories. The major advantage while using this method is that no modification of the engine is required. Experiments are carried out at different load conditions of 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg at constant speed of 1500 rpm. The non-emulsified diesel promotes better-indicated power, and the brake thermal efficiency is superior while using WD20 in the exising engine, as per the experimental findings. With WD30 emulsified fuel engine performance, brake specific fuel consumption (BSFC) and mechanical efficiency (ME) are ideal. Using WD emulsion fuel, there is a drop in the combustion temperature because of the high latent heat of absorption in the inner phase water particles. Regarding emission characteristics, WD10 emits the least amount of CO, and WD20 promotes lower hydrocarbon intensity. WD30 emits the least amount of NOx because water brings down the peak flame temperature. For lower load conditions, minimum smoke emissions is achieved with WD10 and WD20 compared to pure diesel. The particulate matter(PM) emission is significantly decreased by applying the WD30 for the higher load. It is observed that the methodology used to prepare diesel water emulsion gives stable alternative fuel for conventional diesel engine. In general, emulsified diesel combined with water outperforms pure diesel fuel in terms of emission and engine efficiency.

Keywords: Water emulsion Diesel, Emission, Surfactant, engine performance, Span80, and Tween80.

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Patel Kintu Rajeev
(159997119017)

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List of Abbreviations

EGR	-	Exhaust gas recirculation
WED	-	Water Emulsified Diesel
WD10	-	Water diesel 10%
WD20	-	Water diesel 20%
WD30	-	Water diesel 30%
TDC	-	Top dead centre
BDC	-	Bottom dead centre
HLB	-	Hydrophilic liphopilic balance
LPG	-	Liquid petroleum gas
CNG	-	Compressed natural gas
IC	-	Internal combustion
CI	-	Compression ignition
SI	-	Spark ignition
O/W/O	-	Oil-water-oil
W/O/W	-	Water-oil-water
BSFC	-	Brake specific fuel consumption
BTHE	-	Brake thermal efficiency
DEE	-	Di-ethyl ether
EIVC	-	Early inlet valve closure
BMEP	-	Brake mean effective pressure
IMWI	-	Indicated mean effective pressure
MCC	-	Mixing control combustion
HC	-	Hydrocarbons
ME	-	Mechanical efficiency
IP	-	Indicated power
ALFOX	-	Nanoyl phenol ethoxylates
SPAN80	-	Sorbiten monooleate
TWEEN80	-	Sorbitol ester
PM	-	Particulate matter
VCR	-	Variable compression ratio

BTDC	-	Before top dead centre
WPO		Wood pyrolysis oil
BSU		Bosch smoke unit
OCE		Oxygen enriched combustion
BSEC		Brake specific energy consumption
K10D		10% kerosene by volume blend with diesel
DE2D		2% diethyl ether by volume blend into diesel
DMC		Dimethyl carbonate

List of Symbols

kWh	-	Kilo-Watt Hour
kW	-	Kilo-Watt
kg	-	Kilo-Gram
rpm	-	Revolution Per Minute
ppm	-	Parts Per Million
NO_x	-	Nitrogen oxide
NO_2	-	Nitrogen dioxide
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
SO_3	-	Sulfur trioxide
SO_2	-	Sulfur dioxide
O_2	-	Oxygen
%Vol	-	Percentage of volume
°C	-	Degree Celsius
N	-	Newton
mg/m^3		Milligram per cubic meter
kg/kWh		Kilogram per kilowatt hour

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CHAPTER 1

Introduction

1.1 Overview

The transport and many power generation sectors are widely dependent on the diesel engine compared to the conventional gasoline engines. Unlike gasoline engines, diesel engines have several advantages like fuel economy, higher reliability, and more durability. Even though the pollution level caused by the diesel engine is high due to the emission of pollutants like NOx, hydrocarbons, and carbon monoxide, Due to these pollutants, the ozone layer in the earth may deplete, resulting in several environmental issues leading to climate change[1]. The direct fall of UV and IR rays to the human body may cause damage to cells which would, in turn, cause severe diseases. Fuel improvements with little or no modification to the engine hardware can address the emission problem. Among these improvements, fuel oxygenation by mixing water, alcohols, ethers, and biodiesel is an effective means to tackle the emissions concern with no change in the engine performance.

It is known that diesel derives from fossil fuels, considered a non-renewable energy resource [2]. The excess usage of diesel as a fuel would demand a higher amount of diesel, which would affect the reserves of fossil fuels. Researchers have aimed to implement better alternatives for different types of fuel engines to control the emissions [3]. Using biodiesel, and some Nano additives, by adding exhaust gas recirculation (EGR) and catalytic converters, the engine performance can be improved, and the emissions of the pollutants can be reduced. These techniques would enhance the engine combustion, which in turn helps improve the system's performance [4]. The formation of the gases like nitrogen oxide and particulate matter can be reduced by adding water emulsion in diesel (WD) [5]. It would also enhance fuel combustion, which will result in higher performance. Comparative performance analysis of a single cylinder compression ignition engine with diesel, 5% and 10% water in diesel emulsion as fuels have been investigated [6]. Effect of variation in engine operating parameters like inlet pressure, friction coefficient compression ratio, equivalence ratio, and a residual gas fraction on engine performance parameters, i.e., adequate power, effective power density, and total heat loss, have been analyzed. Analysis has been conducted based on isobaric heat addition and isochoric heat rejection. They were assuming temperature variable specific heats and the composition of alternative fuels.

In W/D emulsion fuel, there will be a decrease in the combustion temperature due to the high latent heat absorption of the inner phase water particles. It helps to reduce the NOx emission in the system [7]. The heat sink effect in W/D emulsion and hydroxyl concentration in the water lowers NOx emission. The micro- explosion phenomena can reduce the formation of HC and CO emissions. There is a chance for increased production of HC and CO as the water concentration in the fuel increases [8]. It is due to the rise in hydroxyl concentration, leading to the increased oxidation of carbon to CO. The HC and CO emissions increased when the ignition delay and the low flame temperature of the emulsion fuel increased in the system [9]. While using the W/D emulsion method, the brake thermal efficiency is increased by 3.5%, and the measurement is increased by 25.2% compared to the diesel engine [10]. With water emulsified fuel, the brake power and torque can improve by 5%. About 3 to 5% of engine performance can improve by adjusting the injection timing and the crank angle [11]. The ambient temperature, ambient pressure type of the diesel engine and engine operating conditions may influence the efficiency and performance of the system. All these factors, type of surfactant, and percentage of the surfactant can also be the factors that would affect the working of the system with water emulsion

The micro-explosion behavior will reduce the temperature attained in the combustion chamber by emulsion fuel, and the fuel gets atomized when the emulsion fuel burning occurs. This is due to the micro explosion in the tiny particles of water and will result in soot minimization and combustion enhancement [12]. For the characteristic improvement of the engine, the water emulsion fuel method will be the appropriate method. The homogeneous mixing of the process concentrates on mixing the water with the base diesel, which may create an unstable emulsify character [13]. Any surface-active species will increase the stability of most oil–water systems. Hence, a surfactant can be added to the emission diesel to improve the emulsion fuel stability [14].

Even though water emulsion fuels have many advantages regarding engine performance, they have some environmental disadvantages. The immiscible liquids already bound to the solution may split when it reaches the equilibrium span [15]. The surfactant helps preserve the oil and gas mixtures, which would help minimize the atmospheric surface tension by the adsorption of air and liquid at the interface and reduce the interfacial stress between the oil and water. This is done by adsorbing the ice-liquid interphase [16]. The most commonly used surfactants are Sorbitan monooleate (Span 80) and Octylphenoxy poly ethoxy ethanol (Triton X-100) [17]. The stable emulsion will retain its consistency within a certain amount of time. The time for this retaining will be dependent on the factors like viscosity, specific gravity, percentage water content, and temperature of the surfactant. The interfacial stress will create a strong emulsion between two immiscible fluids in the W/D emulsion liquid [18]. The emulsion stability of the W/D can be improved using a combination of a non-ionic surfactant, creamy layer, and coalescence region. The significant factors that have to consider for the quality of the W/D emulsification phase are surfactant concentration, water concentration, and stirrer speed. 1% is the optimum concentration value of surfactant and stirrer speed at 5000 rpm in W/D emulsification [19].

1.2 Diesel engine

The diesel engine uses diesel as fuel, and the ignition of fuel in the combustion chamber is done by the elevated temperature of the air in the cylinder. The compression of the air is the primary process that helps in the working of the diesel engine. So this engine is known as Compression Ignition Engine (CI Engine). The air compression will increase the cylinder's temperature to a higher rate. It results in the spontaneous ignition of the diesel fuel injected into the combustion chamber [20]. The diesel engine has the highest thermal efficiency compared to all other engines.

1.2.1 Four Stroke Diesel Engine

The four strokes in the diesel engine will be suction, compression, power, and exhaust.

1. Suction stroke – In the suction stroke, the inlet is open, the exhaust valve is closed, and the piston moves from TDC to BDC. This process implies that the crankshaft had completed half of the revolution, indicating the cranking during the first cycle. A pressure difference had created in this stroke. Hence, the air enters the cylinder via an air filter.

2. Compression stroke – In this stroke, the inlet and exhaust valve are closed. The piston movement has been carried out from BDC to TDC in this phase. The air in the compression stroke will be compressed to a ratio of 1:20. The diesel oil used will be sprayed into the cylinder using an injector, and the auto-ignition process will be carried out in this stroke.
3. Power stroke – The power stroke moves the piston from TDC to the BDC, and the valves like the inlet valve and exhaust valve are closed in this stroke. The burnt gases produced will force the piston to move down till the injection of fuel is completed.
4. Exhaust stroke – The exhaust valve is open in this stroke, and the inlet valve is closed. The movement of the piston in this stroke will be from BDC to TDC. The crankshaft revolves half of the rotation, and the energy produced is transferred via the flywheel. The pollutants and the burnt gases produced will be eliminated using the outlet port [21].

1.3 Performance factors of an engine

Certain parameters must consider realizing the performance of the engine. Some parameters are closely related; hence the value of the parameters or relation between parameters changes, and the performance and efficiency of the system also change [22].

1. Speed – Speed is defined as the rotation of the crankshaft present in the engine. The speed is usually measured in revolutions per minute (RPM). The engine speed would help heat rejection and improve efficiency [23].
2. Thrust - After speeding up the system using the air's passage, a force will produce either on the aircraft engine or its propeller, known as thrust. Generally, the thrust is considered as the force applied perpendicularly to a surface or piston. It measures in newtons (N) [24].
3. Torque – The turning moment produced on the shaft is known as torque. The torque is calculated by multiplying the force that causes the moment by its distance from the shaft. The torque signifies the twisting force in an engine where it exerts itself [25].
4. Power – In an engine, the power defines how fast the work is done. The engine power is usually measured in kilowatt or horsepower. The power may indicate the rated power and output the engine can provide for a certain period [26].

5. Efficiency – the fuel wasted while producing the energy in the engine defines the efficiency of the system or engine. The interrelation exists between the total energy in the fuel and the energy used to perform the work [27].

1.3.1 Diesel as Fuel.

In a conventional diesel engine, the air is compressed to very high pressures, thus reaching the auto ignition temperature of the diesel fuel. The fuel is in the form of spray with high pressure injected into the combustion chamber at that ignition temperature. Without this technology, there will be no alternative sources to burn a conventional diesel and a mixed air charge. The minimum temperature at which the fuel can produce an explosive mixture with air is called the corresponding fuel's flash point. The temperature at which the fuel can burn without an external source, like a flash of fire, is called autoignition temperature. The potential for dangerous exhaust emissions such as aldehydes, oxides of nitrogen, and oxides of carbon, particulate matter, and hydrocarbons is unbelievable health and environmental concern. The amount of harmful elements in the exhaust emissions will be reduced by adopting particular techniques.

1.3.2 Unsolved issues regarding the diesel fuel

Although diesel fuel performs very well as a fuel for diesel engines, it is difficult to solve the drawbacks associated with fuel use in the combustion chamber, summarised below.

1.3.2.1 Depletion of fossil fuel

Twenty years ago, it was observed that the quantity of availability of petroleum products was limited and expensive. Ever-increasing population and their need for more than everyday amenities are driving up the number of vehicles and hence the consumption of diesel. The transportation in India was a wide range of petroleum relays. At present, India imports 80% of its total petroleum resources from other countries. Petroleum resources are not renewable natural resources that cannot be regenerated quickly and have taken thousands of years to revive. At the same time, the price of petroleum products is rising in parallel with the increasing demand. Hence there is an urgent need to develop alternative fuels due to the heavy demand for petroleum products in the current years, which will deplete shortly. So there exists an urgent need to find alternative fuels. The scientists and researchers in developing and developed countries are looking forward to developing and testing new fuels.

1.3.2.2 Emission

Emission from gasoline and diesel engines is a significant cause of air pollution, leading to the development of alternative fuels. Exhaust emissions from many vehicles into the atmosphere cause extreme pollution, which contains harmful elements that can adversely affect human life.

NOx emission

The higher burning temperature and accessibility of oxygen inside the ignition chamber depend on the emission of the oxides of the nitrogen. The oxides of the nitrogen react with the environmental gases and produce ozone. This production of the ozone will cause the generation of the photochemical smog. The long-term impacts of the NO emission are the development of cyanosis, especially on the toes, shapes, and lips. The adverse changes in the cell structure of the lung wall are also a significant effect of nitrogen oxide. Those tiny particles penetrate deep into the lung tissue and destroy it.

The combustion temperature will mainly depend on the formation of the oxides of nitrogen. But it is identified that the significant oxide of nitrogen produced during fuel combustion is NO. As a result, there is no NO emission during combustion. A NO portion will be converted into the NO_2 during exhaust and expansion. The atmospheric NOx molecules react with the moisture, ammonia, and various compounds to form particulates and nitric oxide vapors. Ozone is formed by the reaction of the NOx particles with volatile organic compounds, which reduce lung functions and cause lung diseases.

CO emission

The CO discharge is caused by incomplete combustion of the fuel, increased chamber temperature, and variation of the fuel-air mixture. The high fuel-rich compounds induce carbon monoxide during heavy-duty vehicle loading speeds or initial conditions. Carbon monoxide represents an undesirable emission and the loss of chemical energy. Carbon monoxide is formed due to the excess combustion temperature and air ratio. The non-uniformly of fuel or air mixture inside the combustion chamber strongly influences the formation of carbon monoxide.

HC emission

The absorption of carbon and hydrogen by cracking rate, incomplete combustion, and lubrication of the oil films of the fuel are the leading causes of hydrocarbon emission. The increase in hydrocarbon discharge is caused due to absence of adequate oxygen for participating in the reaction process with all hydrogen and oxygen in the rich mixtures. The air-to-fuel ratio for the diesel engine is relatively linear compared to the gas engine. Compared to the gasoline engine, the flue gas discharge in the compression ignition engine is more petite. When flue gas discharges into the air, they lead to irritation and give off a foul odor.

Particulate matter

Particulate is nothing but the tiny solid and fluid particles released from the combustion chamber of the automobile. The emitted particulates from automobiles involve a small amount of matter of carbon and inorganic substances. Diesel is cheaper than gasoline, so people have relied heavily on diesel engines since a decade ago. Compared to the gasoline engine, the diesel engine emits more particulate matter, which is about ten times more than that of the gasoline engine.

The reason for the emission of the particulate matter from the exhaust gas is listed below;

- Combination of very tiny particles of partially burned fuel.
- Partly burnt lubricating oil
- Ash content of fuel oil
- Water and sulphates

Smoke emission

Smoke is the traditional measure of combustion quality. Smoke is the content material of unburnt soot particles and particulates. Due to various reasons, the exhaust fuel plume will be visible. Larger engines are more likely to emit visible smoke.

Carbon dioxide emission

The engine emits carbon dioxide due to the complete combustion of fuel in the combustion chamber. The complete combustion of the HC will produce water and carbon dioxide. However, carbon dioxide is non-toxic and achieves more attention, leading to the greenhouse effect.

Oxides of sulphur emission

The various oils originating from the natural process will cause the emission of oxides of sulphur, since this natural oil contains varying amounts of the sulphur, especially SO_3 and SO_2. By eliminating the sulfur oxides from the fuel entirely or partially, the emission of sulphur can be eliminated.

1.4 Need of alternative fuels

The diesel engine demand has identified uncertainties in two dimensions over the past two decades. Initially, the price of fossil fuel was so high that it caused problems for the wealth of the importing countries. The price difference between diesel and petrol per liter has decreased over the years, yet there is a good chance for the next prize between diesel and petrol.

The combustion of fossil fuels increases the value of the global carbon dioxide level, resulting in global warming. The scarcity of conventional sources is alarming, and alternative sources for internal combustion engines have promoted research into energy sources worldwide. Pollution control measures have been introduced in all countries to reduce vehicle emissions. Regulators are concerned with carbon dioxide, hydrocarbons, particulate matter, carbon monoxide, and nitrous oxide. In the case of vehicles running on diesel, the factors of concern for reducing emissions are the temperature of the exhaust air, exhaust gas recirculation, the filters, and the catalytic converter. Figure 1.1 shows the diagrammatical representations of the necessity and benefits of alternative fuels. The primary needs for the alternative fuel are following;

- Environmental benefits and energy security
- Greenhouse gas emission
- It can be used in spite of diesel fuel

- Minimum modification in engine
- Eco-friendly
- Renewable
- Reduction of transportation cost

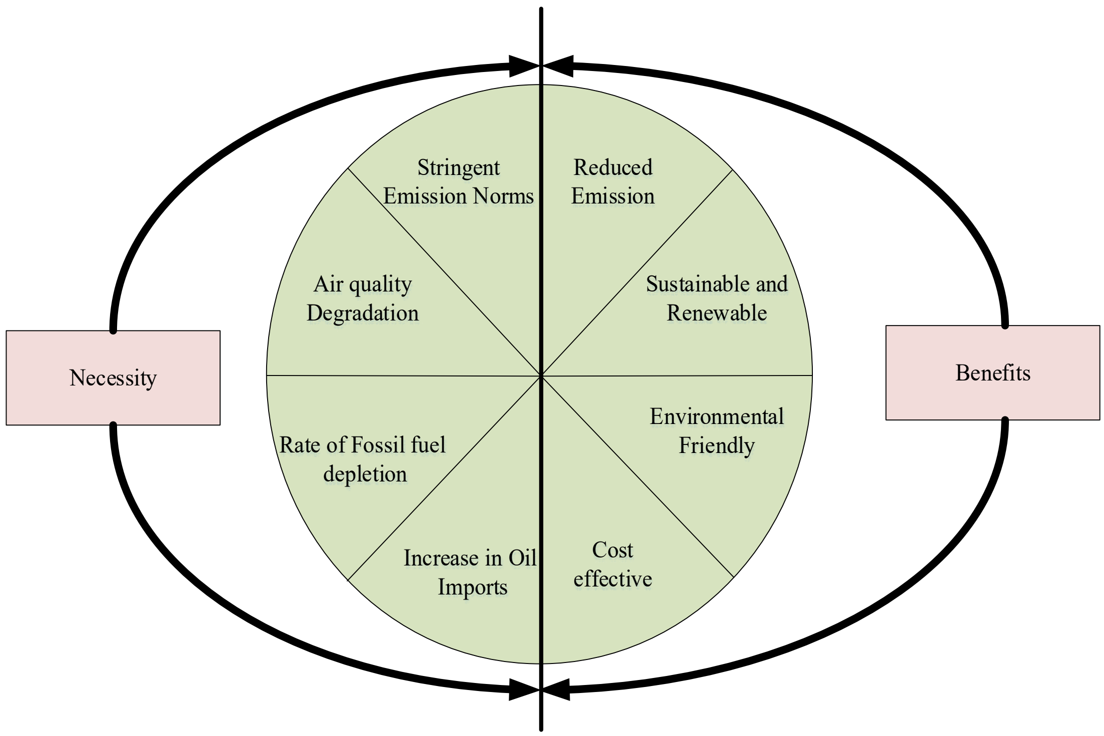


FIGURE 1.1: Necessity and benefits of alternative fuel

1.5 Alternative fuels for diesel engine

The engine design and operation parameters of the engine with the chemical characteristics of the fuel effects performance parameters, the characteristics of the exhaust emission, and the effect of the combustion process. Fuel to be used as a diesel fuel must have the following features;

- The fuel with low auto-ignition temperature must have a high cetane number. The best mixture of the charged fuel must have high volatility.
- The fuel must have a high flash point and high fire point.
- The fuel should produce minimum odor and smoke after the fuel combustion.
- It should be non-abrasive and wear resistance.

- It should be associated with the minimum ignition leg to reduce fuel knocking. The used fuel must have minimum possible kinematic viscosity.

CI engine usually the diesel is used as the fuel. Evaluation of the alternative fuels derived from various sources such as biomass and vegetable oil are suitable alternatives to traditional fuels that are available in gaseous, liquid, and solid phases.

In the future, producing petroleum and crude oil products will be expensive and complicated. There is an increase in the demand for fuels as vehicle use is ever increasing. The currently available fuels are scarce and costly. There is a need to focus on alternative fuels to avoid shortages and reduce the costs of crude oil fuels. The high-use vehicles such as heavy load carriers, earth movers, recliners, trucks, and lorries use diesel as fuel as it has a high compression ratio. Due to the fluctuations in the price of crude oil in the International markets, diesel fuel prices are highly variable. It is essential to adopt alternative fuels to reduce petrol and diesel usage to reduce air pollution.

Alternative fuel is the fuel that can use in the current engine with minor changes in the structure. The alternative fuel is used either in its pure form or blended with the diesel. In addition, the primary cause of global warming is the emission of fossil fuels. Many countries have adopted various techniques to control the pollution caused due to the consequences of igniting the fossil fuel in the combustion chamber. The researchers conduct multiple investigations to study the engine's performance after the injection of the alternative fuel into its combustion chamber. Alternative fuels used are biodiesel and vegetable oil.

1.5.1 Advantages of using alternative fuel

The alternative fuels are made from highly durable and reliable raw materials. For example, from sugar cane, potatoes, corn, and starch, alcohol is produced.

- Biomass and biogas plants are easy to install with the raw materials available.
- Easy and cheaper availability of natural gas.
- Needs little care for maintenance.
- It can be easily produced.

1.5.2 Disadvantages of using alternative fuel

- There is a chance of induction ignition and backfire in the engine.
- It is difficult to store and handle.
- Require high running cost and capital cost

1.6 Possible alternative fuels for diesel engine

There are generally three types of fuels. They are liquid phase fuels, solid phase fuels, and gaseous phase fuels. The primary fuel used in automobiles is petroleum-based fuels. However, some automobile engines use gaseous fuels like compressed natural gas and liquefied petroleum gas. In the following section, different alternative fuels used in the IC engine are discussed briefly;

In the 1800s, when technologies for using petroleum products as fuel were not developed, the IC engine was tested on various fuels. During the development of the diesel engine by Rudolph, coal sludge was used. This coal sludge was mixed with water to produce an emulsion. Figure 1.2 shows the possible alternative fuels for diesel engines.

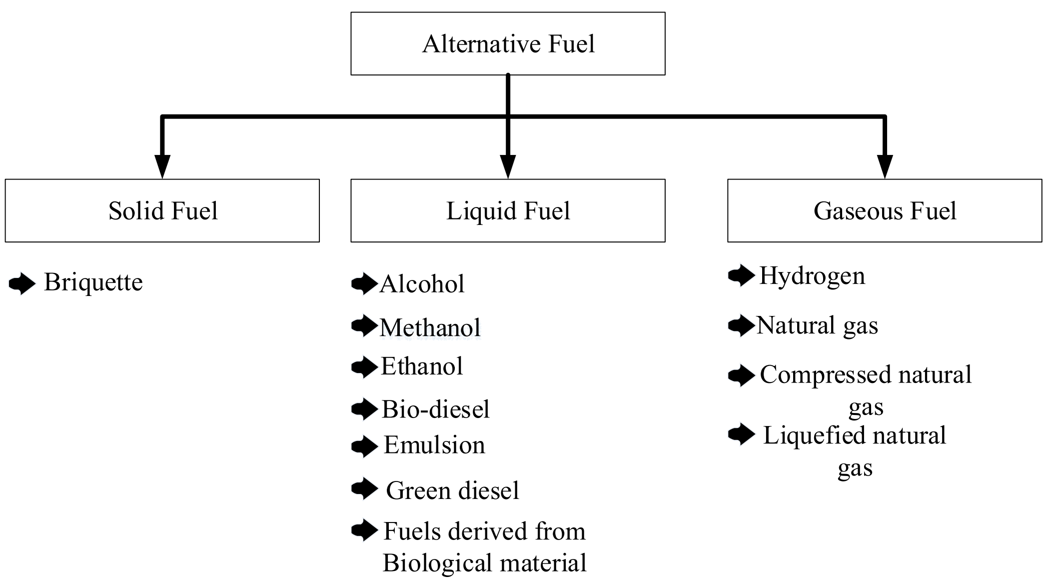


FIGURE 1.2: Different alternative fuels

1.6.1 Liquid Fuels.

Importantly, liquid fuels are used as fuel in IC engines. These have low viscosity and high calorific value. In the category of liquid fuel, the most commonly used alternative fuel is selected as alcohol, ethanol, and biodiesel.

1.6.1.1 Alcohol

Alcohol is a better fuel than other alternative fuels in performance. Alcohol is available from natural resources and can be manufactured. Methyl alcohol and ethyl alcohols are the two widely used types of alcohol.

1.6.1.2 Methanol.

Methanol is called methyl alcohol and is prepared from the distillation process. Here hardwood at a temperature of about 3500^0C and high pressure is used for the distillation operation. The methyl alcohol contains an energy content of 3.7kWh/L with more significant toxicity. Due to this higher toxicity, it cannot use as a fuel in diesel engines.

1.6.1.3 Ethanol

Sorghum, cassava, corn, sugar beets, barley, sugarcane, etc., are the primary raw materials for the preparation of ethanol. The grain is ground and cooked with water to convert the starch to sugar with enzymes. Then sugar is fermented with yeast to produce raw ethanol, and raw ethanol is distilled to remove impurities. Ethanol alone is used as an alternative fuel. Ethanol mixed with gasoline can be used as an alternative fuel to automobiles. This blending is called gasohol. The e-diesel or dishol is a mixture of ethanol and diesel; it functions as an alternative fuel. The oxygen content in the molecular structure of the ethanol can promote the combustion process of such alternative fuel. They reduce emissions and enhance performance.

1.6.1.4 Bio-diesel

Biodiesel is an alternative fuel from vegetable oil, animal fats, animal oils, and waste cooking oil. It is produced by the process called transesterification. It attracts as an environmental pure alternative fuel in a diesel engine. The main advantages of biodiesel are it is biodegradable, produces less emission, and is non-toxic. The reduction of CO_2 emission is higher when compared to fossil fuel emission, maintains the ecological balance, and protects the environment. The emission of CO and HC is lesser. It contains oxygen molecules in ester that provide clean burning during combustion.

1.6.1.5 Emulsion fuel

The alternative fuel of the diesel engine used without any engine modification is called emulsion fuel. It is produced by mixing two un-mixable liquids like oil and water. They were separated by a boundary layer and stayed suspended on one another. The emulsion is not in stable form because it has two phases continuous and dispersion. But it is stabilized by using different surfactants. Using it as an alternative fuel in the diesel engine reduces the combustion temperature, which causes the reduction of NO_x emission and particulate matter emission. The surfactant completely burns out without leaving any exhaust gases. The use of emulsion fuel is economically reliable and environmentally friendly fuel.

1.6.2 Gaseous Fuels

Gaseous fuels are assumed to be the most acceptable fuel for an IC engine because their physical delay is considered negligible compared to liquid and solid fuels. However, due to the lower density of the gaseous fuel, using these fuels as fuel in an internal combustion engine reduces the engine's volumetric efficiency. Some of the gaseous fuel considered as an alternative fuel for diesel engine is briefly explained below.

1.6.2.1 Hydrogen

The vehicle manufacturers tried modified and prototype engines to run on hydrogen fuel as the alternative fuel. The most significant hydrogen features that make this an alternative fuel are fuel availability, lower leakage tendency, low emission, and high energy content.

1.6.2.2 Natural gas

At various levels on the earth's surface, natural gas is received. It is a blend of components, such as methane, with small amounts of other hydrocarbon fuel components. It can be stored in a compressed form or in liquefied form. At a pressure range of 16 bar to 25 bar, the natural gas is stored as compressed natural gas, and at a pressure of about 70 bar to 210 bar and a temperature of -1600^0C it can be stored as liquefied natural gas.

1.6.2.3 Compressed Natural Gas (CNG)

Natural gas is formed by blending hydrocarbon and methane within a suitable ratio. Two methods can prepare natural gas. The first method is the by-product produced from petroleum production. The second method is that it is generated from the gas wells. It can be compressed at a pressure range of 20 to 25 MPa in a cylinder attached to the vehicle, termed a compressed natural gas. India is rich in compressed natural gas, which is more than 689 billion cubic meters of CNG. CNG is one of the significant alternative fuels that will last long to be used as fuel. The CNG is an excellent alternative fuel due to its reduced exhaust emission, fuel quality, maintenance, and low noise power.

1.6.2.4 Liquefied Petroleum Gas (LPG)

Liquefied petroleum gas is a by-product produced in the natural gas production process and in refining petroleum products, which contain propane and butane. This propane and butane have a small amount of propylene and butylene. The LPG properties are considered the same properties as the propane. During the combustion process, there will be a small amount of carbon deposition on the surface of the engine components. This result reduces the life of engine components. The main advantages of the LPG fuel are;

- Reduced emission
- High volatility
- Higher cetane number

1.6.3. Selection of alternative fuel for diesel engine.

The following properties should be considered during the selection of fuel as the alternative fuel to standard diesel;

- The available fuel should be produced locally for easy access and transportation convenience.
- The maintenance cost and capital cost of the alternate fuel production plant should be minimum.
- The produced emulsified fuel must run the conventional engine without major modifications.

The choice of the alternative fuel to diesel depends on the social, political, economic, and technical environmental factors. In 1973, there existed a primary fuel emergency. During that time, the researchers tried various types of fuel for the operation of the IC engines. Inquiries into the exhaust emission, combustion characteristics, and performance parameters suggest that many fuels such as Propane, LPG, alcohol, hydrogen, producer gas, biogas, CNG, and vegetable oils can be used for IC engines of conventional diesel. With unlimited agricultural forestry in India, bio-origin fuels were selected as the best alternative to use as fuel in IC engines.

1.6.4. Required modifications in the engine for the usage of alternative fuel.

The modifications that can be adopted in the engine for the parametric optimization and efficiency improvement are;

- Injection time variation
- Water injection could be done.
- Apply thermal barrier coating on valve facing, piston top surface, and cylinder.
- By adding and removing shims, the compression ratio of the conventional engine can be altered.
- Fuel injection pressure variation. The compression ratio of the variable compression ratio engine can be varied.
- Implementation of the exhaust gas circulation system.

1.7. Effects of introducing water into combustion chamber

The water droplets injected into the combustion chamber have a significant role in the reduction of nitrous oxide emissions. In the combustion chamber, there are mainly two phenomena that take place. One of these phenomena is vaporization which takes place at the time of water explosion into the chamber, resulting in the reduction of the internal energy. The reduction of internal energy which occurs here is proportional to the vaporization enthalpy of the water injected. The other phenomena are the enhancement of the specific heat. The specific heat of the resulting gas after the vaporization increases with the amount of water. Hence the combustion temperature in the combustion chamber will be reduced when the water emulsion is injected into the chamber. Figure 1.3 shows the effect of water emulsified fuel on the combustion chamber.

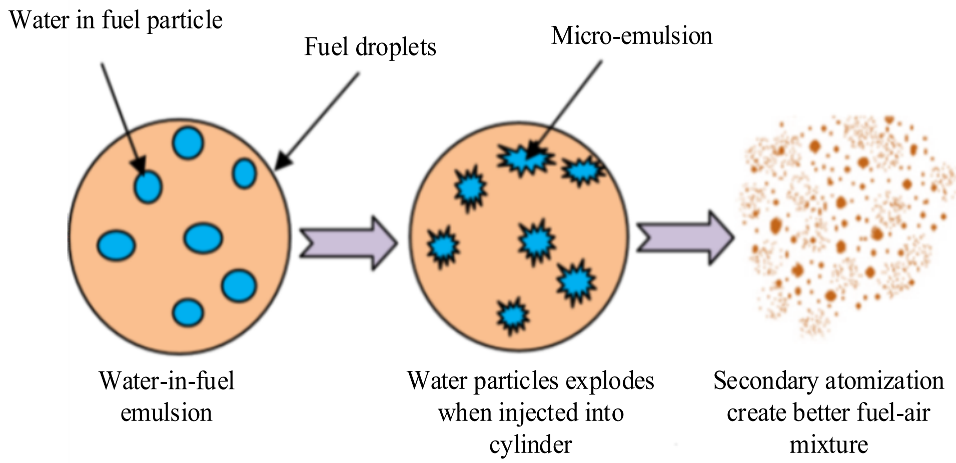


FIGURE 1.3: Water in combustion chamber [28]

Adding the water to fuel is said to start the combustion and reduce the amount of soot as the amount of the water increases. Figure 1.4 shows the methods of water injection. The several techniques used to introduce water into the combustion chamber of the engine can be briefly explained below;

They are:

- Direct water injection
- Intake air humidification
- Water- fuel emulsion

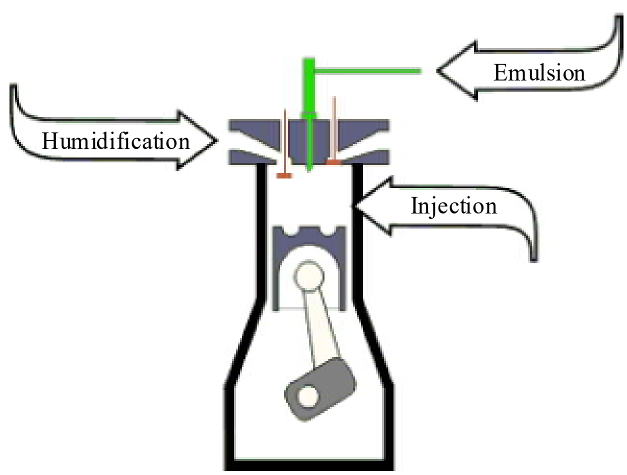


Figure 1.4: Methods of water injection

1.7.1. Direct water injection

In this direct water injection system, separate injection equipment is fitted with the engine to introduce water to the engine's combustion chamber. The common rail system for such types is not helpful. So it requires unique pumps to function as the common rail system. In this system, the injection time should be adjusted, and the water will be directly directed to the engine's combustion chamber. The direct water injection system's benefit is that it requires separate injection equipment for both the water and fuel. The quantity of water injected into the combustion chamber can be regulated by using a different valve.

1.7.2. Intake air humidification

This system leads to a water intake air system, resulting in uniform water distribution in the engine cylinder. Due to this, there has been a 40% reduction in the emission of nitrous oxides. After turbocharger compression, the researchers tested adding the pressurized water to the exhausted air.

1.7.3. Water-fuel Emulsion

The water emulsified fuel can be prepared by blending the water with fuel at a suitable ratio. The emulsified fuel can be prepared with the help of a homogenizer. The resulting emulsion fuel can be subjected to the cylinder with an injecting fuel system. The advantage of this type is that extra injecting equipment is not needed. The main advantage of the intake air humidifying system and direct water injection system is that the engine uses the same injecting equipment and does not require further modifications. Figure 1.5 below shows the structure of water-in-fuel emission.

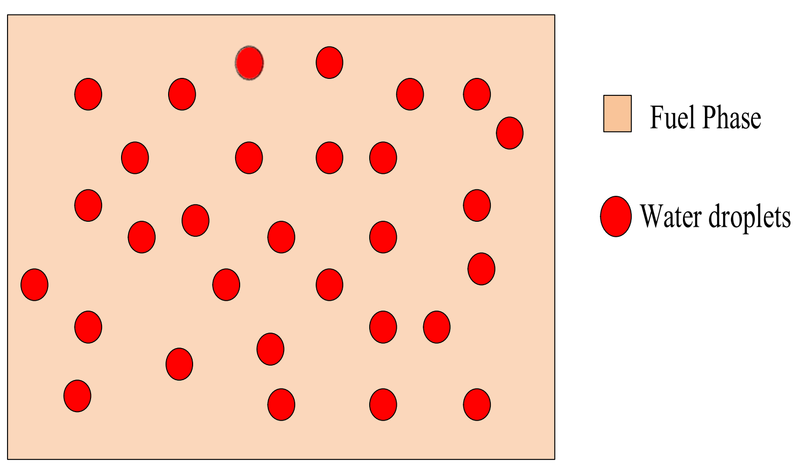


FIGURE 1.5: Water-in-fuel emulsion

1.8. Emulsified fuel

The most commonly used liquid along with the fuel to produce the emulsified fuel will be water. This emulsified fuel can be known as water continuous emulsified fuel since the continuous part of the mixture is water. They are considered a high internal phase emulsion due to the 305 composition of the fuel; in this case, the dispersed fuel becomes the minor component [29]. Compared to the original fuels, the continuous water emulsions are easier to pump, and to make these emulsified fuels easier to handle; they undergo a certain amount of heating and dilution as per the requirement. The used water emulsified fuels will reduce cutter fluids and possess a certain amount of calorific value that helps the fuels to be used appropriately. It would, in turn, reduce the combustion emissions related to the inferior fuels [30].

Two mixtures that will not get immiscible normally can be considered emulsions. It can also be defined as a mixture of two or more liquids present in droplets of microscopic or ultramicroscopic size [31]. For emulsification, the surfactant is the main factor influencing the quality and type of the emulsified mixture [32].

1.8.1. Advantages of using emulsified fuels

- It is possible to reduce the emission of nitrous oxide and smoke with the help of emulsified fuels.
- The emulsified fuel does not affect the uncontrolled pollutants such as poly aromatic hydrocarbons, ketones, and aldehydes.
- It is possible to add normal water to prepare the emulsified fuel instead of distilled water.
- It requires no modification in the engine or a minor modification based on the technology.
- There is a better storage safety measure since the flash point of the emulsified fuel is higher than that of the diesel.

1.8.2. Disadvantages of using emulsified fuels

- The emulsified fuels have lower calorific value because water has no energy value.
- The long-term storage of water emulsion is questionable as it has an issue with instability.

1.8.3. Surfactants

The substance or compound that reduces a liquid's surface tension is a surfactant. The surfactants reduce the surface tension by decreasing the interfacial tension between the two liquids in the mixture. It can reduce the surface tension between a liquid and a solid, lowering the interfacial tension between them. They can minimize act as detergents and wetting agents. Additionally, these surfactants are used as emulsifiers, foaming agents, and dispersants [33]. The selection of appropriate surfactants for the emulsification process is a significant challenge. This proper surfactant selection purely depends upon the HLB (Hydrophilic Lipophilic Balance) value of the surfactant. The surfactant's HLB value is the degree to which the surfactant is hydrophilic or lipophilic [34]. The different kinds of emulsions and their HLB values are shown in table 1.1.

TABLE 1.1: HLB Values of Different Emulsions

HLB Value	Type of Emulsion
<10	Water insoluble (Lipid soluble)
>10	Water soluble
4 to 8	Antifoaming agent
7 to 11	Water in oil emulsifier
12 to 16	Oil in water emulsifier
11 to 14	Wetting agent
12 to 15	Detergents
16 to 20	Solubilize and hydro trope

The HLB value can be calculated as follows;

$$HLB = \frac{(Quantity of\ surfac\tan t1)(HLB surfac\tan t1) + (Quantity of\ surfac\tan t2)(HLB surfac\tan t2)}{Quantity of\ surfac\tan t1 + Quantity of\ surfac\tan t2} \quad (1.1)$$

Usually, the water in diesel emulsion is taken under the category of water in oil emulsion, and the surfactant used along with this emulsion can be taken according to the HLB value. Different kinds of surfactants exist for these emulsions, and their range lies within the value of 7 to 11 [35]. The suitable surfactant for this diesel water emulsion can be taken using the HLB value, which can be chosen from table 1.2.

TABLE 1.2: Surfactants and Their HLB Value for Water in Diesel Emulsion

Surfactant	HLB value
Sorbitan trioleate (Span 85)	1.8
Sorbitan monooleate (Span 80)	4.3
Sorbitan monosterate (Span 60)	4.7
Sorbitan monopalmitate (Span 40)	6.7
Sorbitan monolaurate (Span 20)	8.6
Polyoxyethylene sorbitan trioleate (Tween 85)	11
Polysorbate 60	14.9
Polysorbate 80(Tween 80)	15
Polysorbate 40	15.6
Polysorbate 20	16.7

1.8.4. Solubility of emulsified fuel

It is essential to know the characteristics of the water, such as pour point, cloud point, miscibility, etc. These features of emulsified fuel vary with the amount of fuel used and the ratio of diesel and water in the blend.

1.8.4.1 Solution

A solution is a homogeneous fluid at the molecular level stage and can be defined as a single-phase liquid system. Water diesel blends are the solution of additives in diesel fuel plus water.

1.8.4.2 Cloud Point

The cloud point is nothing but the temperature at which the phase separation or initial crystallization of the fuel begins.

1.8.4.3 Pour Point

The pour point can be defined as the temperature below which the fuel pour will not happen. The fuel will not flow at this temperature. In winter, diesel fuels should be modified with additives to improve flow at a lower temperature to avoid fuel gelling in cold countries or phase separation.

1.8.4.4 Miscible

The miscible is nothing but the misconceptions of two or more components that are mixed in any ratio without separating the two phases. It isn't easy to make a solution with water and oil due to the immiscible property of liquids. This property mainly depends on the temperature. The solution may separate when the temperature is lower than the room temperature.

1.8.4.5 Emulsion

The emulsifier includes tiny droplets like fat in the liquid. Moreover, it is an immiscible liquid. When the emulsion is stored, there will be a separation of two phases takes place.

1.8.4.6 Micro-Emulsion

A microemulsion is water, oil, and a surfactant system, a single optically isotropic and thermodynamically stable solution. The clear solution containing micron-sized droplets is called micro-emulsion. Here the mixture of the water and diesel is taken as micro-emulsion. Water and a small amount of surfactant additive called emulsifier are required to form a microemulsion.

1.8.4.7 Ultralow Interfacial Tension

Interfacial tension is the force of attraction between the molecules at the interface of two fluids in the emulsion. Interfacial tension is measured in milli-Newtons per meter (mN/m). For ultralow interfacial tension, its value is about 10^{-2} to 10^{-4} N/m. The oil/water solubilization capacity increases as the interfacial tension of the micro-emulsion systems decreases. They are affected by the presence of a co-surfactant, electrolyte and temperature, pressure, and oil chain length.

1.8.4.8 Large Interfacial Area

The interfacial area is the total contact area between two liquids in the emulsion. The physical degradation of emulsions is due to the spontaneous trend toward a minimal interfacial area between the dispersed phase and the dispersion medium. The droplet radius decreases with the increase in emulsifier concentration because of the large interfacial area.

1.8.4.9 Thermodynamic Stability

In stable thermodynamic emulsions, the average drop size remains the same. In contrast, droplet size grows continuously with time in thermodynamically unstable emulsions, so that phase separation ultimately occurs under gravitational force. The thermodynamically stable solution, oil, and an amphiphile are a single optically isotropic.

1.8.4.10 Ability to Solubilize

Ability to Solubilization is the ability to form a thermodynamically stable, isotropic solution of a substance ordinarily insoluble or slightly soluble in water by adding a surfactant.

1.8.5. Diesel water emulsion

The diesel water emulsion is one of the critical examples of water emulsified fuel, and recent studies introduced these. The concentrations of the liquids are different from each other, especially when it comes to diesel and water emulsion since diesel is an oil type. The diesel is a lighter liquid than the water; when mixed to produce the emulsion, the diesel will be seen at the top of the mixture, and then water will be seen at the bottom side [36]. Hence, to produce the diesel water emulsion, the liquids should become immiscible, and there should be a bond between them. Appropriate surfactants are used to create the bond between the water and diesel, which help bind these two liquids [37]. Adding a water mixing agent to the diesel would provide some advantages to the system. The main advantage achieved by this method was that it reduces the flame temperature, which in turn helps to achieve the main objective of the diesel water emulsion, which is the reduction of NOx emissions from the vehicle. When water is added to the diesel, it enhances the atomization and mixing process in the system. It helps in the production of droplet microemulsion [38]. Several trials were conducted to produce stable emulsions that will stay the same for a long time. If the emulsion remains still for many days, then larger droplets of chemically coated water may settle at the bottom of the tank. In other cases, some coagulated particles are seen in the emulsion, which will settle down at the bottom of the emulsion tank. Even if agitation is provided slightly in the tank, fuel will be mixed again, and the tank is refueled [39]. It is mentioned that the fuel is created by making an emulsion of diesel and water using an appropriate surfactant, and this emulsion should be stable for a long time. The produced emulsion will be used in the laboratory-installed diesel engine and an eddy current dynamometer [40]. In figure 1.6, the effect of emulsion fuel on engine emission is pictorially represented.

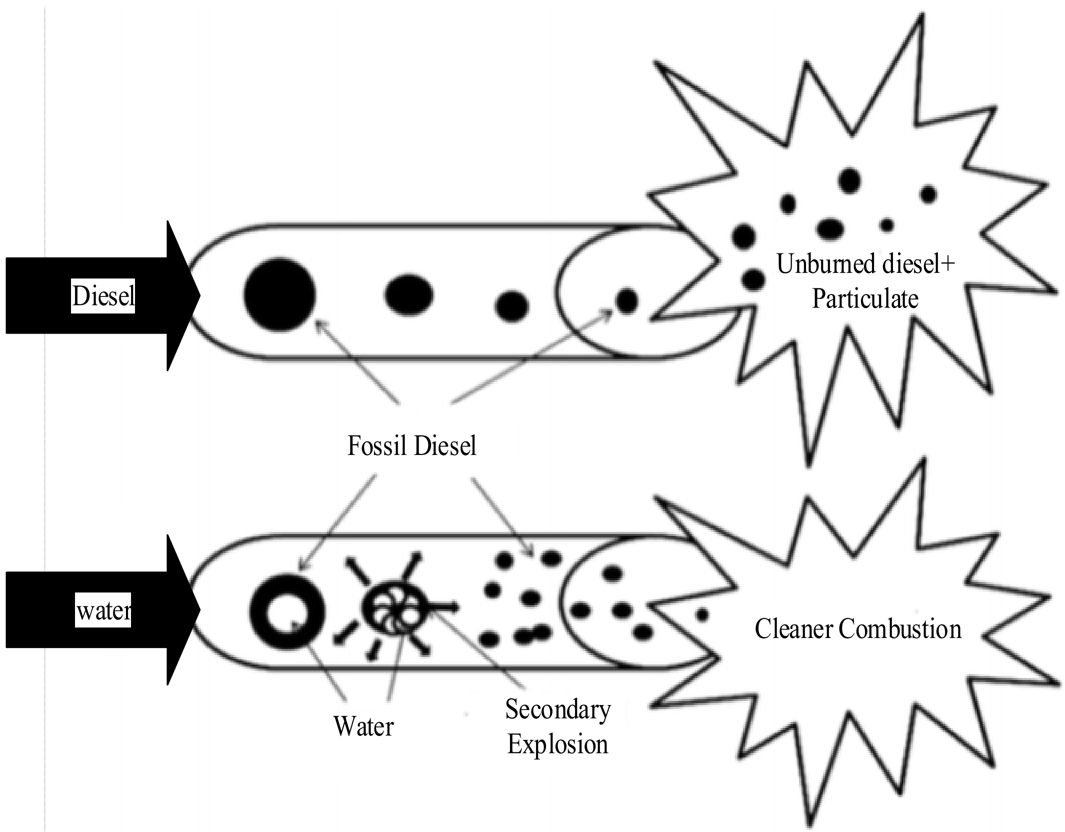


FIGURE 1.6: Effect of emulsion fuel on engine emission [41]

The actual processes occurring in a diesel engine are shown in figure 1.7(a), and the emission of pollutants in the diesel engine can be identified by analyzing this figure. In a diesel engine, the fuel diesel is provided in the fuel tank, and the atomization process takes place in the engine. The temperature in the engine is increased, and hence the fuel combustion takes place. But, the combustion occurred in the diesel engine will be incomplete combustion, resulting in the production of soot, smoke, water vapour, and other pollutants, which in turn increase the pollution level [42].

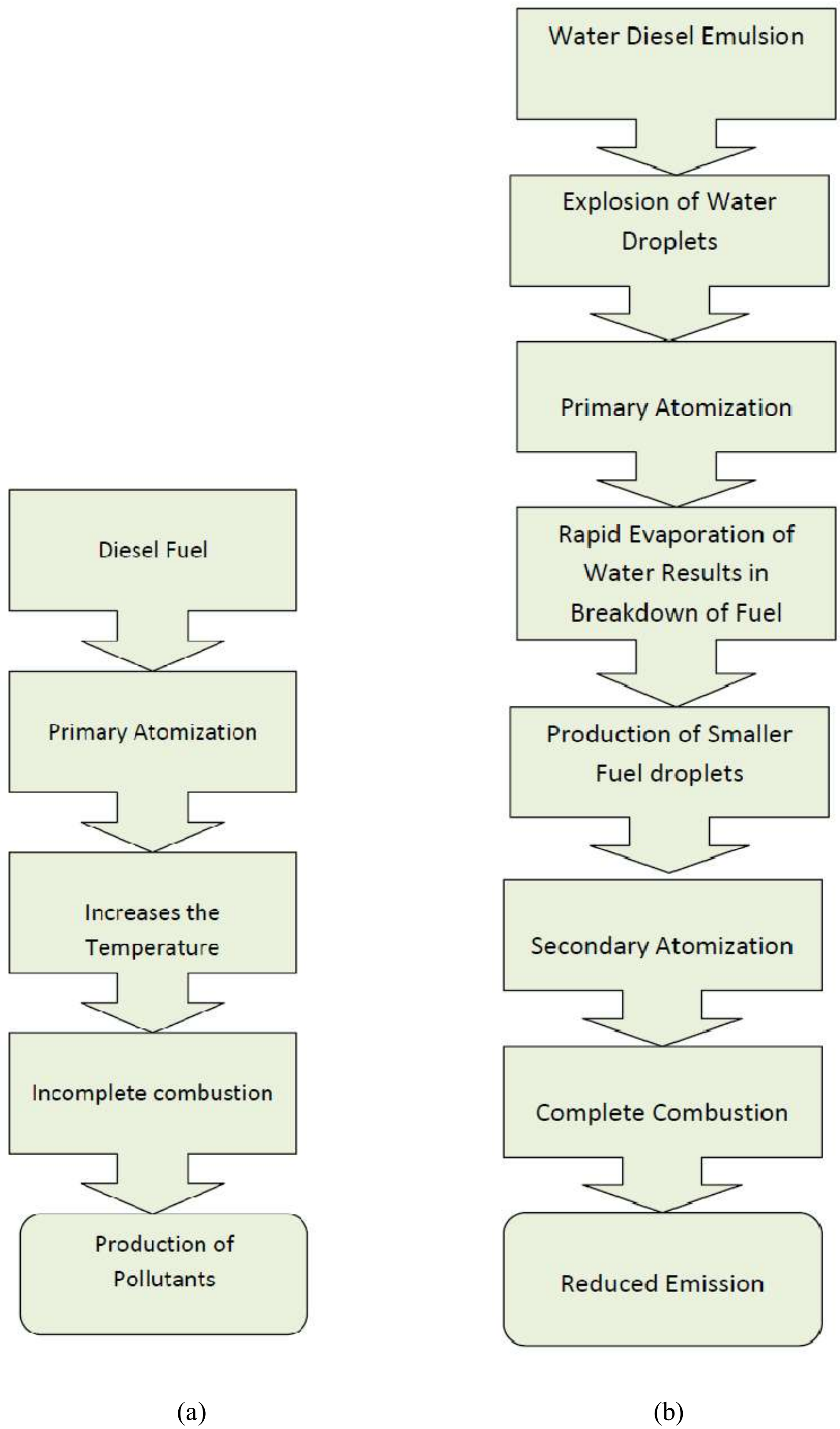


FIGURE 1.7: (a) Processes in a diesel engine (b) Processes in water diesel emulsified fuel engine

The process in the engine when an emulsified fuel is used is shown in figure 1.7 (b), and analyzing this figure will provide the advantage of the water emulsified diesel fuel in an engine. The diesel fuel droplets containing the water droplets are injected into the fuel tank and then into the engine. The water droplets inside the fuel would explode since the temperature inside the engine increases. The explosion adds there by the rapid evaporation of the water, breaking down the fuel droplet in the engine and the water. This would result in the production of smaller fuel droplets inside the engine, so the primary atomization takes place. Since the fuel is seen in smaller droplets in the engine, the complete combustion of the fuel is possible, reducing the pollutants produced in the engine [43].

There will be a secondary atomization process in the diesel water emulsification shown in figure 1.8. The emulsified fuel contains the emulsifier, and microscopic water droplets, encapsulated in diesel fuel. This emulsified fuel and oxygen enter the combustion chamber, and the fuel is super-heated, expanding at a temperature of 60 - 90^0C. Here, the micro explosion occurs, which develops, and flash boils the water droplets. The micro explosion process takes place a 400 -600^0C, which results in the increase of the surface area of the fuel by four times, and this, in turn, increases the diesel droplet's density by 64 times. At a temperature of 600- 1000^0C, the detonation of the emulsified fuel is carried out, and the increased surface area and higher droplet density would result in the complete burning of the fuel at a lower temperature [44].

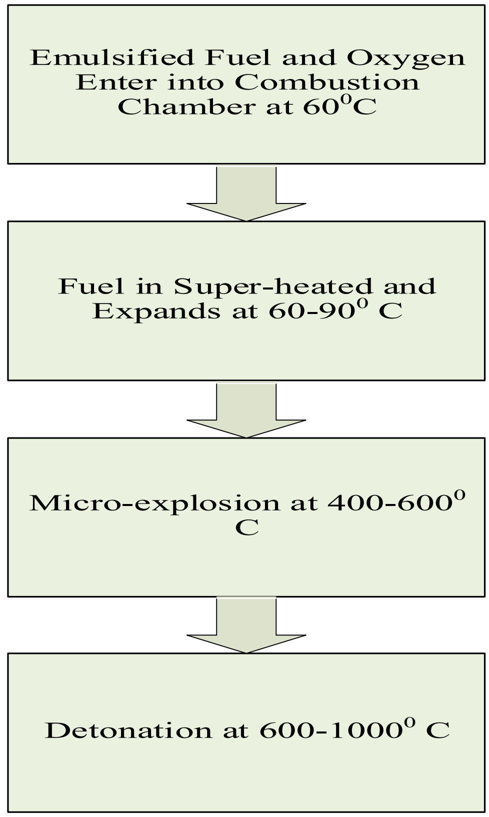


FIGURE 1.8: Secondary atomization process in water diesel emulsified fuel engine

The most effective substitute for the diesel fuel selected is the diesel-water emulsion. Since water and diesel are indispensable, non-iron surfactants are used to form emulsified fuel. Through its shape, the emulsified fuel looks like yogurt or milk, which reduces the concentration of the major controlled pollutant nitrous oxide and other particulates. It does not affect uncontrolled contamination, including ketones and aldehydes. At a temperature of about 40^0C, the flash point of the emulsion increases in the presence of water. The maximum amount of water in the emulsified fuel can be about 50% of the diesel. During the emulsified fuel, the engine power and torque will have a minor change compared to pure diesel. But due to the amount of water composition, the specific fuel consumption increases. There will be lower temperatures in the combustion chamber because of the addition of the water into the pure diesel. This addition will change the corresponding amount of fuel. The reduction of the combustion temperature in the combustion chamber further reduces the emission parameters.

1.9. Combustion process with conventional fuel and emulsified fuel

On spraying the diesel fuel into the combustion chamber of the diesel engine, the fuel will form small droplets ranging from 25 to 100 microns. Because only the surface of the fuel is exposed to air, the larger fuel droplets are no longer completely combustible, and the volatile particulates and hydrocarbons rely on the exhaust gas. The secondary atomization occurs during the injection of the emulsified fuel in the combustion chamber. They result in the sudden formation of steam from the water content in the injected emulsified fuel. This section converts water vapor into tiny droplets in the base fuel environment, smaller than a combustion chamber with conventional fuels. These fine droplets of fuel may have a larger surface area, which boosts combustion. This is a unique characteristic of emulsified fuels and is called secondary atomization. Hence the reduction of nitrous oxide emission and combustion temperature happens due to a decrease in peak combustion temperature. The reduction of peak combustion temperature occurs due to the conversion of water into the steam during secondary atomization. The reduction of particulate matter emission is achieved by the change in the kinetics of the combustion.

1.10. Recent technique of producing water emulsion

In diesel water emulsion or biodiesel water emulsion, water should be in a scattering medium of minimal piece size. In the case of high-grade emulsified fuels, it is essential to keep the size of the particle in the submicron or micron range. The emulsion process can be carried out by adding primary fuel to the centrifugal mixer having a speed range of between 4000 to 10,000rpm. The proliferation of oil droplets and exceptional water is unstable and inevitable; after a certain period, it retains its initial state. As this stage causes separation, emulsified fuel may have a problem at the specified time from the beginning of the production. Hence, a study into the emulsified fuel and supply is still in progress. Also, it is challenging to evaluate combustion efficiency due to the phase separation process. Many experiments have been done to get a stable WDE, and various concentrations of different emulsifiers were tested in the WDE [45]. There have been some recent developments in the manufacture of ready emulsified fuels. One is emulsification, widely used by the upcoming international emulsified fuel suppliers. This can be carried out by using a centrifugal pump which creates impact forces and shear. The centrifugal pump uses the processes of agitation, centrifugation, and compression for the manufacturing of this ready emulsified fuel. The use of a fluid circulatory system can achieve excellent emulsification. Implementing a single technique is not achievable. Therefore a continuous circular is implemented to maintain the complete condition of the emulsion. This type of technology eliminates the first stage of splitting that occurs in the conventional emulsifier.

1.11. Performance Parameters

The critical performance parameters of diesel engines are mechanical efficiency, brake-specific fuel consumption, indicated power, and thermal efficiency.

1.11.1. Mechanical Efficiency

Machine efficiency is the ratio between a machine's output power and input power. The mechanical efficiency of the engine decreases with the increase in engine speed. This is because the friction losses between the moving pairs of the engine increase significantly with the rise in engine speed. The increase of injected fuel per cycle results in reduced mechanical efficiency. The difference in the mechanical efficiency between diesel fuel and emulsion fuel decreases with the increase in engine speed. The combustion is improved due to the micro explosion of the emulsion fuel's water droplets, especially at high load and high engine speed conditions.

1.11.2 Brake Specific Fuel consumption

Brake specific fuel consumption is a parameter that reflects the efficiency of an engine that burns fuel and produces power. The BSFC of the emulsion fuel is higher than that of pure diesel because of the lower heating value of the emulsion fuel. However, in terms of energy input for every unit of power output, the emulsion fuel is more efficient than pure diesel.

1.11.3 Indicated Power

Power output is an important parameter in evaluating engine performance. Based on the operating conditions of an engine, the indicated power varies. The relationship between indicated power and revolution frequency is called speed characteristics. The power lost due to losses (friction power), and the amount of the power generated at the crankshaft (actual power) is indicated power. The power increases slightly as the water percentage increases, the increase in power output for the emulsions is because the emulsion's water influences fuel combustion.

1.11.4. Brake Thermal Efficiency

Brake thermal efficiency increases with emulsion fuel; the improvement in BTE is due to longer ignition delay and micro-explosion phenomena. Further, it indicated that the increase in ignition delay leads to more fuel accumulating, resulting in a higher heat release rate, higher fuel burning in the pre-mixed stage, and better brake thermal efficiency. An increase in flame propagation speed and flame-lift-off length with emulsion fuel promotes better mixing of air-fuel mixture and results in complete combustion and improved BTE. The emulsion fuel with high water concentration could enhance the engine's efficiency at high load conditions; however, there was a drop in efficiency when the engine was operating at low load conditions.

1.12. Diesel Emission

A diesel engine is a hot engine that puts diesel and air inside the engine. The required air temperature of the fire is significantly compressed inside the heating chamber. This produces temperatures high enough for diesel fuel to ignite when inserted into a cylinder automatically. A diesel engine uses heat to dissipate the chemical compounds of diesel fuel and convert it into active energy.

Hydrogen and carbon form the basis of diesel fuel as much of the mineral energy. The total fuel temperature will only produce H_2O and CO_2 in the engine combustion chambers for optimal thermodynamic equilibrium. Factors such as air-fuel ratio, temperature, disturbance in the combustion chamber, air concentration, and fire temperature affect the diesel engine's performance. HC, PM, NOx, and CO are the most dangerous emission products.

1.12.1 Carbon Monoxide

Carbon monoxide is the effect of incomplete or partial combustion where the oxidation process is not entirely taken place. Air fuel mixture is responsible for CO concentration as less than one value for excess-air factor results in high concentration and is called a rich compound. Engine start and sudden acceleration require rich mixtures for combustion, resulting in less oxygen in the combustion chamber and inefficient oxygen for CO_2 conversion. This results in CO concentration. Although CO is formed through operation in rich compounds, a small proportion of CO_2 is also released under harsh conditions due to the effects of kinetic chemicals. The carbon monoxide emission from the exhaust gas is analyzed using infrared sensors devices connected to the exhaust channel. The carbon monoxide emissions from the exhaust gas in diesel engines must be less than 0.1%. A flue gas analyzer is a machine to measures the content of CO in the exhaust gas, as shown in figure 3.16 (d).

1.12.2 Nitrogen Oxides

Diesel engines increase fuel temperature with highly compressed hot air. The air, mainly made up of nitrogen and oxygen, is pumped into the fire chamber. The compressed air is pumped directly into the fuel, which is injected above the pressure in the fire chamber. Heat is created when fuel is burned. Nitrogen and oxygen do not combine naturally, and the high temperature (1600°C) atmosphere in the engine is the source of reaction between oxygen and nitrogen, resulting in NOx production. As a result, it is rational to assume that the temperature and oxygen concentration in the combustion process are the primary determinants of NO_x formation. A high-temperature cylinder, oxygen concentration, and length influence the amount of NO_x created. Most NOx emissions are made when the piston is close to the top dead center, nearer to the nozzle at the start of the ignition phase. The flame temperature is at its peak at this moment. The concentration of emission of NO_x from the diesel engine is between 50-1000ppm. The stack sampling kit monitors the NO_x concentration in the exhaust gas.

1.12.3 Hydrocarbons

Hydrocarbon extraction is done with unburnt fuel due to insufficient heat occurring close to the cylinder wall. Hydrocarbons contain thousands of species, such as aromatics, alkenes, and alkenes. Hydrocarbons are one of the emissions whose emission levels are low. Light loads often cause hydrocarbon diesel emissions because of the lean mixture, which causes the flame speed to be too low for a fire to be completed in the blast. These HC emissions are measured by using a flame ionization detector. The range of hydrocarbon emissions from the diesel engine must be 300-6000ppm. The HC concentration in the exhaust is measured using the stack sampling kit shown in figure 3.16 (b).

1.12.4 Particulate Matter

Particulate matter emissions are the outcome of the partial burning of fuel in the combustion process transferred out by exhaust gas. They are derived from particles of tiny size, incomplete particles of burned fuel, partially burnt lubricated oil, petroleum ash content, and cylinder into oil or sulphates and water. Diesel particles are usually about 15-40nm wide, and about 90% of the PM size is lesser than 1µm wide. The formation of PM emissions depends on many aspects such as the process of heating and enrichment, the quality of the fuel, lubricating oil quality, the use, the fire temperature, and the gas cooling. The particulate matter from the emissions is measured using the concentration are size distribution method, and the equipment used for measurement is a stack sampling kit. The range of PM concentration in the emission must be 50-300nm.

1.12.5 Smoke

It is believed that the emulsion fuel's micro explosion significantly enhances the fuel's evaporation and improves the mixing with air; as a result, less smoke is formed. The emissions of smoke for both pure diesel and emulsion fuel are found to increase with the increase in load at constant engine speed, and it is because of a higher fuel consumption rate at higher engine load. As the engine speed is kept constant, sufficient time is unavailable for combustion of the increased fuel consumption at a higher load. The smoke emission is found to be less with emulsion fuel than that with pure diesel.

1.13. Organization of thesis

Chapter 1: Introduction

Chapter 1 briefly describes the diesel engine, various emissions, alternative fuels, emulsified fuels, surfactants, etc.

Chapter 2: Literature Review

A brief study of emulsified fuels, alternative fuels, their effects on the diesel engine, emissions, etc., from various researches, is included in chapter 2.

Chapter 3: Methodology

Chapter 3 describes the water emulsion diesel and the performance characteristics and emission rates.

Chapter 4: Results and Discussion

Chapter 4 gives the results of BTHE, Mechanical efficiency, Indicated Power, BSFC, and emission like CO, NO_X, HC, PM, etc., for the neat diesel and water emulsion diesel.

Chapter 5: Conclusion

Chapter 5 section contains the conclusion and future scope of the presented work.

CHAPTER 2

Literature Review

2.1 Overview

The challenging task for diesel engines is minimizing gas emissions and improving engine performance. Hence for the reduction of emissions, alternative fuels have a significant role. The majority of these alternative fuels are derived from conventional energy sources. In the field of alternative fuels, researchers have focused on and tried various fuels. The direct use of alternative fuels to the existing engine does not need any engine modification. At the same time, some of these engines need slight modifications with the application of these fuels. The researchers in the field of alternative fuels attempt to develop fuels to reduce the use of fossil fuels for the operation of the internal combustion engine. The emulsification of biodiesel and diesel involves the development of alternating fuels in recent research. The emulsified fuel will reduce the pollutants of the diesel engine as well; it will help to reduce the fuel consumption rate. In developed and developing countries, various emission regulating techniques are implemented to reduce the emission issues. The first step for setting obligations in industrialized countries is the Kyoto protocol in 1997 to reduce the emission level.

2.2. Performance of Diesel Engines

Nowadays, diesel is considered a dominant fuel used in the fields like agricultural sectors, commercial transportation, and industries due to the economy of fuel, durability, efficient power, and mass-duty application. The diesel engines are considered the most efficient combustion engine and also widely produce black smoke and other matters like nitrous oxide, sulphur oxide, which cause air pollution in urban areas and cities. Jeffrey et al. [46] provided a two-stroke opposed piston diesel engine. The engine includes a fluid gap and thermal shield. The cooling fluid encircles the housing of the cylinder by transferring into a helically shaped passageway. This future helps to reduce the temperature to a uniform one. The engine also had an injector that injected fluid into the cylindrical chamber. The combustion fluid is injected through pistons in the same direction as the swirl in the combustion chamber. Reinhard and Knoll [47] designed and developed an AVL to improve the potential of the small uniflow two-stroke engine. Hsu and Bertrand [48] analyzed the combustion of diesel engines and stated that the diesel engine was the most efficient type of heat engine and had wide application in many fields. The combustion process was a significant process used to determine the diesel engine's performance.

Hua et al. [49] studied the direct injection of internal combustion engines. The direct injection method was also simultaneously applied to the light-duty diesel engine and spark ignition gasoline engines. The reason for the use of direct injection to the light-duty diesel engine and spark ignition engine was the improved efficiency of the engine for automotive application. Thereby the performance characteristics of both engines would be increased to some limits. They also investigated that the high-speed direct injection diesel engine achieved considerable success in the commercial field due to the better performance characteristics and fuel economy. But the direct injection high-speed diesel engine and heavy duty diesel engine had a challenge of emission of pollutants. They focused on the historical development of the high-speed direct injection diesel engine. Kannan and Udayakumar [50] stated that the diesel engine plays a significant role in heavy-duty vehicles. It acts as a primary source. Depending on many parameters, the diesel engine's performance and emission characteristics could vary. One significant parameter considered for analyzing the performance and emission of diesel engines was fuel injection pressure. Experimental studies for the performance and emission effect by taking different fuel injection pressure of 150 bar, 200 bar and 250 bar on a light duty direct injection diesel engine were done. By adjusting the tension of the injector spring, the fuel injection pressure was changed, and the performance analysis was done in a graphical manner. They concluded that the fuel injection pressure of 200bar was better for a light-duty diesel engine to improve the performance.

Nashine et al. [51] studied the emission and combustion characteristics of a common rail direct injection diesel engine. They numerically investigated the engine characteristics by considering the compression ignition. The experiment was conducted using fuels like algae biodiesel and diesel. The various compression ratios used to perform the investigation were 16.5-18.5. The simulation work was done with the help of a commercial numerical software Diesel RK for the diesel engine. The internal combustion engine's performance depended on the fluid flow inside the combustion chamber. The results obtained by conducting the experiment with the optimum compression ratio of 17.5 for full load condition was compared with the results from the numerical model. The parameters like exhaust gas temperature, cylinder pressure, brake thermal efficiency, cylinder pressure, and specific fuel consumption are predicted with the implementation of the simulation. This simulation considers carbon dioxide, particulate matter and nitrous oxide emission for a load condition under 100% load at a constant speed. The results show that using algae biodiesel would reduce the torque by 6.66%, nitrous oxide by 0.5%, carbon dioxide by 6.1%, brake thermal efficiency by 2.73%, and particulate matter by 60%.

2.3. Need for alternative fuels in diesel engine

The use of alternative fuels in the diesel engine reduces harmful emissions like carbon monoxide, carbon dioxide, nitrous oxide, sulphur oxide, and particulate matter. Thereby the reduction of the environmental pollution. Alternative fuel is nothing but the fuel other than the conventional petroleum. It protects against the global warming caused due to the emission of pollutants from conventional fuel. The reserves for petroleum-based fuel are limited in number. The resources are limited to some countries, and others need to import petroleum from those countries. So there is a need to produce alternative fuels in the country. Various sources are used to produce alternative fuel economically. Some of the alternative fuels are produced from vegetables. But the studies in this field analysed that the vegetable oil failed to use directly in the diesel engine due to the poor cold flow properties, high viscosity, and low volatility. But the derivatives of the vegetable oil are directly used in the diesel engine as an alternative fuel. The transesterification process is used to derive the alternative oil from the vegetables. Kannan and Pallavi [52] studied hydrogen as an alternative fuel. The alternative fuel that was introduced to overcome them is the fortune of conventional oils. With the oil price increase, the use of alternative fuels increased. More obstacles were overcome to allow the application of alternative fuels in all the fields. The issues observed were infrastructural, economic, and technological issues.

Rahman et al. [53] studied the need for alternative fuels in the current world. They stated that there were a limited number of conventional fuel sources, which were decreased daily. So the need to develop an alternating fuel for a diesel engine was deliberated. They investigated some procedures for producing an alternative fuel from the Jatropha. The Jatropha curcas was a non-edible renewable plant. In the country's semi-arid regions, the jatropha was fast and widely growing. The jatropha seed contains a maximum of 50% to 60% oil and this oil was converted into biodiesel by implementing a transesterification process. This derived oil was used on the engine to evaluate its performance. Sithar et al. [54] experimentally investigated the mixing of two biodiesel as an alternative fuel for diesel engines. They studied the deficiency of conventional fuel in the world due to the increasing demand. They analysed the effects of the duel biodiesel on a single cylinder direct injection air-cooled high-speed diesel engine. The experiment was also conducted with a constant speed of 3000rpm for various engine loads. The emission test would check the influences of carbon dioxide, carbon monoxide, hydrocarbon, nitrous oxide, and black smoke. The thermal efficiency of the alternating fuel used in the test was higher than that of the thermal efficiency of the conventional fuels. Also, nitrous oxide, hydrocarbon, smoke, etc., emission from the blended alternating fuel was more than conventional fuels. But the dual biodiesel had an exhaust gas temperature less than the diesel fuels.

Nedunchezhian et al. [55] proposed a review to study the use of vegetable oil and its derivatives for diesel engine operation. Due to the increasing price rate of fossil fuel, it was essential to develop an alternating fuel with better performance characteristics and reduced emissions. They investigated the vegetable oil and its derivatives in diesel engines and compared the properties of the vegetable oil with the characteristics of the internal combustion engine. The properties of the alternating fuel selected are compared with the characteristics of the combustion engine, such as heat release rate, peak pressure, and vibration. The analysis of this characteristic of combustion engine compared with the conventional diesel fuel.

2.4. Emulsified fuels

The emulsified fuel was nothing but the emulsion imperturbable of combustible liquid like fuel or oil and water. The water-in-diesel emulsion (WiDE) is the widely used emulsion fuel. The emulsion consists of generally two phases: continuous phase and dispersed phase. Either macro emulsion or microemulsion is mainly used as emulsion fuels. The main differences between these two emulsion fuels are particle size distribution and stability. The macro emulsion is rotten to creaming, and there may be changes in the particle size according to the time. At the same time, microemulsion are nothing but some type of isotropic. Radha Krishnan and Premkartikkumar [56] studied the emulsified fuels and their applications in diesel engines. They analyzed that the diesel engine was the major contributor to particulate matter and Nitrous oxide. This nitrous oxide emission occurred due to the very high combustion temperature. They concluded that the best technique to reduce the NO_x emission was water in diesel emission. Due to this technique's adaptation, the combustion chamber temperature was reduced to some peak temperature. The micro explosion process had a significant role in WiDE. This technique would reduce solid and gaseous emissions. Figure 2.1 represents the comparison of emission rates of diesel and emulsified diesel.

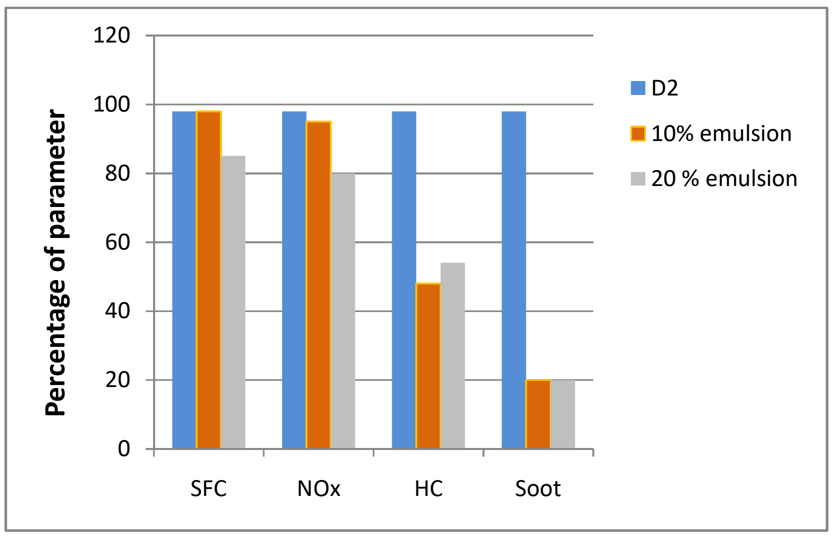


Figure 2.1: Emission characteristics for a combination of diesel and emulsion fuel [56]

Yamin et al. [57] promoted the emulsion of diesel and water, which could reduce the nitrogen, oxides, and particular matters which cause the emission. They studied the effects of diesel and emulsified fuel on the environment and tested the performance when the diesel engine was powered with different quantities of water in diesel fuel. The volume of water content added to the diesel fuel is about 5% to 30% of diesel. A diesel engine's speed range ranges between 1000 to 3000rpm. It was found that the emulsified fuel used would provide improved NO_x emission and greater or similar thermal efficiency. The use of this emulsified fuel increases the brake specific fuel consumption too. They also analyzed that using water would reduce nitrous oxide levels. The amount of CO_2 emitted from the emulsion fuel was higher compared to the CO_2 emitted from the pure diesel.

Gopidesi and Premkartik Kumar [58] studied the effects of emulsified fuel like combustion characteristics, emission, and performance. The continuous increase of pollutants in the environment is caused due to the emission. The emission rate would be reduced by fulfilling the parameters affecting the diesel engine's performance. Due to the greater temperature in the combustion chamber, pollutants like nitrous oxide would be produced. The engine using duel fuel generally reduces the emission of pollutants that cause environmental pollution and improves the performance parameters. The diesel engine could be converted into duel fuel mode by adapting various methods like fumigation, blending, and emulsion. The improvement of thermal efficiency could be obtained with the help of this combination of gaseous fuel and emulsified fuel which would reduce the nitrous oxide emission. The brake specific fuel consumption increased about 10% using biodiesel fuels. Using biodiesel as fuel would reduce nitrous oxide emission in the range of 30 to 70% if the water amount in the emulsified fuel were about 10 to 30%. The available diesel engine could be converted into a dual mode with minor modifications, and this dual mode had better thermal efficiency than the single fuel mode. This could be achieved by the use of techniques like emulsion with fumigation.

Vallinagam et al. [59] reviewed the trends in the emulsified fuels and analyzed that three steps were mainly used to introduce the water into the engine's combustion chamber. The three ways to introduce the water into the chamber were water with inlet air in gaseous or liquid form, parallel diesel, and water injection, and with and without considering the surfactants during diesel emulsion. The first two methods have more cost than the third method. Since that two-way needs a separate injection system. They compared and tested the emulsified fuel with pure diesel and analyzed the emission rate. The result shows the use of emulsified fuel reduces the amount of emission and reduces the combustion duration. The brake thermal efficiency of the engine could be improved to 14.2% with the use of 10% emulsified fuel compared to pure diesel fuel. This additionally reduces the nitrous oxide emission by around 30.6%. They analyzed a lower heat value for emulsified fuel than pure diesel and concluded that less energy is produced in the combustion chamber when the emulsified fuel is ignited. The combustion duration for emulsified fuel was less than that of diesel.

Using biodiesel in diesel engines helps reduce the emission of hydrocarbon (HC), carbon monoxide (CO), and particulate matter, which cause environmental pollution. Alam et al. [60] reviewed the effects of emulsified fuels in the diesel engine. The biodiesel could be produced from plant sources, reducing carbon dioxide would occur due to the natural carbon life cycle basis. They analyzed that the use of biodiesel reduces the amount of pollutants like hydrocarbons, carbon monoxide, and particulate matter with the use of biodiesel. They conducted a test on a single-cylinder diesel engine with the use of water-diesel emulsion as fuel. They reported that there was a reduction of CO and exhausted temperature for varying loads. The studies would show that for small load conditions, the CO emission is high at the initial state and reduced to some limits when the engine achieves high speeds.

Permsuwan et al. [61] implemented their experiment by taking crude palm oil (CPO) and diesel emulsion as fuel for diesel engines. Analyzed the engine performance and emissions during fuel ignition in the combustion chamber. The different compositions of crude palm oil/diesel/water of 0/95/5, 0/90/10, 5/90/5, 5/85/10, 10/85/5, and 10/80/10 by volume used in the four-stroke single cylinder diesel engine. The four-stroke single-cylinder engine used here had a pre-combustion chamber, and the range of the speed of the engine could be taken in the range of 1000 to 2000 rpm. By analyzing the results obtained it was concluded that the performance would be reduced when the water and CPO amount were increased. The emission due to the diesel fuel could be reduced with emulsified fuel having crude palm oil and water. Thereby the reduced emission of CO, nitrous oxide, and black smoke could be achieved. They analyzed that the amount of water increased the reduction of heating value and viscosity could occur. After 200h operation, it was found that the wear that happened in some parts of the engine could be the same as that of the diesel oil instead of emulsified fuel.

Murugan et al. [62] conducted studies on natural processes like pyrolysis of wood and thereby derived bio-oil. The comparison of diesel operation for pyrolysis oil derived due to the pyrolysis of wood and Jatropha methyl ester (JME) is done to analyze performance, combustion, and emission characteristics. They emulsified the wood pyrolysis oil and JME with a combination of 5/95%, 10/90%, and 15/85% of volume and were represented as X_1JOE5, X_1JOE10, and X_1JOE15, respectively. The JME had greater peak cylinder pressure and fast ignition rate when emulsified with wood pyrolysis oil and ignition improver of Diethyl ether. The process was carried out in an air-cooled four-stroke diesel engine. The brake thermal efficiency of emulsified WPO is higher than that of the pure diesel and is 6.34, 9.5 for Diethyl ether with 2% and 4%. There would be a reduction in the nitrous oxide emission, and the percentages for which were identified for each fuel were 19.21, 28.38, and 34.81, respectively.

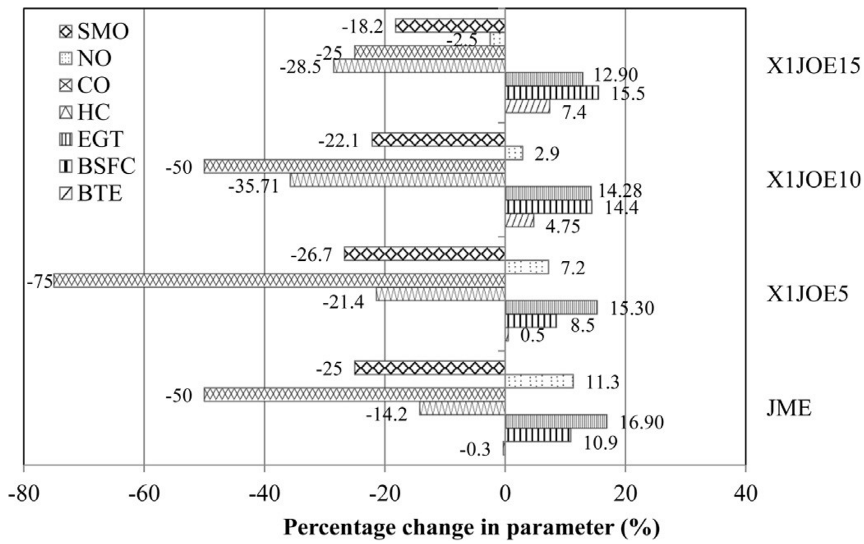


Figure 2.2: Percentage change in the performance and emission parameters for tested fuels with respect to diesel at full load condition[62]

Agung et al. [63] attempted to study the performance of a single-cylinder diesel engine with water in oil-type fuel. They use diesel oil mixed with 10 % of water and some surfactants of 1%. This combination's ratio could be seen as 89% diesel oil, 10 % water, and 1% surfactant. A mechanical mixer was used to mix this component, and by controlling the blending, fuel could be produced. A surfactant was used to prevent the water from separating from the mixture. These surfactants would provide an oil surrounding the water droplet. Oil with water encapsulated micrometer sizing was used to avoid the contact of water with any mechanical part of the engine. The experimental study could perform the single cylinder engine with 2000 rpm speed. Different load conditions might be used to find the diesel engine's performance with the emission of various pollutants.

Ali Alahmer [64] investigated the performance of emulsified fuel in diesel engines and studied the main pollutants emitted from the diesel engine after the ignition of the fuel in the combustion chamber of a four-cylinder water-cooled four-stroke direct injection diesel engine. They used 0 to 30% volume of water in emulsified fuel. The speed range used to conduct the performance analysis is about 1000 to 3000 rpm. The results show that the emulsified fuel would reduce the emission and improve the diesel engine's performance. In addition to achieving that under this condition, the diesel engine obtained maximum thermal efficiency, minimum BSFE, torque, and maximum brake mean effective pressure. The increased engine speed would increase the emission, and the high water content would reduce the emission. They concluded that there would be a reduced amount of emission particles compared to pure diesel oil under the same condition. The amount of oxygen emitted would be increased with the increase of water content in the emulsified fuel. They compared the calorific value of heat, viscosity, and density of emulsion fuel and pure diesel with different water ranges.

Hyungik et al. [65] evaluated the possibility of the use of emulsion fuel in the conventional diesel engine. The fundamental characteristics of the conventional diesel engine and the diesel engine with emulsion fuel were evaluated. They measure the characteristics of spray like spray distribution and penetration in this experiment, which is analyzed with the help of digital image processing. The pure diesel engine characteristics, emission, and fuel consumption were compared with the features of a diesel engine with emulsified fuel. The droplet size of the water could be measured for the quantitative analysis, and four surfactants were used to evaluate the performance. The appropriate diesel–water emulsified (DE) fuel performance could be achieved using the exact droplet size of water and the major parameter considered. The kinetic viscosity depends on the size of the water droplet in the DE. As the size of the water droplet increases, the kinetic viscosity also increases. The resulting reduction of evaporative spray characteristics.

Breda Kegal et al. [66] investigated the atomization of emulsified fuel droplets among a single droplet for analyzing the breakup characteristics. The emulsified fuel was inserted into the furnace with the help of a fine wire for conducting the single droplet experiment. A high-speed camera could be used to observe the secondary atomization behavior. With the help of energy conservation and mass equations, the micro- explosion of water vapor could be calculated in the mathematical model by making some assumptions. A numerical method is used to study the fuel spray's characteristics and present the emulsified fuel's experimental results. They investigated the effects of water droplets in the diesel oil during the ignition period, and the resulting feature like the reduction of emission was also analyzed. Kannan et al. [67] commented that biofuels had a significant role in recent years. The biofuels from the vegetable oil had effective emission characteristics and comparably good performance. They compared the performance of the combination of two fuels used in the diesel engine. A suitable blend of biodiesel could be obtained with the blending of biodiesel with the diethyl ether to improve the diesel engine's performance and reduce the emission effects. The experiment was conducted with different ratios like 5%, 10%, 15%, and 20% of the volume of emulsion fuel in a single-cylinder diesel engine. The result would show that the use of 15% of emulsion biodiesel fuel had a better brake thermal efficiency of about 31.6% over all the other ratios used in the experiment at full load. For 20% of emulsified fuel, the emission reduction could be obtained at about 41% for emulsified biodiesel at full load. The comparison shows that the smoke emission was less for the biodiesel than for the DEE blend. They concluded that the emulsified biodiesel would have better performance and less emission than the DEE blended biodiesel and stated that the emulsified fuel had a much priority for the reduction purpose of the emission over other fuels used in the diesel engine.

Tayseer et al. [68] investigated generating diesel water emulsion fuel with a stable condition, which was used in different conditions of diesel engines. The stable emulsion with 10% and 30% of water in diesel could be produced with the use emulsified agent and by using proper mixing. For one week to four weeks, the stability of the emulsion could be maintained. The physical properties of this emulsified fuel were pour point, density, and viscosity. They studied the effects of emission pollutants, speed, brake power output, brake thermal efficiency, and exhaust gas temperature. The results thus show that water emulsified fuel has a better performance and reduced emission rate when operated in the single cylinder diesel engine compared to pure diesel oil. The results show that the diesel engine's performance was better when the water emulsified fuel was used.

Palanisamy et al. [69] conducted an experimental study on the emulsion of Jatropha biodiesel which the peroxidation could produce. The properties of the biodiesel could be improved by using a transesterification reaction with peroxidation. With the help of emulsifying surfactants, the three-phase oil droplets in-water-droplets –in-oil (O/W/O) could be produced. The biodiesel product was emulsified from distilled water with the help of a mechanical homogenizer. The O/W/O and biodiesel include an NO inhibitor agent made of aqueous ammonia. A direct injection single-cylinder diesel engine was used to analyze the performance and emission characteristics of the emulsified fuel. Using the recorded data, the brake thermal efficiency (BTE) and brake specific fuel consumption (BSFE) were calculated. Aqueous ammonia in the used biodiesel curtails the NOx formation, thus reducing the NOx emission. The conclusions made in this study were that biodiesel could be used for the conventional diesel engine as an alternative fuel by making some small modifications to the system hardware.

Udayakumar and Kannan [70] could report the effects of the emulsified fuels. They analyzed the BTE, hydrocarbon emission, brake specific fuel consumption, and nitrous oxide emission. With constant speed, the experiment would be completed on a four-stroke, single-cylinder diesel engine. The fuel injection pressure here used was about 200 bars. The volume of water used for conducting the test on the engine, diesel fuel, and commercial diesel fuel was 20% and 10%. The test results showed an improved BTE and brake specific fuel consumption was achieved when using the emulsified fuel. The experiment concluded that using water emulsified fuel would reduce nitrous oxide and hydrocarbon emissions. The pollution level due to the nitrous oxide and particulate matter could be changed due to the presence of water droplets in the diesel fuel was reported by Selim and Ghannam [71]. The fuel emulsion could be prepared by mixing high-speed water into the commercial diesel emulsifier. With the help of a pycnometer, the physical properties like the density of emulsified fuel and diesel fuel were measured. The viscometer was used to measure the viscosity, and the surface tension was measured. The water droplet interaction of fuel could be evaluated by using a system called a computer image analyzer. The analyzers, in addition, assess the water droplet distribution. The W/D emulsion stabilization was done for 4weeks and 10 days for 10% and 20% of water content. This process was done by adding 0.2% surfactants at 15,000 rpm for a mixing time of 2 minutes. With a water concentration of 20%, the stability period was decreased to 5 hours. The surfactant added had a polydispersity behavior. Since 40% of water in W/D needs 2% of surfactant. The total mixing number of revolutions changes based on the average diameter and droplet distribution of water. In terms of viscosity, surface tension, and density, the properties of stable W/D could be investigated and measured.

Chang et al. [72] stated that the water emulsified diesel had a better ability to improve the combustion efficiency and performance of diesel engines. They investigated the effects of various amounts of water in light duty engines to analyze emission and thermal efficiency. The multiple combinations of WD made were represented as WD-0, WD-5, WD-10, and WD-15, respectively. The gas analyzer was used to analyze the nitric oxide, hydrocarbons, carbon monoxide, and carbon dioxide. A low-pressure electrical impactor was used to measure the number concentration and particle size. The thermal efficiency can be calculated by measuring the fuel consumption. The results suggest that the emulsified had a significant role in better thermal efficiency and emission reduction. Using water emulsified fuel instead of diesel fuel would increase the thermal efficiency by around 1.2 to 19.9%. Further, the emulsified diesel by water reduces nitric oxide in the range of 18.3 to 45.4%. They conclude that the water emulsified fuel could improve the engine's performance and reduce exhaust emission.

2.5. Effect of water emulsion on diesel engine

During the last decades, many studies have been implemented to reduce emissions and improve the diesel engine's thermal efficiency. The thermal efficiency of the diesel engine could be improved by implementing techniques like exhaust gas recirculation (EGR), selective catalytic reduction (SCR), catalytic converter, NO_x trap, homogeneous charge compression ignition, and plasma reactor were used. But this technique could not reduce the emission effects. The water was acquainted with the chamber of the engine by mainly three methods. The methods used were water diesel emulsion using suitable surfactants, fumigation, and water injection using a separate injector nozzle.

K.A. Subramanian [73] conducted a comparative study of water diesel emulsion to find water's effect on diesel engines. The analysis of emission and combustion characteristics of water emulsified fuel used for diesel engines would be analyzed for different operating conditions. The ratio of water taken to make the water diesel emulsion fuel was about 0.4: 1 by mass. The exact ratio would be maintained for the water injection method to access the emulsified fuel's potential advantages. A constant speed of 1500 rpm was used to perform all the tests at the various output. For all the tests, the static injection timing was kept at 23^0BTDC. By conducting some experiments, the characteristics like emission, combustion, and performance of the engine after the use of emulsified fuel could be evaluated in the first phase. The surfactant with an HLB value of 7 prepared the emulsion. In compression stroke, the emulsion was injected with the help of a system called conventional injection. The water was injected into the intake manifold using an auxiliary injector in the period of suction stroke. This was performed during the second phase. The injector operation was controlled with the help of electronic control unit. The experimental results show that the injection and emulsion would reduce the nitric oxide emission. With the base diesel at full load, the nitric oxide emission would be reduced to 645ppm from

1034ppm. The smoke emission was more with the water injection than the emission, which is about 2.7 BSU(Bosch smoke unit). But HC and CO emission is less in the case of water injection than that of the emulsion. It was concluded that for all loads, the emulsion was superior to the other one.

The water-diesel emulsified fuel in a single cylinder diesel engine was conducted by M. Abu-Zaid [74] to investigate the effects on the engine performance. This experiment used W/D of volumes 0, 5, 10, and 20 in a direct injection single-cylinder diesel engine. The engine was operated at a speed of 1200 to 3300 rpm. The results indicate that emulsified fuel in the engine would improve thermal efficiency. The increased water percentage in the emulsified fuel increases engine torque, BTE, and power. Using a 20% volume of water emulsified fuel would increase the BTE by about 3.5%. As the percentage of water content in the W/D increases, the exhaust gas temperature and BSFC reduce. Ali Alahmer [75] investigated the diesel engine's performance on the emulsified fuel application. The experiment was conducted on a four-stroke, water-cooled direct injection diesel engine for a load range (25-100%) at speed of 3000 rpm. Here the investigation was born with an emulsified fuel with a water content of 0 to 20% by volume. For 20 % of water in the emulsified fuel shows minimum in cylinder pressure and pressure rise rate compare to diesel fuel for all load range. Under this condition, the thermal efficiency and torque would have a maximum value. The carbon dioxide emission was decreased with the water content and increased with the engine speed. At constant conditions, the nitrous oxide emitted from the emulsified combustion chamber's ignition is less than that of the pure diesel engine. The oxygen emitted increases the amount of water content in the emulsion fuel.

Attia and Kulchitskiy [76] studied and investigated the effects of the W/D fuel emulsion in three water-cooled diesel engines. The membranes having a pore size of 0.45μm and 0.2μm were used to change the emulsion structure based on the membrane emulsification by maintaining the same water fuel emulsion volumetric content. That means that 17% of water in emulsion fuel uses an emulsifier content of 0.5%. The results show that there would be a considerable emission reduction with the help of larger water droplets, up to 25%. The finer droplets of water would improve the practical efficiency of the engine by up to 20%.

Lin and Wang [77] studied the effects of oxygenated emulsified fuel on two and three-phase diesel emulsion characteristics. The diesel engine was used widely in industrial power plants and marine transportation systems. But the pollutants produced from fuel combustion in the diesel engine chamber would result in pollution in the atmosphere and health problems for the human body. They studied that the use of emulsion fuel reduced the effects of emission. The emission particles emitted from the emulsified fuel were less compared to the diesel oil. The three-phase emulsion was usually used in the pharmaceutical, food, and cosmetic industries. They studied the emission and performance characteristics of the two, and three-phase O/W/O emulsified fuel for diesel engines. The results would show that using this O/W/O will reduce the EGT, nitrous oxide, carbon monoxide, and black smoke. Agudelo et al. [78] studied the engine's performance using water oil emulsion. They conducted a test to examine the main pollutant effects, hydrocarbon and particulate matter. Here the engine used was a turbocharger indirect injection inter-cooler diesel engine tested for five operating conditions. To conduct the test on a diesel engine for every operating condition, a commercial fuel was used as a reference fuel and an emulsion fuel. The reported results suggested that the brake efficiency could be slightly improved by applying emulsified fuel in diesel engines. It also reduces the diesel engine's hydrocarbon, nitrous oxide, and PM formation.

Chen and Lin [79] stated that the pollutants emitted from the diesel engine due to the ignition of the diesel fuel had an essential role in air pollution. The emulsification method is widely used to reduce diesel engines emission. The human ear could not detect the ultrasonic sound wave with a frequency more prominent than 20 kHz. The rapid physical and chemical reaction due to the ultrasonic waves would cause cavitation and hotspots. The experimental study uses ultrasonic sound waves with a frequency of 40 kHz for the preparation purpose of multi-emulsion. They measured and analysed the properties of the diesel emulsion fuel. The ultrasonic emulsion method would effectively prepare the multi-emulsion with tiny-sized water droplets. The processing time for ultrasonic emulsion was increased, resulting in a more remarkable temperature rise. The mentioned method would reduce NO_x emission, black smoke, and soot as well as greater BSFC and carbon monoxide emissions than diesel oil.

Anand and Kannan [80] carried out experiments on a direct injection single cylinder diesel engine with diesel, diestrol, and biodiesel to analyse the combustion, emission, and performance of the engine at a speed of 1500rpm for various load conditions. The results showed that biodiesel had a greater BSFC than diesel. Moreover, diesel had a higher emission of CO, NOx, hydrocarbon, and black smoke than other emulsion fuels used in the experiment under all load conditions. The microemulsion fuel had a lower cylinder gas pressure than the diesel at low loads. But the cylinder gas pressure might be identical to the diesel at medium and full load conditions. The biodiesel heat release rate was higher than that of the diesel fuel for all the loads. But the microemulsion fuel needs a large ignition period than the biodiesel. Hogan et al. [81] stated that the fast pyrolysis for producing bio-oil had highly acidic and viscous properties. This bio-fuel requires a large ignition period since it contains a large amount of water. To overcome the problems due to bio-fuel ignition, the pyrolytic bio-diesel was used and emulsified in No.2 diesel fuel. In this process, a very large amount of the heavy bio-fuel and solid can be removed by centrifugation and by producing emulsions with a light fraction obtained by centrifugation. The stability of the emulsion thus created would change according to the processing condition. Several emulsification runs are performed to analyse the relationship between processing costs, emulsion stability, and process condition. The five variables examined were temperature, the concentration of the bio-oil, residence time, power input per unit volume, and surfactant concentration.The optimal operating conditions produce stable emulsions. The surfactant concentration required to make stable emulsion ranges from 0.8 to 1.5 wt% of total and depends on power input and concentration of bio-oil. Costs for producing stable emulsions with the help of commercial surfactants ranged from 2.6 cents/L for the emulsion of 10% and 4.1cents/L for the emulsion of 30%. They characterized the properties of fuels like viscosity, heating values, and corrosivity. With the help of Einstein’s equation, the viscosity of emulsified fuel was evaluated for solid dispersion.

Rangkuti et al. [82] analysed the diesel engine's performance and evaluated the emission when using the emulsified fuel in the presence of Gemini and conventional surfactants. The major air pollution source which emits the pollutants in large amounts was identified in the diesel engine. The emulsification method here implemented mainly has two purposes: reduction of emission and cost minimization. The W/D formed emulsification was used to reduce the emission of SO_x, NO_x, CO, and PM. The emulsion fuel with different contents of diesel and water were prepared and stabilized with the help of Gemini and conventional surfactants. They recorded constraints like emulsification time, surfactant usage, stirring intensity, mixing time, and emulsifying temperature. The results show that the Gemini surfactant had better-distributed water droplets than the conventional surfactants. They analysed and examined the emission and performance of diesel engines. The comparative study was performed using constraints like torque, specific fuel consumption, BMEP, PM, nitrous oxide, and carbon monoxide emissions. The study shows that there was a reduction in the efficiency of the engine. Also, there were many benefits associated with the emulsified fuel regarding environmental hazards.

Chen et al. [83] aimed to study the efficient use of emulsified fuel in the diesel engine. They used ethanol-biodiesel-water microemulsion as the emulsified fuel. The experiment was conducted on a direct injection single cylinder diesel engine and utilized microemulsion and pure biodiesel as a fuel. This process could be completed under various operating conditions. The results of biodiesel and microemulsion were compared and concluded that the microemulsion had identical peak cylinder pressure. The peak pressure and heat release rates are increased for high and medium engine loads. The rate of peak heat release and peak pressure rise is low for low engine loads. The ignition period required for the microemulsion was lower than that of the neat biodiesel. They concluded that the microemulsion had lower brake-specific energy consumption (BSEC) and slightly higher BSFC. For increased engine speed, there was a drastic reduction of black smoke emitted; for all ranges of engine speed, there would be a lower reduction of the nitrogen oxide. For medium and low engine speed, carbon monoxide and hydrocarbon emissions were higher than the neat biodiesel.

GequnShu et al. [84] evaluated the effects of W/D emulsion and oxygen-enriched combustion on the performance of turbocharged diesel engines. They experimented with the diesel engine to improve the thermal efficiency, emission, and brake power output. The aim considered in this experiment was the W/D emulsion would help to reduce the emission caused by the oxygen-enriched combustion (OEC). Also, analyse the effects of OEC over many concentrations and particle sizes. Intake air with a concentration of 21 to 24% volume of oxygen could be used. The emulsified fuel contains a water volume of 0%, 10%, 20%, and 30%, respectively could be used for to experiment. After performance analysis they concluded that the OEC would result in higher cylinder pressure, lower BSFC, and shorter ignition delay. The nitrous oxide reduction and PM reduction could be analyzed by combining the water diesel emulsion with the Oxygen enriched emulsion. The increasing amount of oxygen in the emulsion would increase the particle number of nucleation mode concentration. But in the accumulation mode, the number of particle concentrations would be reduced by the increasing amount of oxygen. The optimal operating condition was obtained by using the W/D emulsion below 20% with the oxygen enrichment.

Biao Xu et al. [85] conducted an experimental study to analyse the effects of the oxygen-enriched air and water emulsified fuel in a turbocharged diesel engine. The use of oxygen-enriched combustion would improve thermal efficiency. But the oxygen-enriched combustion increased the nitrous oxide emission. The two conditions, the constant speed of 2000rpm and 57% of the original maximum load, were considered during the experiment with the mentioned diesel engine. The investigation was conducted at 2000rpm with 100% load. The improvement of NO and black smoke emissions could be achieved by using the combination of both the W/D emulsified fuel and oxygen enrichment. The results show that the NO smoke emission was lower when the intake oxygen concentration was 21 to 21.5% and water emulsion was 0 to 20% for an engine load of 180 Nm. It is the same if taking the intake oxygen concentration of 21 to 22%. The BSFC didn't exceed 5% of the actual value. The use of oxygen enrichment increases the ignition period advance to some limits. It led to an increase in peak pressure in the cylinder slightly and accelerated the combustion. The combustion temperature decreased according to the rise in water emulsion. The more extended ignition period can occur when the water emulsion ratio increases.

2.6. Surfactant

Surfactant was used to reduce the surface or interfacial tension between a liquid and gas, between two liquids, or between solid and liquid. Additionally, there was act as a detergent, emulsifier, foaming agent, or wetting agent. Norah et al. [86] evaluated and synthesized the Gemini surfactants. From crude oil-derived diesel, the mentioned surfactants were evaluated and synthesized as wax anti-settling additives. With the help of co additives, the Gemini's with multiple ionic heads having C18 chain lengths were explored. By using a controlled radical polymerization technique, the copolymers were prepared. Here revolutionary polymerization technique of atom transfer radical polymerization technique was used. The structure-activity relationship between polymeric additives and Gemini surfactants was revealed with the help of crystallization studies. The cold filter plugging point was decreased to 11^0C by the combination of both the flexible spacer Gemini's and polymeric additive with lower molecular weight. The presence of aromatic Gemini's reduces the efficiency.

Neeraj Kumar et al. [87] focused on a study on the diesel engine's performance with the presence of surfactants on emulsified fuel. The emulsified fuel used here is prepared with the adaptation of optimized processing on parameters. They evaluated the emission and performance characteristics of the engine using stable water emulsion. The experiment was conducted on 54 samples, which were made by taking various ratios of water-diesel combination. After the emulsification period of 24hr and 48hr, the water separation, stirring speed, and surfactant amount was recorded. These recorded data were optimized to produce the parameters, which helps the process of emulsification could be done with the help of artificial neural network- particle swarm optimization. The parameter thus obtained was a 0.9% surfactant, 20% water diesel ratio at 2200 rpm for 14.33% water separation. The W/d fuel exhibits the same base fuel properties. For medium and full loads, the emulsified fuel's peak pressure rise, cylinder gas pressure, and peak heat release rate were higher than the base fuel. The emulsified fuel prepared had improved thermal efficiency on the engine due to the improved air-fuel mixing. The emulsion fuel achieved the exhaust gas temperature with water droplets. These water droplets absorb the heat in the combustion chamber. The use of W/D emulsion reduces the CO, NO, and HC emissions by about 8.890%, 26.11%, and 39.60%, respectively, compared to pure diesel.

Neto et al. [88] studied the performance and emission characteristics of the engine on the application of W/D emulsification blended with a non-ionic surfactant. They use surfactant as nonylphenol with a microemulsion of diesel. These were mixed and tested on the diesel engine and analysed the performance and emission characteristics. They recorded the data like density, cloud point, viscosity, and corrosiveness. The results show that the diesel-based microemulsion had greater viscosity and density than the pure diesel engine. They concluded that the carbon and nitrogen emissions for diesel-based microemulsion were greater than pure diesel. But there would be a reduction of the black smoke in the diesel-based microemulsion. Santhanakrishnen et al. [89] experimented with studying the effects of the orange peel oil biodiesel (BD_{100}) blended with the oxygenated additive like water in different fractions. The experiment used 4 and 8% volumes of hard water blended to the BD_{100}. The water into the biodiesel was emulsified with the help of a span 80 surfactant. The results show that the three would improve brake thermal efficiency due to the addition of water into the BD_{100}. There would be a reduction of HC, CO, smoke, and NO_X to

9.89%, 11.4%, 5.14%, and 3.36% when the 94% volume of biodiesel and 2% volume of surfactant. The reduction of HC, CO, smoke, and NO_X to 10.11%, 12.22%, 6.18%, and 4.85% when 90% volume of biodiesel, 8% volume of water, and 2% volume of surfactants, respectively, compared to the $BD_{100.}$ Figure 2.3 shows the difference in HC and NO_X emission with brake power.

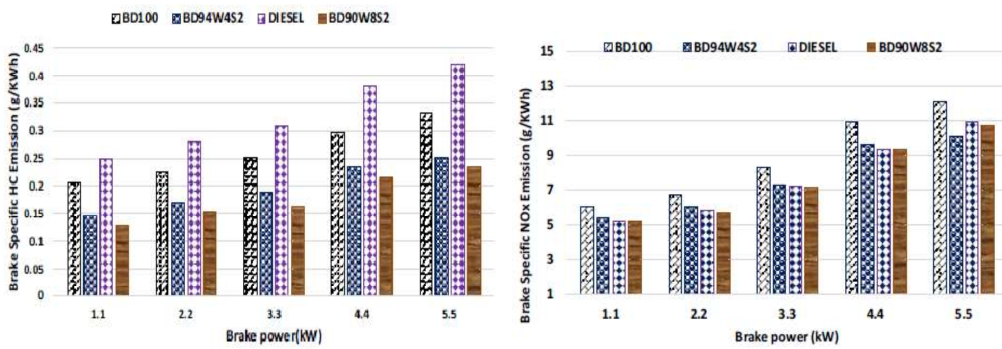


Figure 2.3: Difference in HC and NO_X emission with brake power [89]

Maxim et al. [90] stated that for various operating and environmental conditions, the water diesel microemulsion fuel attains a central challenge of achieving the thermal stability of all the phases for possible storage and utilization. These would be a possibility of controlling emulsified fuel's stability in various temperatures. The experiment was conducted to maintain the thermal efficiency with a temperature range of -21^{0}C to +73^{0}C. They recorded values like the concentration of ammonium acetate, D/W ratios, surfactant ratios, and co-surfactant ratios of various alcohols used in the experiment. The microemulsion was stabilized by adapting a co-surfactant like various C_5 to C_9 alcohols.

2.7. Various emissions from diesel engine

The diesel engine had high durability, efficiency, and reliability with minimum operating cost. This advantage makes the diesel engine most preferred. But the use of diesel engines has a few drawbacks too. One of the critical drawbacks of the diesel engine was environmental pollution due to the emission of pollutants. Ibrahim et al. [91] stated that there were mainly four pollutant emissions from the diesel engine such as nitrogen oxide (NO), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). The diesel engine leads to many health problems too. They reviewed the emission from the control system and diesel engines and all the emissions and comprehensively examined them alone.

Lisa et al. [92] measured the nitrous oxide emission from the light duty diesel engine and light duty gasoline engine. The emission was measured using a test called chassis dynamometer testing. To group the emission as the driving condition functions, a subset testing of the vehicle was also conducted with other driving cycles. Low sulphur gasoline/diesel was used to test the new vehicles. The nitrous oxide emission illustrates the emission factor variability in the form of a driving condition function. They investigated nitrous oxide emission's effect as a sulfur fuel function. Hoon and Yoo [93] studied the effect of nitrous oxide. Nitrous oxide (N_2O) is a third major greenhouse gas. The N_2O in the atmosphere was stable and had a global warming potential of 310 times greater than that of carbon dioxide. After photo degradation in the stratosphere, nitrous oxide becomes a secondary condemnation. They studied the changes in the rate of nitrous oxide emission for the concentration of sulphur and nitrogen contents in the fuel on a diesel engine. The experiment was conducted on a four-stroke direct injection mechanism at a speed of 2600rpm and an output of 12kW. The test was conducted with 75% of the total load. By using six additives, the nitrogen and sulphur concentrations are varied. The six nitrogen additives used were Pyridine, Quinoline, Indole, Petrol, and propionitrile. Di-tert-butyl-disulphide was the sulphur additive used in the experiment. They concluded that less than 0.5% nitrogen content would not emit nitrous oxide in all kinds of additives and concentrations. The presence of sulphur additive in the fuel increases the nitrous oxide emission.

Devaraj et al. [94] studied the emission characteristics of the diesel engine. As a fuel additive, the diesel engine's emission was investigated using a cetane improver called Dimethyl carbonate (DMC). The test fuel used was diesel, the combination of neem oil biodiesel and dimethyl carbonate and neem oil biodiesel. About 0.5% volume of the DMC was added to the biodiesel in bio-diesel to experiment. The experiment was conducted on a single-cylinder four-stroke diesel engine. The concentration of DMC in the biodiesel would reduce the emission of carbon monoxide. Sivamurugan et al. [95] aimed to study the emission characteristics of the mustard biodiesel or M100 with methane as duel fuel. The results show a reduction of carbon monoxide and other emission particles in methane-biodiesel compared to pure biodiesel for a flow rate of 51 pm. But the emission of nitrous oxide is more for the mentioned condition. Oduro et al. [96] presented a test to investigate the emission performance of the jatropha oil blends in diesel engines. The experiment was conducted on a single cylinder direct injection engine, which is operated on jatropha oil, diesel fuel, and jatropha and diesel oil mixtures. The proportions of diesel fuel and jatropha used for the experiment were 50%/50%, 80%/20%, and 97.4%/2.6% by volume, and the investigation was conducted with all the loads on the engine. The carbon monoxide emission was approximately similar for all the fuels and had a slightly lower atmospheric emission.

Jianwei et al. [97] studied the characteristics of aromatic hydrocarbon emission from the diesel engine when operated with the fuel like diesel and biodiesel. The aromatic hydrocarbons from the mobile source lead to environmental pollution. The experiment could be carried out in the turbocharged direct injection diesel engine. The fuel selected was biodiesel, diesel, and blends of diesel and biodiesel. The results show that using B100 and B20 reduces the amount of polycyclic aromatic hydrocarbon emission. A correlation between the particulate matter and hydrocarbon emission could be analysed with the help of the results obtained, and it was more significant when the fuel used was biodiesel. Xiao et al. [98] tested the diesel engine to investigate the effects of emissions. The experiment used fuel heptane. An increasing amount of diaromatic methylnaphthalene and monoaromatic toluene were added to the heptane. The oxygenated components that are included in the blends were also tested. The result shows that both the fuels would increase the hydrocarbon and other particles, which leads to emissions. They concluded that the emission of these particles increases due to the more extended ignition period. The oxygenated fuel would reduce the emission of black smoke and nitrous oxide.

Yang et al. [99] experimentally and analytically investigated the engine's particulate matter emission and performance. The chemical particles from the engine and the concentration of the soot particles were analysed with the help of a particle aerosol mass spectrometer and differential mobility spectrometer. The correlation relationship of the soot particles could be analysed with the help of the Eigen value and Eigenvectors for the ellipse method. Axel et al. [100] studied the strategies for meeting the future particulate matter emission. The experiment was conducted on a direct injection homogeneous gasoline diesel engine. They discussed the reduction of emission of particulate matter by considering the system component requirements and control strategies. On the control side, important parameters considered for heating conditions with catalyst were injection slitting and timing. The encouragement of the experiment would reduce the particulate matter emission. The reduction of the particulate matter emission lower than that of the proposed limit was achieved.

The characterization of particulate matter in the large ship diesel engine was studied by Moldanova et al. [101]. With the gas phase emission composition, the environmental and health issues of the emitted particulate matter could be investigated. Chemical compositions, mass, and size distribution of the particulate matter were investigated. There were two maxima for the bio model shape; one was accumulation mode, and the other was the coarse mode. The PM composition was dominated by sulphate, ash, and organic carbon composed only a few percent of the particulate matter. Comparison of various WED method performance analysis is detailed in Table 2.1.

Table 2.1 Comparison of various WED method performance and emission analysis

	Performance characteristics			**Emission characteristics**			
Authors & References	BP	BSFC	BTE	NO_x	PM	CO	Smoke
El-Din et al.(2013)	Increased	Slightly diminished	Not information	Decrease under the 8% of water content added	Not information	Decrease	Not information
Lin et al.(2003)	Slightly diminished	Increased at high engine speed	Not information	Decrease	Decrease	Decrease	Not information
Subramanian et al.(2011)	Increased at high engine load state	Not information	Increased	Slightly diminished	Not information	Not information	Not information
Cherng-Yuan et al.(2004)	Not information	Decrease	Not information	Increased	Not information	Slightly diminished	Not information
X. Fan, et al.(2008)	Not information	Increased up to the utmost level	Slightly diminished	Not information	Increased	Not information	Not information
Lou, Di-ming, et al.(2011)	Not information	Decrease at high engine speed	Increased	Not information	Not information	Increased	Not information
Omar Badranet al.(2011)	Not information	Slightly diminished	Increased	Decreased with the various emulsified conditions	decreased	Not information	Increased
Vigneswaran, R., et al.(2018)	Not information	Not information	Increased	Not information	Not information	Increased	Not information

Xiankun, et al.(2009)	Not information	Slightly diminished	Increased	Increased	Decrease	Decrease	Decrease
Isabel, et al.(2006)	Not information	Increased	Not information	Not information	Not information	Not information	Not information
Samec, et al.(2002)	Increased	Increased under various loads	Increased	Slightly diminished	Decrease	Decreased under the different load state	Not information
Pijush Kanti Mondalet al.(2020)	Similar and more at more load	Increases except identical if clean diesel measured	Similar and more at more load	Max. Diminishes by 75%	Diminishes by 49%	Increases	Not information
Suresh Vellaiyan(2020)	Not information	Diminishes at supreme load of engine	Not information	NOx Emission is 46.1% at 75% of load state	--	CO emission is 11.2% at 75% of engine load state	19.3% of lesser smoke opacity
Zhiqing Zhang et al.(2019)	The BP diminishing is enhanced by the addition of water content.	BSFC of W4 is less	High BTE	Decreased NOx emission and water content quantity in WBE blend is increased	Not information	Improved the oxygen content.	Not information
PijushKanti Mondal(2019)	Increases the net power output	decreases BSFC at the load increasing	Increasing the efficiency with the high load	significantly Less NOx Emissions	Not information	At high load diminished the CO emission	significantly less Smoke
HomaHosseinzadeh-Bandbafhaet al.(2020)	BP diminishes	BSFC is increased with less energetic state	Not information	NOx formation is increased	Not information	increased emission by the water addition	Not information
Sangki Park et al.(2016)	Not information	Improved	Not information	drastic increased the NOx emission	concurrent reduction of PM	decreased CO as the load of engine	Not information
Noor El-Din et al.(2019)	Not information	decreases with the high load engine	increases with the high water content	NOx emissions are decreased	--	Increases CO emission with the high load engine.	increases Smoke emission as the high engine load
PijushKanti Mondalet al.(2017)	output power is enhanced	Decreased with the high engine load	slender less BTE at less load	Not information	Not information	Not information	Not information
VezirAyhan et al.(2018)	High BP output	decrease in SFC	19% of improvement	NO emission is reduced	Not information	CO is reduced	smoke emission is diminished

2.7.1 Emission Control Techniques in Diesel Engine

Various techniques such as experimental methods adoption of numerical methods were used to control the emission of diesel engines.

2.7.1.1. Experimental methods

Molina et al. [102] studied predicted mechanical loss in terms of combustion parameters and nitrous oxide evolution. The model was implemented to optimize and control the operation of the direct injection diesel engine. The surface methodology response was one of the vital factors considered during the modelling of the experiment. There were two groups considered. The first was associated with the engine input, and the second was associated with the combustion parameters. The combustion parameters like burn angle, effective pressure, and peak pressure were influenced by factors like injection settings and intake charge. The engine output could be predicted with the help of second groups. The engine output includes energy consumption and nitrous oxide evolution. The flexibility could be enhanced by using the modeled and experimental parameters. The energy consumption and mean error prediction of the nitrous oxide are about 6% and 2%, respectively, for the combustion parameters obtained from the experiment in cylinder pressure with a 5.5ms time. If the operation on the combustion parameters could be done on the modeled structure, the period required was reduced to 1.5ms. In a global model to predict NO_X and BSFC, the mean error increases to 14% and 4%, respectively. The result justifies the interest of using a split model to consider two paths: the faster, using input parameters, and the more accurate, from experimental in-cylinder pressure. So the use of the model would help evaluate the nitrous oxide emission, fuel consumption values, etc.

To evaluate the exhaust emission, engine performance, and combustion, Patil et al. [103] used a direct injection diesel engine. Here DEE(diethyl ether) was used and which is the additive of diesel and kerosene. 2 to 25% volume of DEE was blended into the diesel with various proportions. Compared to diesel oil alone, the blended DEE reduces NO emissions. The use of DE15D (15% kerosene by volume blended with diesel fuel) would give optimum engine performance. The adulteration of the diesel was done in three steps by adding 5% of kerosene in each step. The experiment was done for various engine speeds such as 10%, 25%, 50%, 75%, and full load. Table 2.2 shows the physicochemical properties of DEE- Kerosene- diesel blend fuels. The decrease in calorific value, kinematic viscosity, and density results after blending. When the proportion of the DEE increased, the cetane number and oxygen content would increase. Using diesel-DEE kerosene would lower the emission of NO compared to the DE15D.

Allen Dobson et al. [104] studied some methods and systems for controlling the emission for a control device of layered emission, which is coupled to a manifold. The enabling of various emission control can be achieved by making multiple formulations. The different emission control functions could be grouped within a plurality of layers. That means the first layer might be an oxidizing catalyst, the second layer must include an HC trap, and finally, the third layer might include various catalysts for oxidation. In between the first and third layers, the second layer was positioned. These layers might reduce the various functions of emission. I. Pegg et al. [105] investigated the early inlet valve closure (EIVC) influences the diesel engine emission. They used four cylinders direct injection common rail diesel engine and studied the effects after the deactivation of two cylinders. The experiment was conducted by setting the inlet valve closing time to 60 crank angle degrees. The effective compression ratio would be reduced to 13:7:1 from 15:2:1 for the earliest timing. The EIVC assigned to 40CA (crank angle) only changed the effects of the emission, which was very sensitive to the engine speed. Soot emission reduction occurred at 2 bar break mean effective pressure (BMEP). But in addition, it leads to increased hydrocarbon and reduced fuel rail pressure. For 6bar BMEP with increasing speed, there would be a soot reduction and deterioration of hydrocarbon and nitrous oxide. There would be a temperature rise of $>50^0$C for all the conditions of EIVC. They compared the experiment's results with and without eliminating two cylinders and concluded that the deactivation of the cylinder made the system performance much better than earlier.

Xiaokang et al. [106] studied the effects on the emission and combustion of the diesel engine with the manifold water injection. Intake Manifold Water Injection (IMWI) was an effective way to control the emission and combustion process in the diesel engine. Various effects were associated with the IMWI, like chemical, thermal, and dilution. They investigated the effects mentioned above on the direct injection four-stroke turbocharged diesel engine with the help of CFD simulation. The results show that the pressure and temperature inside the cylinder would be reduced, and the period required for fuel ignition was more. The implementation of the IMWI makes a considerable reduction in soot and NO emissions.

Zongjie Hu et al. [107] investigated the effect of water injection on a common rail diesel engine during the compression stroke to optimize thermal efficiency. One of the most significant ways to reduce the emission was the direct water injection method to the diesel engine cylinder. The experiment was conducted on a two-cylinder diesel engine with some modifications by implementing a common rail system and injecting water directly into the system. After water injection into the cylinder, they relieved the water injection to compression stroke and thermal efficiency optimization. They studied the timing for water injection and the duration of water injection. The results obtained show that there would be a better thermal direct water injection compression stroke. The thermal efficiency achieved during the period of the test condition is about 4.08%. The thermal efficiency improvement could reduce the negative compression stroke since it helps increment the positive power strokes and heat absorption. The thermal efficiency would be raised to some limits till it reaches some peak value and is reduced to some limitations with the injection of the water. The more amount of water injection would cause deteriorate the combustion and thereby a reduction in the thermal efficiency.

Samiur Rahman Shah et al. [108] experimented with studying the effects of water injection on the inlet manifold water injection diesel engine. Here a high-speed common rail automotive diesel engine was used to experiment and evaluate the emission and combustion effects after water injection to the manifold by a fine mist. They mainly focused on the water injection cooling effect. They also studied the influences of the water injection on the rate of heat release, particulate matter, ignition delay, and nitrogen oxide

TABLE 2.2: Physicochemical properties of DEE- Kerosene- diesel blend fuels[103]

Fuel blend	Distillation recovery		Kinematic Viscosity @ 40 °C (cSt)	Density @ 15 °C (kg/m^3)	Net calorific value (MJ/kg)	Cetane number	Oxygen content (wt.%)	Carbon content (wt.%)	Hydrogen content (wt.%)
	IBP (°C)	FBP (°C)							
D100	146	374	2.45	836	43.26	52	0	86.14	13.86
DE100	-	-	0.23	713	27.76	125	21.6	64.81	13.59
K100	148	282	1.15	797	41.78	41.4	0	84.61	15.39
DE2D	-	-	-	833	42.99	53.46	0.37	85.77	13.86
DE5D	56	381	2.10	829	42.59	55.65	0.93	85.22	13.85
DE8D	-	-	1.90	826	42.19	57.84	1.49	84.67	13.84
DE10D	41	381	1.8	823	41.92	59.3	1.88	84.29	13.83
DE15D	36	377	1.67	817	41.23	62.95	2.83	83.35	13.82
DE20D	36	378	1.4	811	40.53	66.6	3.80	82.39	13.81
DE25D	36	377	1.25	805	39.83	70.25	4.78	81.42	13.80
K5D	145	377	2.27	834	43.19	51.47	0	86.07	13.93
K10D	145	376	2.24	832	43.12	50.94	0	85.99	14.01
K15D	145	373	2.22	830	43.05	50.41	0	85.92	14.08
DE15K5D	38	377	1.60	816	41.15	62.42	2.83	83.27	13.90
DE15K10D	38	378	1.29	813	41.07	61.89	2.83	83.19	13.98
DE15K15D	38	377	1.49	811	41.00	61.36	2.83	83.11	14.06
Test methods	IS 1448 P:18	IS 1448 P:25	IS 1448 P:16	IS 1448 P:6 & P:7	-	-	-	-	-

for a different amount of water and various operating conditions of the engine. Kadota and Yamasaki [109] evaluated the recent advances in water emulsion fuel, including water as base fuel. The water fuel emulsion could be prepared by mixing water as base fuel, and a trace amount of surfactant to the neat fuel was mixed. They aimed to focus on the fundamental mechanism for the micro explosion. The limits of water and hydrocarbon could be predicted in the liquid phase with the help of two models, kinetic and probability models. The effects of the micro explosion were also studied to suppress the heterogeneity related to the temperature profile. This helps to avoid any explosion before the micro explosion. The emulsion droplet was the primary objective considered for the process of evaporation and combustion. They studied the conditions which lead to the micro explosion and the structure of flame, which helps the emulsification.

2.7.1.2 Numerical Methods

Gjirja et al. [110] measured the emission from the direct injection diesel engine by considering the ECE R4913 mode cycle. A comparison of the exhaust gas circulation with and without adding the water into the neat diesel and for microemulsion fuels and water in diesel emulsion was studied. In this case, both the microemulsion and emulsion water significantly changed the soot emission. Yaning Zhang et al. [111] studied bio fuel emission and combustion characteristics used in the diesel engine via AVL Fire. To validate the result, pure diesel was used in the diesel engine, and the results obtained from this experiment were compared with those obtained from the conventional method. The pure diesel oil and biodiesel blends were injected into the cylinder without any premixing of the parameters. The result analysis concluded that the soot emission reduction occurs with the premixing of biodiesel in the combustion chamber. Also, there would be an increment in the emission of NO. They concluded that using main injected fuel as pure diesel and premixed fuel as biodiesel reduces the soot emission considerably.

Soni et al. [112] discussed the biodiesel's effects on the diesel engine's performance. They aimed to reduce the harmful emissions that occurred during the ignition of the biodiesel in the combustion chamber. The experiment was conducted on a bus diesel engine having an M system injection. Under various operating regions, the results obtained from the mineral diesel engine were compared with those gained after using biodiesel. The comparison was made using parameters like fuel spray, injection, and engine characteristics. The fuel chosen was derived from rapeseed oil. The sound velocity, viscosity, surface tension, and density of the mentioned oil were experimentally determined and compared to the mineral oil. The most important factors like injection value, fuel spray, and characteristics of the engine were analyzed. Numerical methods were used to determine the injection characteristics for various operating regimes. Under torque at peak conditions, the fuel spray was obtained. They concluded that the harmful emission could be reduced to some limits using biodiesel by adequately adjusting the injection pump's timing.

Luka et al. [113] studied the heavy-duty diesel engine's emission, performance, and combustion characteristics with various fuels like diesel and biodiesel and their blends numerically and experimentally. The experiment was carried out in a heavy-duty bus diesel engine with neat diesel fuel, biodiesel fuel, and combinations of biodiesel fuel with 25% and 50%. They experimentally studied the characteristics of the engine test-bed like emission, combustion, and performance with the fuel selected to experiment. These were numerically evaluated with the help of the AVL BOOST simulation program. Within the BOOST program, an empirical sub-model could be implemented to determine the parameter for the combustion model. Considering the engine speed and fuel type, the parameter required for all the models, could be evaluated. When increasing biodiesel's percentage, the engine power and torque would be reduced to some limits. A better oxidation process could be achieved with the help of increasing the biodiesel containing more oxygen content. The use of mentioned fuel would reduce the emission of carbon dioxide and nitrogen oxide at various speeds.

Gurbuz and Huseyin [114] used multiple injection strategies to analyse the performance and emission characteristics of the diesel engine. They conducted the analysis on a turbocharged light duty compression ignition diesel engine. The engine was loaded with a DC dynamometer. With regular fuel, the experiment was conducted for various engine speeds. The mixing control combustion (MCC) module, which uses AVL BOOST simulation software, was adequate for hydrogen combustion. This MCC was used to create and verify the engine model in the second stage. The parameters used in the simulation process were identified as cylinder pressure and engine performance values. The last stage of this experiment was a numerical examination of the emission and engine performance. This could be done by selecting the main fuel as diesel and post fuel as pure hydrogen. The hydrogen was also used as the pilot for the simulation program, and this simulation program could be performed with a strategy called the multiple hydrogen injection strategies. They concluded that the 2 pilot injections would reduce the soot emission as compared to 1 post-injection strategy. But in all the injection applications, the nitrous oxide emission was increased. There would be a significant improvement in engine power. Paul et al. [115] conducted an experiment to analyze emission and combustion characteristics of the diesel engine fuelled with Jatropha biodiesel. They used a numerical investigation too to analyze the same. The performance and emission characteristics were experimented with to be compared with Diesel-RK software with simulated data. The experiment was conducted by using jatropha and pure diesel as fuel. After completing the performance analysis, they concluded that the jatropha fuel would reduce the thermal efficiency and increase the brake thermal efficiency. Figure 2.4 shows a comparison of brake thermal efficiency of simulation and experimental data for diesel and jatropha biodiesel. The results recorded showed that the pure biodiesel had a maximum efficiency of 21.2% and pure diesel had a maximum efficiency of 29.6%. The jatropha oil had a maximum efficiency of 27.5%, and pure diesel had a maximum efficiency of 30.3% in the simulation program. In simulation and experimental studies, there would be an increased nitrous oxide emission with both the increase of load and biodiesel. After the practical and simulation analysis, a new simulation was developed, using the same fuel of the earlier simulation and experimental program. The experimental studies would show that using jatropha biodiesel increases the BSFC. But it reduces the brake thermal efficiency. After analysing the combustion characteristics, it was noted that the black smoke and PM emission decreased with the increase of peak pressure in the cylinder. There was an increase in nitrous oxide and carbon dioxide emission for the same.

RaduChiriac et al. [116] experimented to numerically evaluate the different energetic functions of hydrogen and the impact of biodiesel blends on the mixture formation, pollutant emission formation, engine performance, and combustion characteristics. The experiment was carried out with the help of a four-stroke four-cylinder direct injection tractor diesel engine. The engine was rated as 50kW with a speed of 2400rpm. The AVL codes such as BOOST 2013 and HYDSIM were used to conduct the simulations.

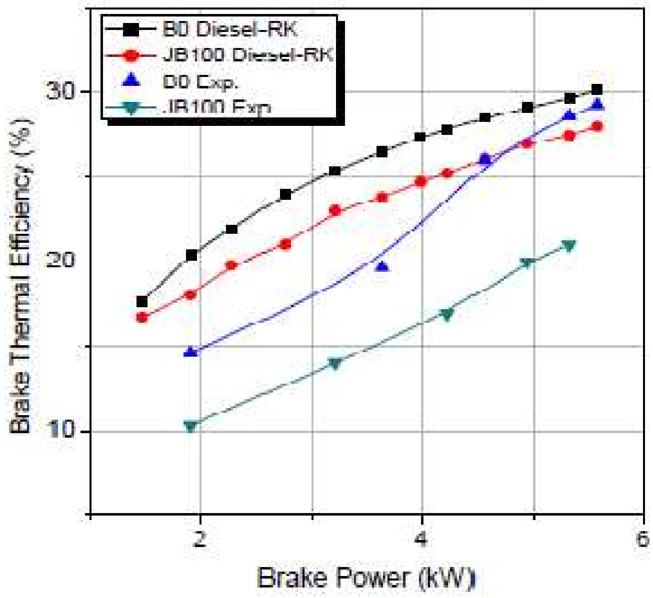


Figure 2.4: Comparison of Brake thermal efficiency of simulation and experimental data for diesel and jatropha biodiesel [115]

The experimental data and simulation results were compared to each other by considering needle lift, inline pressure, and in-cylinder pressure curve for pure diesel and biodiesel and were performed with a speed of 1400rpm and 2400rpm, respectively, for an operating condition of full load. The biodiesel used had a lower ignition delay. The emission of CO and smoke hydrocarbons decreased by adding hydrogen to the biodiesel.

2.8. Finding of the Literature Review

Many researchers have investigated and studied various methods and ways to reduce or control the emission and improve the performance of the diesel engine. Many methods are used to manage the emission in the engine by using W/D as fuel. Also, direct water injection into the engine cylinder was used to reduce the emission. The problems that have not been addressed in the previous literature are as follows.

- The performance can be improved by injecting the water directly into the combustion chamber needs a carburettor, which makes the system very complicated.
- The mixing of air and water can be improved.
- A technique needs to be developed to reduce the emission of various gasses and particulate matter.

- There is a need for better fuel additives to reduce CO and HC emissions.
- The use of catalysts is mandatory for achieving better oxidation of the hydrocarbon.
- The water injection reduces the NO emission. But at the same time, carbon monoxide and hydrocarbon emissions increase due to incomplete combustion.
- Microemulsion can improve engine performance.
- Effect of surfactant on engine performance and pollutants needs to be study.
- A microemulsion is one of the prominent techniques to reduce pollutants.
- Study of stability of water diesel emulsion during operation.

2.9. Objectives

The main objectives of this research are:

- Study the influences of microemulsion on affecting parameters
- Experimentation on diesel engine with micro emulsified fuel
- Optimize parameters of water diesel micro emulsified fuel on engine performance and emission
- Parametric study of every test sample.

2.10. Summary

In this chapter, the performance of the diesel engine on water emulsion and various biodiesel blends are discussed. Research implemented different methods to control the emission and improve the diesel engine's performance. Multiple studies are carried out to evaluate the effects of direct water injection to the cylinder and fuel as W/D emulsion. The preliminary conclusions arrived from the literature review based on the technical facts are following;

- Various studies have been conducted with the emulsified fuel for the diesel engine.
- The use of emulsified fuel reduces the emission of nitrous oxide and smoke.
- Emulsified fuel improves the mixing of air and water in the diesel engine.
- The steam injection will improve the mixing of water and inlet air.
- The water emulsion requires no modification of the diesel engine.

CHAPTER 3

Methodology

3.1 Background

The current study is about testing the temperature, performance, Brake Thermal Efficiency (BTHE), Mechanical Efficiency (ME), Brake Specific Fuel Consumption (BSFC), emissions such as CO, HC, CO_2, NO_x, Smoke, etc. in the laboratory. These parameters are comparable to the similarities found when the engine is powered by diesel. The results obtained are analyzed and described with the help of the work done and reported by several investigators. The emulsion is mixing one liquid into another immiscible liquid in the form of tiny globules. Emulsions are usually prepared by dispersing methods. Most emulsions are prepared by mixing two liquids with a suitable emulsifier and then passing the mixture through a colloid mill or similar. Some liquids, determined mainly by the emulsifier, are separated by shear forces into smaller globules with emulsion effects. The primary emulsification was conducted by using the continental method in water, hydrocolloid, and oil emulsifier types. Table 3.1 represents different types of surfactants and their advantages and disadvantages.

Different fuels that can be used for CI engines are a water-in-diesel emulsion (WD), with the current engine setup without re-engineering. It has the impact of eliminating NOx and particulate matter at the same period, as well as enhancing fire performance. In certain cases, emulsions like water-in-oil-in-water (W / O / W) and oil-in-water-in-oil (O / W / O) can be seen. Most emulsions are usually solidified with a mix of hydrophilic and hydrophobic surfactants. Many emulsions are complex, with tiny droplets produced by larger droplets and distributed in a continuous phase. Water droplets are kept in place by massive diesel droplets dispersed in a continuous water process in W / O/ W emulsions, for example. The emulsions need low and high HLB to be introduced into the system.

TABLE 3.1: Different Types of Surfactants

Surfactant	Advantage	Disadvantage
Tween 20	No toxicity	Oil in water surfactant
Hypermer B246SF	Handling is easy while continuous emulsification is done	Diluted with methanol
Span 80, Triton X-100	Better stability	Price is high
Polyethylene glycol monooleate and sorbitol sesquioleate	Reduce the amount of hydrocarbon	The solution cannot be recycled
Igepal CO-630	Non-ionic surfactant enhancement biodegradable oil	High toxicity
Span 80 and tween 80	Three-phase emulsion non-toxic	Two times mixture
Gemini surfactant	Reduce the amount of PM	Nil
Span 80 and emarol 85	An emulsion is stable with minimal interfacial tension	The stirring speed for the blend is high
AOT(Sodium bis sulfosuccinate)	Emulsion formation without any co-surfactant is possible	The mixture is of high concentration
Sodium dodecyl benzene sulphonate	The droplet size is small	Water surfactant includes salt oil
Salt, sugar, sodium carbonate	Improvement of the fuel system is not needed	High viscosity

A microemulsion is a clear, inert, and isotropic mixture of oil, water, and surfactant, often mixed with a co surfactant. There is a significant impact of temperature on emulsion stability. Temperature affects the physical properties of interfacial films, water, oil, and surfactant solubilities in the water phases and oil. Therefore, it affects the stability of the emulsion. Temperature significantly affects the viscosity of the emulsions, as viscosity decreases when the temperature rises. The effect of temperature on the stability of the emulsion is important. This affects the consistency of the emulsion. The probability of droplets collision increases as temperature increases due to the increase in the thermal energy of the droplets. It also leads to decreased coalescence and a faster filming rate resulting from lowered interfacial viscosity.

Emulsion droplets can be as small as a micron or as large as 50 microns. A histogram or distribution function is often used to represent droplet size distribution. In general, emulsions with smaller droplets would be more stable. Drops must coalesce to separate water, which takes longer to separate when the drops are smaller. The size distribution of droplets affects it as emulsion viscosity is higher when droplets are more petite. When the droplet-size distribution is narrow, emulsion viscosity is higher.

As inorganic acids and bases are added to interfacial films, their ionization is heavily influenced, and the film's physical properties are drastically altered. The rigidity of the interfacial films is affected by the pH of the water. The interfacial films produced from asphaltenes are best in low pH acids and weaken with increasing pH. The films become very poor or transform into mobile films when exposed to an alkaline medium. Resin films are best in a base medium and lowest in an acid medium. Asphaltenes can make solids in oil-wet emulsion, and this effect is greater in an acidic medium than in a basic medium. These partly oil-wet solids stabilize water-in-oil emulsions. The type of emulsion produced is also influenced by pH. Water-in-oil emulsions are made by acid or low pH, and oil-in-water emulsions are caused by simple or high pH.

By doing so, installing a water-fuel emulsion engine results in a reduction of NOx up to 50% in the amount of water required by about one percent of each NOx reduction area. The limiting factor in water emulsions is the power delivery of the injection system [117]. If emulsions are to be used without engine modification, the amount of water and NO_x reduction rate is limited to 10-20%. However, the engine may not be able to reach its maximum capacity, operating at a reduced rate. Initially, emulsion diesel is selected with various water concentrations to perform the test function. Three different diesel water emulsion is 10%, 20%, and 30% of water emulsion in diesel. In all three dimensions, all content is diesel. In addition, 2% surfactants, Span80 and Tween80, are used with water emulsion to form a stable emulsion. This emulsion (WD) diesel and pure diesel are used to operate a single-cylinder diesel-powered engine separately with changing load conditions and continuous speed. Finally, better emulsion fuel is determined by measuring engine performance such as indicated power, thermal efficiency, mechanical efficiency, binding to the use of certain fuels, and output levels such as CO, NOx, and HC. The proposed system is explained in figure 3.1

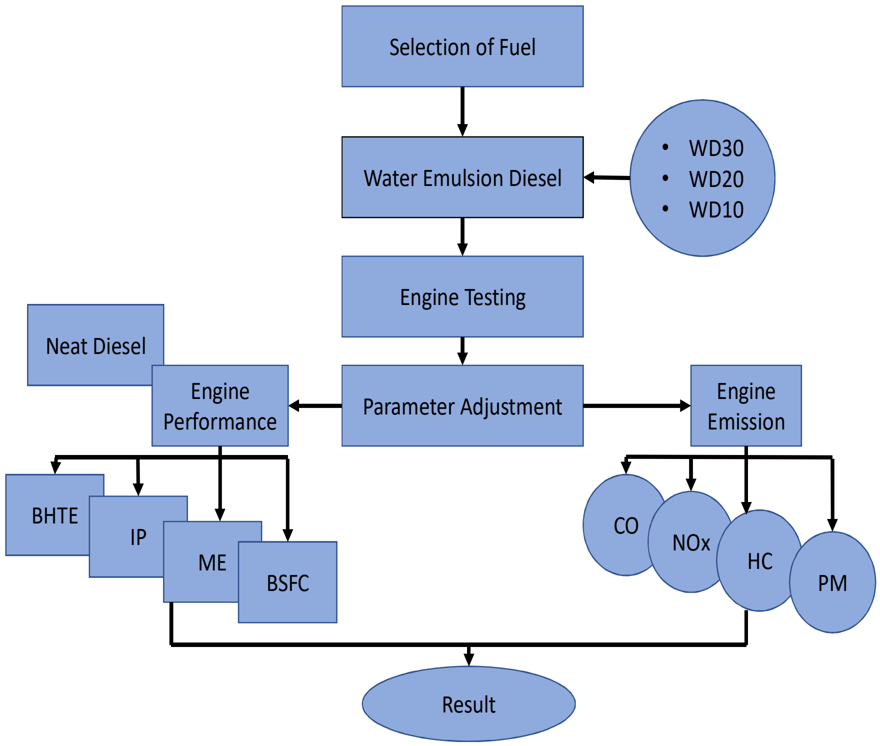


FIGURE 3.1: Proposed Method

3.2 Different Samples of Emulsion Preparation

The preparation of mixing two or more liquids and that process is called emulsion. The fundamental components of water diesel emulsion are water, emulsifier, and diesel. The methodology of water diesel emulsion preparation is explained in this chapter.

FIGURE 3.2: Emulsion Preparation of Sample 1

A sample of 200ml is taken, containing 180ml diesel, 18ml water, and 2ml emulsion. The emulsifier taken in this sample preparation is nonylphenol Ethoxylate, as shown in Figure 3.2. Using an electromagnetic stirrer, water and emulsifier are mixed at a speed of 800rpm. Diesel is stirred with water at 1000 rpm speed for 8 min to formulate water in oil emulsion. HLB value of the surfactant used is 4.3. After the preparation of the sample using electromagnetic stirrer and after resting time of 24hr the water diesel emulsion sample has an opaque physical appearance. The specifications of surfactant;

- Specific gravity- 0.96 gm/ml
- Water content – 0.05 %
- ALFOX – 9.5 mole

FIGURE 3.3: Emulsion Preparation of Sample 2

The second sample contains 90% of diesel, 8% of water, and 2% emulsifier shown in figure 3.3. Nonylphenol Ethoxylate is used as an emulsifier. With the help of a mechanical stirrer, water was mixed with an emulsifier at a speed of 8200 rpm for 3 minutes. The diesel is mixed with water, and the emulsion output is prepared at a rate of 11600rpm for 8 minutes. Emulsion turns in milky white physical appearance.

FIGURE 3.4: Emulsion Preparation of Sample 3

In the third sample, 90% of diesel, 9.5% of water, and 0.5% of emulsifier Span80 are taken. At a speed of 8200rpm for 2 minutes, with the help of mechanical stirring, the water is mixed with an emulsifier. The emulsion is prepared at a speed of 11600 rpm for 8 minutes shown in figure 3.4. The appearance of the produced emulsion was found to be milky in color, as shown in figure 3.4.

Table 3.2 defines the description of the emulsifier in the case of each parameter. The parameters such as molecular formula, HLB, specific gravity, molecular weight, and viscosity are discussed. The parameters are compared with different surfactants such as Tween 80, Tween 40, ALFOX-200, and SPAN 80.

TABLE 3.2: Specification of Emulsifier

Sr. no.	Parameter	Tween 80	Tween 40	ALFOX-200	SPAN 80
1	Molecular Formula	$C_{64}H_{124}O_{26}$	$C_{22}H_{42}O_6 (C_2H_{4O})_n$	$C_9H_{19}C_6H_{14}(OCH_2CH_2)_n OH$	$C_{24}H_{44}O_6$
2	HLB	15	15.6	9.5	4.3
3	Specific gravity a@ 25^0 C (gm/ml)	1.06-1.09	1.083	0.96	0.99
4	Molecular Weight (g/mol)	1310	1277	220.35	428.62
5	Viscosity @25^0 C (cst)	300-500	400-650	240	1000-2000

FIGURE 3.5: Emulsion Preparation of Sample 4

180ml diesel, 16ml water, and 4ml emulsifier for preparation of emulsion WD20 for a sample size of 200ml. An emulsifier, Polyethylene sorbitol ester, is used in emulsion together with water with the assistance of a mechanical stirrer at a speed of 8200 rpm for 3 minutes. The stirring of diesel with water occurs at a speed of 11600 rpm for 5 minutes. During that time, the water in diesel emulsion was prepared and is shown in figure 3.5.

Figure 3.6: Emulsion Preparation of Sample 5

In the 5th sample preparation process shown in figure 3.6, the emulsifier taken is polyoxyethylene sorbitan monooleate. The mechanical stirrer is used for the preparation of emulsion.

FIGURE 3.7: Emulsion Preparation of Sample 6

In the 6th sample, the emulsifiers used are polyethylene sorbitol ester and polyoxyethylene sorbitan monooleate. The mechanical stirrer was used to mix the water with the emulsifier at a speed of 8200 rpm for 3 minutes. The microemulsion shown in figure 3.7 is prepared at a speed of 11600 rpm for 8 minutes.

Several samples were prepared with different concentrations of water, different emulsifiers, and a variation in methodology.

3.3 Microemulsion Fuel Preparation and Its Properties

The composition of emulsion fuel (WD) depends entirely on the regenerative functions. Here in this thesis, three different concentrations of water emulsion, such as 10%, 20%, and 30%, can be added to diesel fuel. At all water emulsion rates, 2% of surfactant is used. Two different surfactants, Sorbitan monooleate [$C_{24}H_{44}O_6$] (Span80) and Polyethylene sorbitol ester [$C_{64}H_{124}O_{26}$] (Tween80), are used in this work. Emulsifier properties are shown in table 3.3.

TABLE 3.3: Emulsifier properties

Sr. No	Parameter	Span80	Tween80
1	Molecular Formula	$C_{24}H_{44}O_6$	$C_{64}H_{124}O_{26}$
2	HLB	4.3	15
3	Molecular Weight (g/mol)	428.62	1310
4	Specific gravity a@ 25^0 C (gm/ml)	0.99	1.06-1.09
5	Viscosity @25^0 C (cst)	1000-2000	300-500

Initially, 30% WD emulsion is prepared by stirring 28% water with 1% Tween80 to form a mixture with an electromagnetic stirrer at a speed of 1200 rpm. In order to aid this continuous movement, 70% of diesel fuel and 1% of Span80 are mixed at 1200 rpm separately. Water is added uniformly to form an emulsion with an electromagnetic stirrer. Finally, the complete emulsion is stirred using a mechanical stirrer at 8200 rpm speed. The fuel emulsion preparation is shown in figures 3.8 and 3.9. As the amount of water content in the emulsion increases, the brighter milky emulsion produces. The properties of different emulsified diesel are given in table 3.4. Properties of emulsified fuel were tested in different laboratories, and test results are attached in Annexure-A and Annexure-B.

FIGURE 3.8: Preparation of microemulsion

FIGURE 3.9: 10%, 20% and 30 %Water- Diesel Micro Emulsion

TABLE 3.4: Properties of neat diesel and water emulsion fuel

Sr. No.	Parameter	Diesel	WD10	WD20	WD30
1	Density @15^{0}C (gm/ml)	832	838	849	852
2	Kinematic Viscosity @ 40^{0}C (cst)	2.22	2.34	2.39	3.80
3	Kinematic Viscosity @ 100^{0}C (cst)	9.52	9.62	10.10	10.45
4	Gross calorific Value (Kcal/kg)	10642	10484	10410	7525
5	Cetane Number	52	52	52	52
6	Flame temperature (^{0}C)	240	242	246	247
7	Molecular weight(gm/mol)	170	171	171	171
8	Sulphur (%)	0.04	0.06	0.08	0.09
9	Flash Point (^{0}C)	95	92	91	90

The effect of Water content on the kinematic viscosity of the micro emulsion is shown in Figure 3.10. Water diesel microemulsion exhibits greater viscosity than pure diesel fuels, and both water content and size of droplets dispersed in emulsion significantly influence its viscosity.

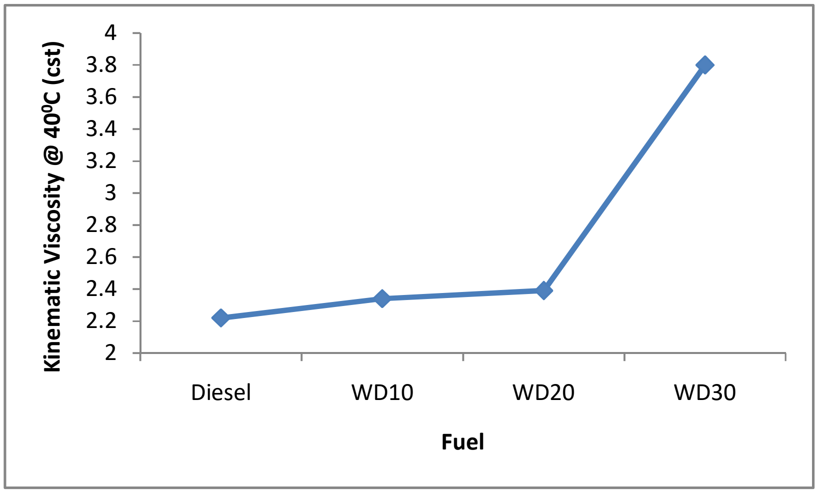


FIGURE 3.10: Effect of the water content on the viscosity of micro-emulsion

Table 3.5 shows the Ultimate analysis of samples with Instrument: Leco TruSpec CHNS) tested at SVNIT, Surat(Sophisticated instrumentation centre Mechanical Engineering Department), as per Annexure- A.

TABLE 3.5: Ultimate analysis of micro emulsified diesel

Parameter	WD10	WD20	WD30
Carbon %	79.3	71.1	55.5
Hydrogen %	13.4	12.7	12.4
Nitrogen %	12.7	13.0	14.4
Sulfur %	0.135	0.215	0.253

3.4 Injection Pressure Variation

A fuel injector is an electronically operated mechanical system spraying or injecting fuel into the engine. Advances in fuel injection technology have given rise to various fuel injection arrangements, such as throttle body fuel injection, direct injection, multipoint fuel injection, and manual fuel injection, which can be used depending on the application. Still, when it comes to the types of fuel injectors, it is a difficult task to classify them. The fuel injectors are classified into different categories. Based on fuel metering, they are classified as mechanically controlled and electronically controlled fuel injectors.

Ashok Leyland comment mark 3 Viking model is used to study injector pressure variation. Fuel injector equipment for AL 370(Derated) engine and Mico Bosch Injector test bench for Nozzle Pop test is used for the study. The overall performances of the fuel-injected vehicles are better than that of carburetted vehicles. The utilized fuel injector model is represented in figure 3.11.

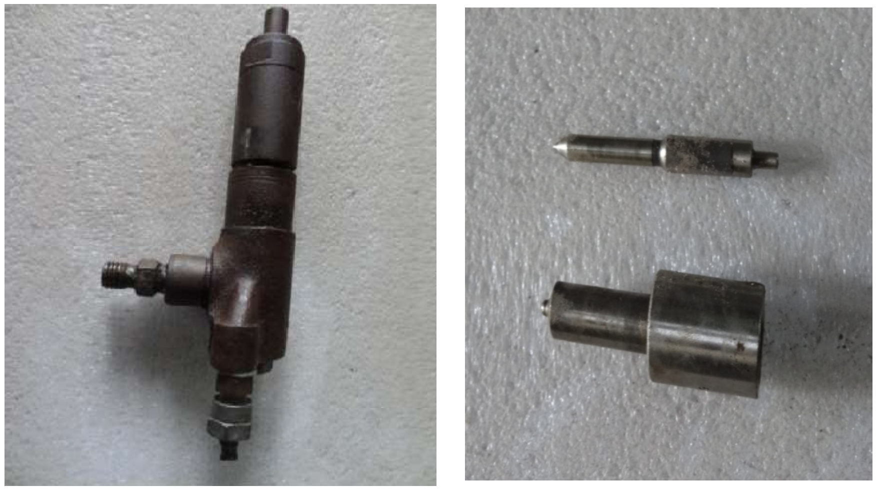


FIGURE 3.11: (a) Onsite picture of fuel injector and nozzle

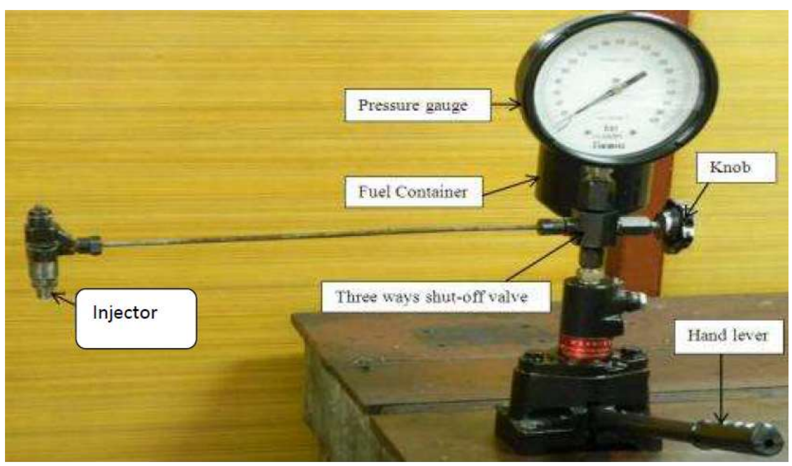


FIGURE 3.11: (b) Schematic diagram of Fuel Injector test setup

3.5 Engine Setup and Engine Specification

For examining the performance of internal combustion engines number of parameters such as fuel consumption, power, thermal efficiency, and exhaust temperature are measured.

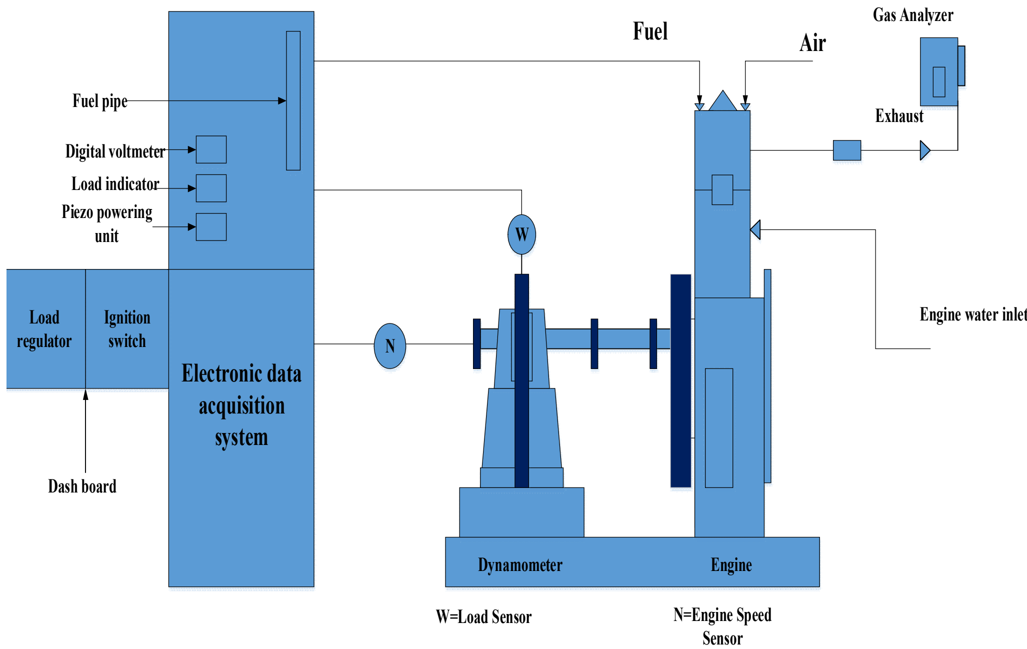


FIGURE 3.12: Schematic Layout of Experimental Setup

For this purpose, a 4-stroke single-cylinder diesel engine is used to analyze the output and performance. Engine features are measured using input conditions such as a constant speed of 1500 rpm, and a trial at various load conditions such as 2kg, 4kg, 6kg, 8kg, and 12kg is done. Here, 444N five gas analyzer is used to measure NOx, CO, and HC emissions. The schematic layout of the setup used for this purpose is shown in Figure 3.12. The current AVL eddy meter is integrated with the engine using load absorption. The airflow meter is used to measure the airflow rate. The final setup is interfaced with a computer through a high-speed data acquisition system. Figure 3.13 shows the experimental setup of this work.

FIGURE 3.13: Experimental Setup-Diesel Engine

Table 3.6 shows the specification of the engine used in this experiment. The single Cylinder, four Stroke, Multi fuel, and VCR (Computerized) Test rig is selected for this work, equipped with Eddy current dynamometer. The engine runs at 1500 rpm speed using a direct injection system. Experiments were performed on three different engines set up at the different locations. Follow the standard procedure for experimentation from manual provided by manufacturer. Ensure cooling water circulation for eddy current dynamometer and piezo sensor, engine and calorimeter. Start the set up and run the engine at no load for 5 minutes. Gradually increase the load on the engine by rotating dynamometer loading unit. The pretests were performed so as to obtain the operating conditions of the test engine. Afterward, the stabilization time of the engine was found and the engine was ensured to stabilize for all test fuels before the engine experiments. The engine was operated with neat diesel fuel and waits for steady state to collects the reading.

TABLE 3.6: Engine Specifications

Specifications of Engine	
Engine Type	Single cylinder, 4- stroke, water cooled
Swept Volume	661 cc.
Bore (mm)	87.5
Stroke (mm)	110
Diesel mode	5.2 KW @1500 rpm

3.6 Emission parameters

The detection method is based on the concept of selective infrared energy absorption at a wavelength unique to a given gas, which that gas will absorb. Figure 3.14 displays a photograph of pollution measurement instruments. The sampling probe should be inserted as close as possible to the exhaust valve in the exhaust tailpipe, but due to different fittings and space limitations, it was inserted two feet from the cylinder head.

FIGURE 3.14: a) 444N five gas analyzer, b) stack sampling kit, c) smoke meter, d) flue gas analyzer

The exhaust gas sample was transferred through a moisture separator and filter element to prevent the entry of water vapor and particulates into the analyzer. The analyzer is serviced and calibrated regularly using a normal gas mixture of n-hexane and CO. Among various pollutants, HC and CO are released due to partial combustion and non-combustible fuel, whereas NOx is emitted due to temperatures above 1,600^{0}C. These polluting pollutants have severe consequences for human health and the environment. Even though there are methods and applications to prevent the fatal effects and meet stringent pollution regulations, robust discharge control systems can only achieve the elimination of emissions from diesel engine exhaust gases.

3.7 Summary

Attempts are made to utilize different approaches to test the preparation of micro emulsified fuel for the diesel engine. Experimental studies on the diesel engine are conducted to understand the outcome of varying operating parameters and emission parameters. The preparation of the emulsion sample is explained briefly. The emulsion process uses different sample iterations to find a better output and optimize the influential parameters. The experimental setup of the diesel engine used is discussed in this chapter. The experimental testing of fuel using a fuel injector is also described. Various emissions from the exhaust gas and its measuring instruments are briefly explained.

CHAPTER 4

Results and Discussion

4.1 Overview

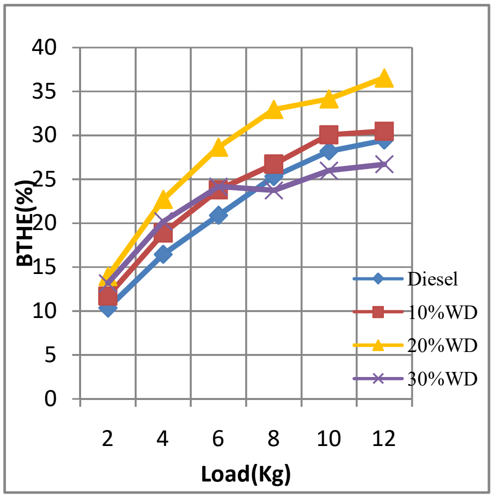
This section assesses emission quality and engine performances with varying engine load conditions to conduct a performance review of different concentration levels of the water emulsion diesel-fuelled single-cylinder four-stroke diesel engine. The best water emulsion fuel proportion is determined by analyzing emission characteristics and engine efficiency behaviors. This section discusses the output of diesel engines in terms of key pollutant emissions (CO, HC, NOx, PM, CO_2, and Smoke). Also, the engine's performance is evaluated in regards to indicated capacity, mechanical efficiency (ME), Brake specific fuel consumption (BSFC), brake thermal efficiency (BTHE), and emission characteristics. Even though innumerable implementations have been introduced into the diesel engines to meet strict pollution requirements and mitigate the adverse effects of emission of pollutants, the after-treatment emission control systems can remove contaminants from the diesel exhaust gas.

4.2. Brake Thermal Efficiency

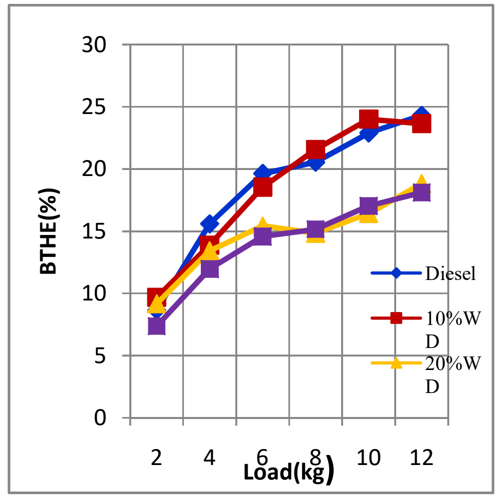
Figure 4.1 represents the BTHE of neat diesel and water emulsion under various load conditions. Because of these heat losses, the BTHE is lower, and more heat is transferred to the engine cylinder wall. The neat diesel has poor BTHE compared to the emulsion diesel fuel as it has a low heating benefit. As a result, the mechanical power transfer is reduced when the engine load is raised, resulting in increased power and increased performance without accounting for friction losses.

The emulsion fuel outperforms the tidy diesel fuel in terms of increasing BTHE. The improved combustion efficiency of the emulsion fuel, primarily because of its micro-explosive behavior and enhanced mixing of air and fuel causes this effect. From figure 4.1

(a), the WD20 fuelled diesel engine reaches the highest BTHE of 36.54%, while the tidy supports the lowest BTHE of 29.45%. For figure 4.1(b), at lower load, WD10, WD20, and WD30 have the same BTHE as diesel fuel, while at higher load, WD10 and WD20 have higher BTHE compared to pure diesel fuel.



(a)



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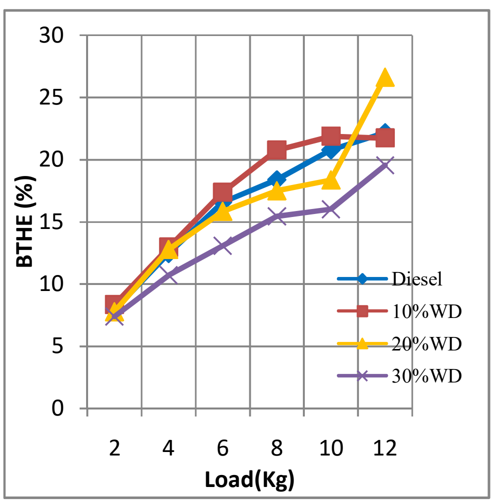
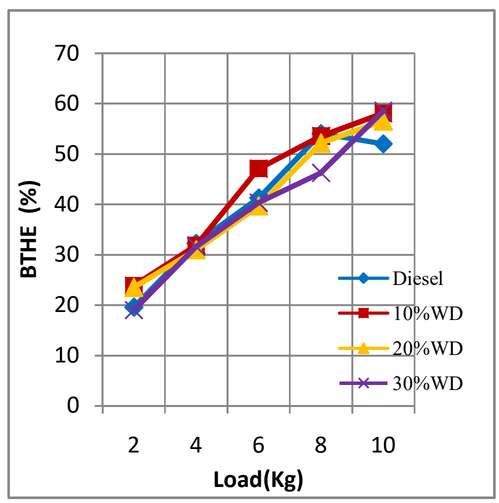


(c)



(d)

FIGURE 4.1: Brake thermal efficiency traces of neat diesel and water emulsion diesel

Figure 4.1(c) shows that for a 6kg load with WD10, BTHE is 17.37%, WD20 and diesel fuel have a BTHE of 15.85%. At 12kg load, the highest BTHE is 26.64% with WD20, while BTHE is 21.75% with diesel fuel. Figure 4.1(d) shows a lower load with 2 kg WD10, WD20 having BTHE of 23.87% higher than diesel fuel, and WD30 of 19.03%.

From experimental results, it is clear that WD10 emulsion has BTHE comparable to diesel fuel for all load ranges.

4.3. Brake specific fuel consumption (BSFC)

Figure 4.2 represents the BSFC of a diesel engine fuelled with neat diesel and water emulsion diesel under various load conditions. By analyzing figure 4.2(a), it is observed that as load factors are raised, the BSFC of the diesel and WD decreases. Since the emulsion fuel has a lower calorific value compared to neat diesel, it has a higher BSFC and thus consumes more fuel. According to the graph, 10%WD has a low BSFC rate of 0.296 kg/kWh, while 30% of WD emulsion has a higher BSFC rate of 0.491kg/kWh.

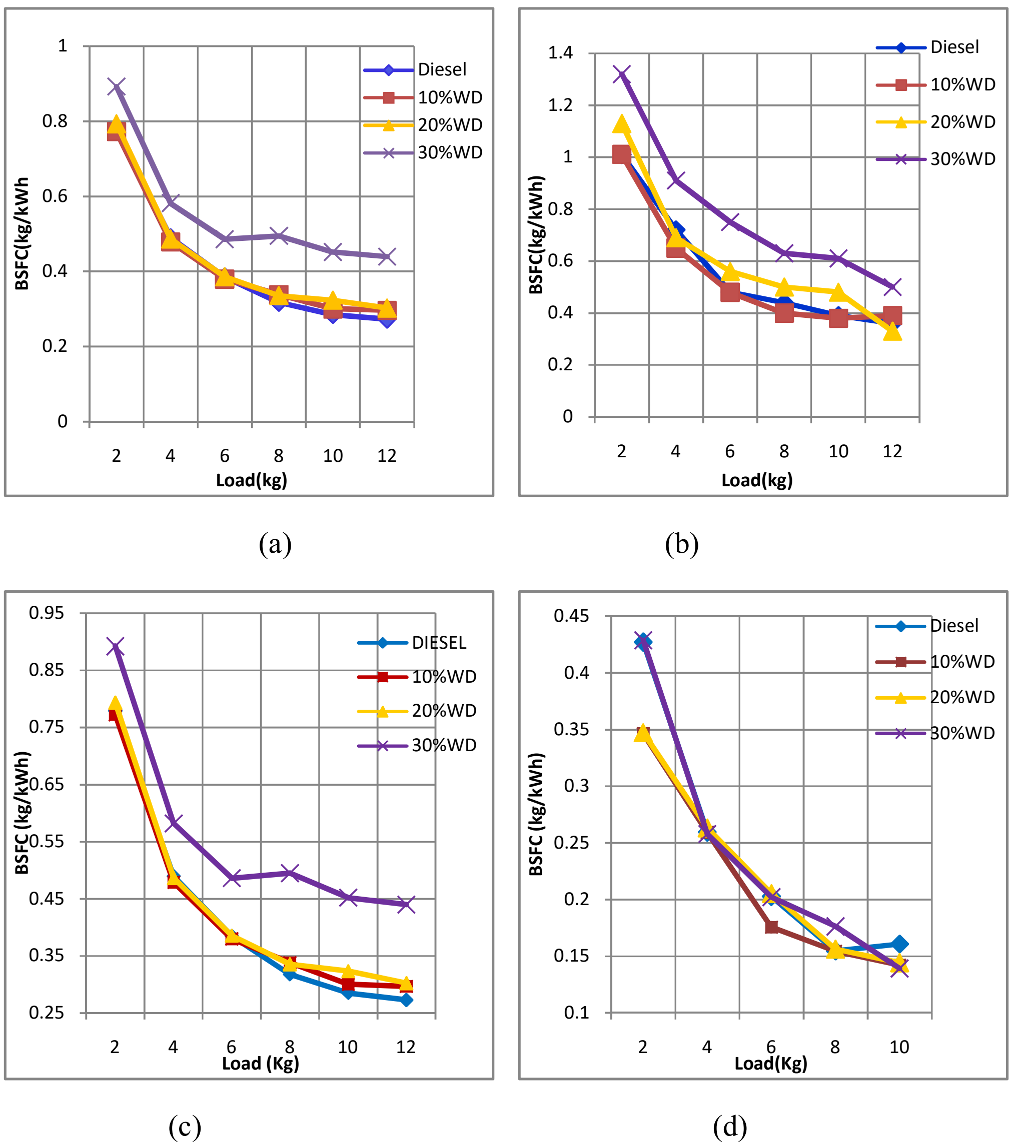


FIGURE 4.2: BSFC for neat diesel and water emulsion diesel (WD)

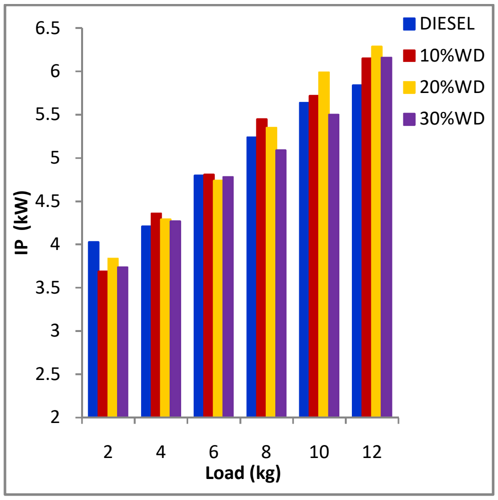
From figure 4.2(b), at a lower load with diesel and WD10 the BSFC rate is 1.01kg/kWh, while WD20 and WD30 the BSFC rate increases to 1.13 kg/kWh, and 1.32 kg/kWh, respectively. At 10kg load, pure diesel and WD10 have a BSFC of 0.38 kg/kWh, with a WD20 higher rate of 0.48kg/kWh, and the highest BSFC with WD30 is 0.61kg/kWh. As load increases the BSFC decreases and there is increase in the burning efficiency. From figure 4.2 (c), from lower load to 6kg load diesel fuel, WD10 and WD20 have comparable BSFC rates, while at 12kg load diesel fuel, with minimum BSFC of 0.27kg/kWh and WD30 has 0.43kg/kWh. Figure 4.2(d) shows that WD30 has higher BSFC than diesel, while WD20 and WD10 BSFC rate increases nominal at high load and is almost the same as diesel fuel at low load. Since the emulsion fuel has a lower heat quality, this effect occurs.

4.4. Indicated power (IP)

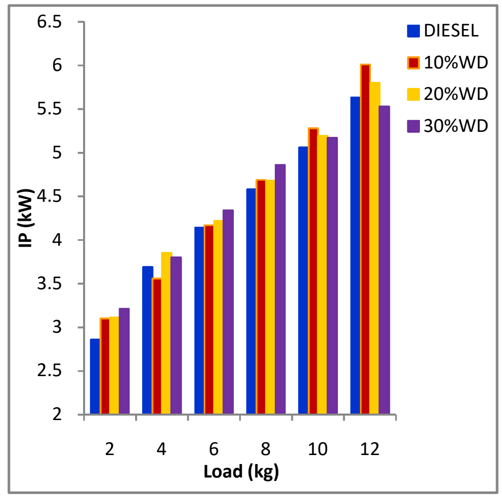
The indicated power is compared to neat diesel and three separate water emulsion diesel in Figure 4.3. As the input load rates are increased, the indicated power increases.

The minimum IP is obtained at initial load conditions of 2 kg, followed by the final load value of 12 kg. When using neat diesel in the engine, the lowest kinematic viscosity and highest calorific value maximize the indicated power. At lower loads, power output is low due to improper combustion of fuel but as the load increases and the fuel supply increases, improving the combustion and increasing the indicated power. From figure 4.3(a), at a 4kg load, diesel fuel IP of 4.03kW reduces with WD30 to 3.74kW, and with WD10, it is 3.69kW. At full load with diesel fuel, IP is 5.84kW which increases with WD10 by 6.15kW, WD30 indicated power is 6.16kW, and the highest value of IP with WD20 is 6.29kW. Figure 4.3(b) shows indicated power increases from 3.1kW to 6.01kW with no load to full load condition with WD10. At lower load, power with diesel fuel is 2.86kW, which increases by 3.1 kW, 3.11kW, and 3.21kw, respectively, as water content increases. While at full load, WD10 IP increases up to 6.01kWand with WD20 and WD30, it decreases by 5.8kW and 5.53kW, respectively. In figure 4.3(c), water emulsion fuels 10%WD increases indicated strength, but it is less than neat diesel fuel. Because 10% of WD contains minimal viscosity ranges and superior evaporation and combustion behaviours, this occurs.

Furthermore, it aids in the reduction of ignition delay. The neat diesel's maximum indicated power is 6.19 kW, while the WD30 is 4.218 kW. At low load, indicated power with WD10 is reduced by 16%, and at high load with WD30, reduction in power by 34%. Figures 4.3 (b) and (d) show that WD10 indicated power is higher than diesel fuel.



(a)



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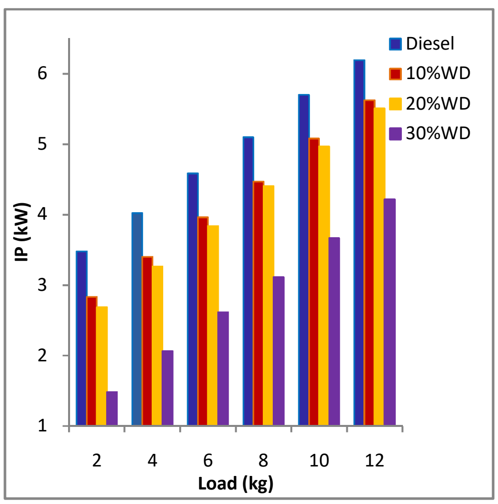

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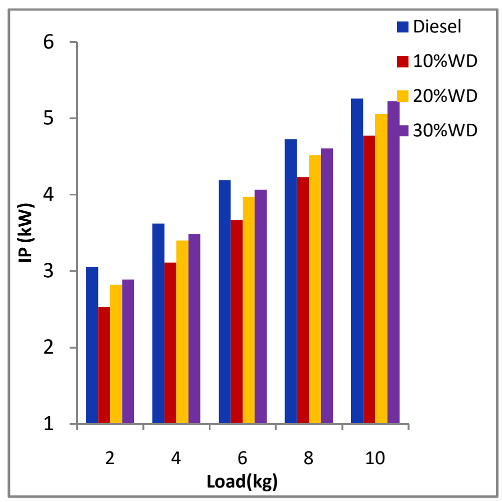


(d)

FIGURE 4.3: Indicated power versus Load

4.5. Mechanical Efficiency

Three different water emulsion diesel, such as 10%, 20%, and 30%, are shown in Figure 4.4. The engine's mechanical efficiency is proportional to the applied load conditions, i.e., the engine's mechanical efficiency increases as the load increases, for constant speed friction power is almost constant therefore increasing brake power increases mechanical efficiency.

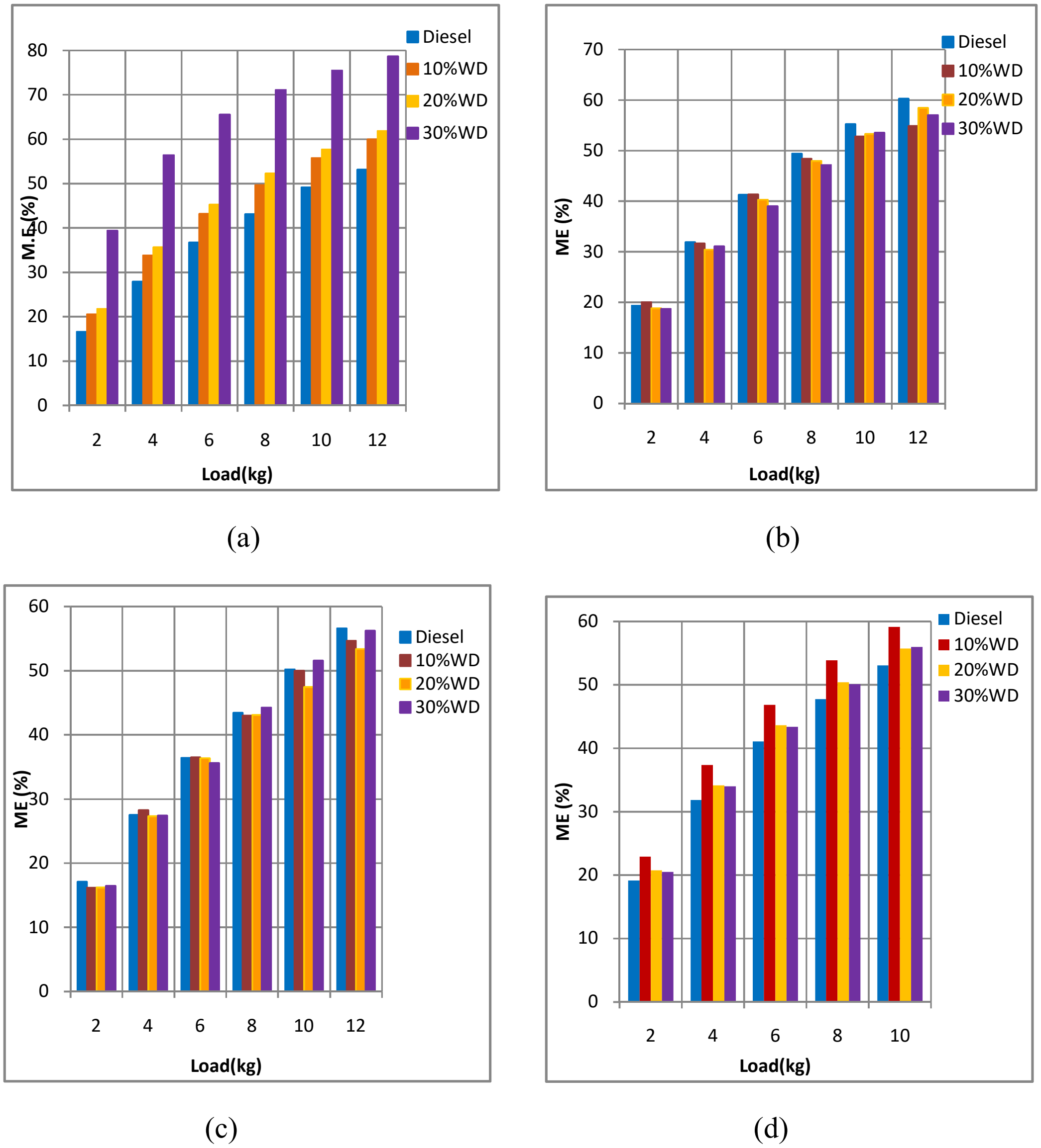


FIGURE 4.4: Load versus Mechanical Efficiency

When the load rises on the engine, the fuel injecting rate per cycle tends to decrease. Furthermore, because of the micro explosion activity of water droplets, the combustion behavior of the fuel is increased under heavy loads with emulsion fuel. When using the WD30, the engine's mechanical performance is improved by 78.66% at the final load of 12 kg. The mechanical efficiency achieved by a diesel-fuel engine is 53.16%. It shows the mechanical efficiency is lesser in diesel fuel engines compared to WD fuelled engines. Figures 4.4 (b) and (c) showed similar behaviour for mechanical efficiency for WD10, WD20, and WD 30 emulsion fuel.

4.6. Uncertainty Analysis

Three runs of tests were performed under identical conditions to check for the repeatability of all results. In general, the repeatability of the results was found to be within 5%. Each reading of the fundamental quantities measured is the average of three values.

If R is a function of the independent variables X1, X2, X3,..., Xn. Thus,

$$R = R(X_1, X_2, X_3..X_n) \tag{4.1}$$

Let ωR denote the result's uncertainty, and w_1, w_2,...,w_n denote the independent variables' uncertainties[118]. If the independent variables' uncertainties are all provided with the same odds, then the result's uncertainty is also given these odds.

$$\omega R = [(\frac{\partial R}{\partial x_1} w_1)^2 + (\frac{\partial R}{\partial x_2} w_2)^2 + ... + (\frac{\partial R}{\partial x_n} w_n)^2]^{\frac{1}{2}} \tag{4.2}$$

The measurement's uncertainties were calculated using the instrument's resolution or given by the manufacturer. Table 4.1 shows the values of uncertainty analysis.

- The time measurement uncertainty, t = 0.1 sec.
- Volume flow calculation uncertainty, m = 1ml
- The Load Measurement Uncertainty, m = 0.1 kg
- The R.P.M. measurement uncertainty, m = 10 rpm

The error in measuring the fuel mass flow rate is estimated by considering the error in calculating the time used for the engine to consume the fuel. The timer used has a resolution of 0.1s. Thus, the uncertainty in the fuel mass flow rate values is estimated at 0.23–0.45%. Uncertainty analysis was performed for the derived quantities, such as power, brake-specific fuel consumption, and thermal efficiency. The uncertainty analysis indicates that the uncertainty in such quantities is 1–5%.

TABLE 4.1: Uncertainty analysis

Load (kg)	**BP (kW)**	**Uncer tainty (%)**	**FC (kg/hr)**	**Uncert ainty (%)**	**SFC (kg/kWh)**	**Uncer tainty (%)**	**BTHE (%)**	**Uncert ainty (%)**
2	0.58	5.04	0.47	0.23	0.81	5.05	12.28	5.05
4	1.15	2.59	0.59	0.28	0.51	2.61	19.54	2.61
6	1.71	1.80	0.70	0.33	0.41	1.83	24.36	1.83
8	2.23	1.43	0.83	0.35	0.37	1.47	27.17	1.47
10	2.82	1.21	0.96	0.40	0.34	1.27	29.59	1.27
12	3.35	1.08	1.10	0.45	0.33	1.17	30.78	1.17

The estimated error in the measurement of the fundamental and derived quantities does not significantly influence the overall uncertainty in the final results.

4.7. Injection Pressure Variation

Ashok Leyland comment mark3 Viking model is used to study injector pressure variation. Fuel injector equipment for AL 370(Derated) engine and Mico Bosch Injector test bench for Nozzle Pop test is used for the study. The overall performances of the fuel-injected vehicles are better than that of carburetted vehicles. Injector pressure shows a reading of 1551.32kPa for diesel and 1654.74kPa for 10%WD emulsion. Minor variation for 20%WD and 30% WD emulsion has been observed above 1654.74 kPa. The utilized fuel injector model is represented in figure 3.10.

4.7.1. WD10 Emulsion Fuel Injection

Figure 4.5 represents the fuel injection process of WD10 fuel. Injector pressure shows 16.54 bar pressure for WD10 emulsion. Fuel injection systems significantly influence the combustion process and have a pivotal role to play in improving engine fuel consumption and reducing noxious exhaust emissions.

FIGURE 4.5 WD10 emulsion fuel injection

4.7.2. WD20 Emulsion Fuel Injection

Figure 4.6 depicts the experiment setup; the sample contains 80% of diesel, 18% of water, and 2% of surfactants. Spray with WD20 emulsion visually differentiated from diesel fuel. The deeper penetration from WD20 fuel was also beneficial in reducing PM emissions.

FIGURE 4.6 WD20 Emulsion fuel injection

4.7.3. WD30 Emulsion Fuel Injection

Figure 4.7 shows the fine spray behaviour of 30% water-diesel emulsion. Nominal variation in pressure for the sample has been observed above 16.54 bars. Micro explosion is when the whole droplet breaks up into tiny droplets quickly.

FIGURE 4.7 WD30 emulsifier fuel injection

4.8. Carbon Monoxide (CO) Emission

Factors such as cylinder pressure, temperature, and ignition delay play a significant role in the generation of CO emissions. Furthermore, the relationship between fuel spray and spray-spray affects CO formation. Figure 4.8 depicts the CO emissions obtained by varying the engine load conditions in the water emulsion diesel and neat diesel.

The water emulsion generates a certain maximum amount of CO during the combustion phase at a minimum level of load conditions than neat diesel due to the lower combustion temperature. Simultaneously, except for 30%WD, 10%WD, and 20%WD, emission rates are lower than clean diesel. This is primarily due to the tendency of 30%WD to produce more water, resulting in a lower flame temperature than neat diesel and a greater need for oxygen to convert CO to CO_2. The leading causes of CO formation are incomplete fuel-air mixing and incomplete combustion. According to graph 4.8(a), the WD10 contains the least amount of CO emissions. The complete combustion activity and the availability of surfactants are responsible for this effect. The oxygen molecules in the surfactant assist in the generation of CO_2 from CO. CO emission rates are decreased. Simultaneously, in emulsion fuels containing 30%WD, the larger water molecules have a lower combustion temperature, resulting in higher CO emissions due to incomplete combustion. From the entire graph 4.8, WD20 emitted the same or reduced amount of CO emission.

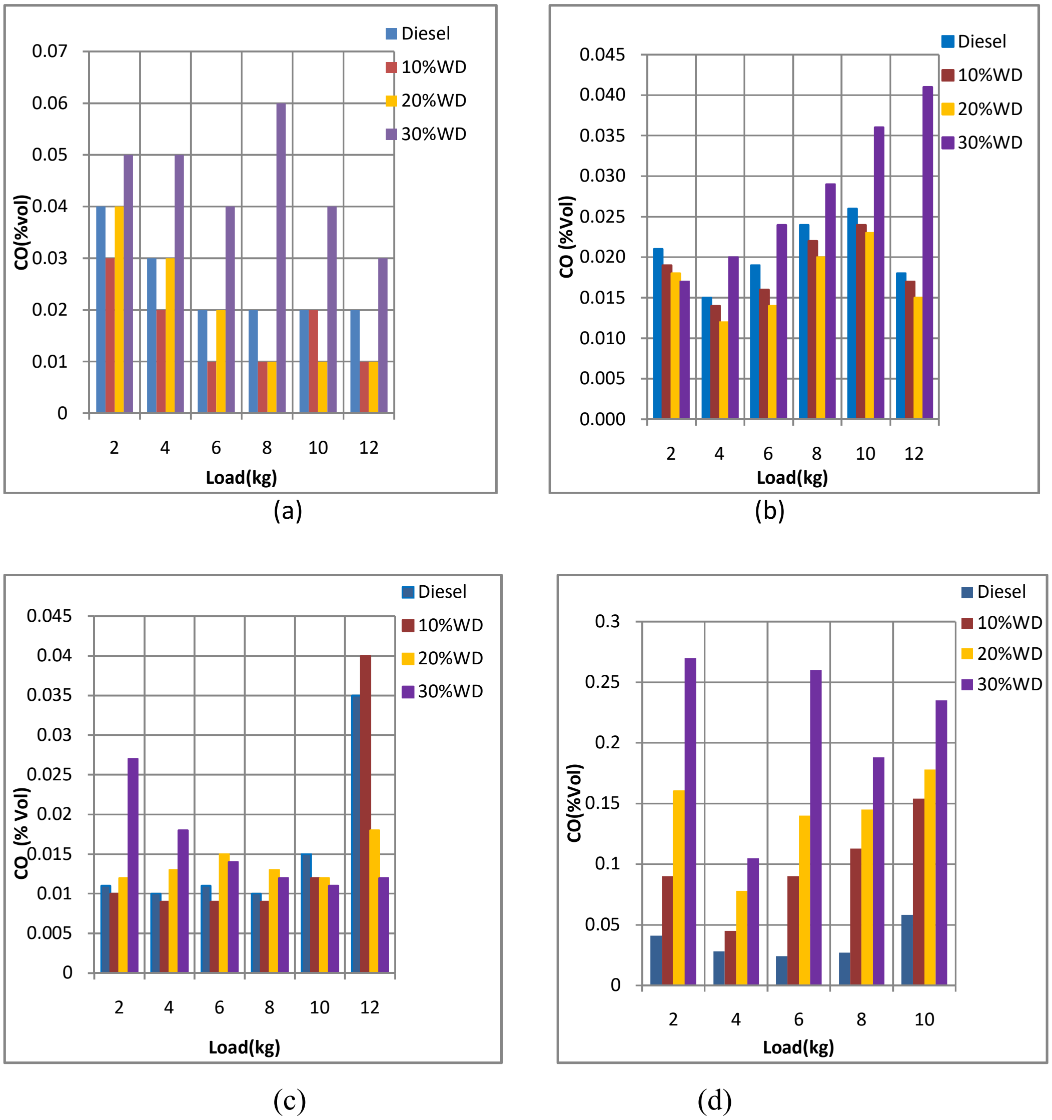


FIGURE 4.8 Carbon monoxide emission rates at varying loads.

4.9 NOx Emission

Figure 4.9 displays the nitrogen oxide emissions from diesel and WD emulsion diesel at various loading conditions. There is a remarkable reduction of NOx in all W/D combinations compared to diesel. The percentage of NOx reduction is almost proportional to the percentage of water content in W/D.

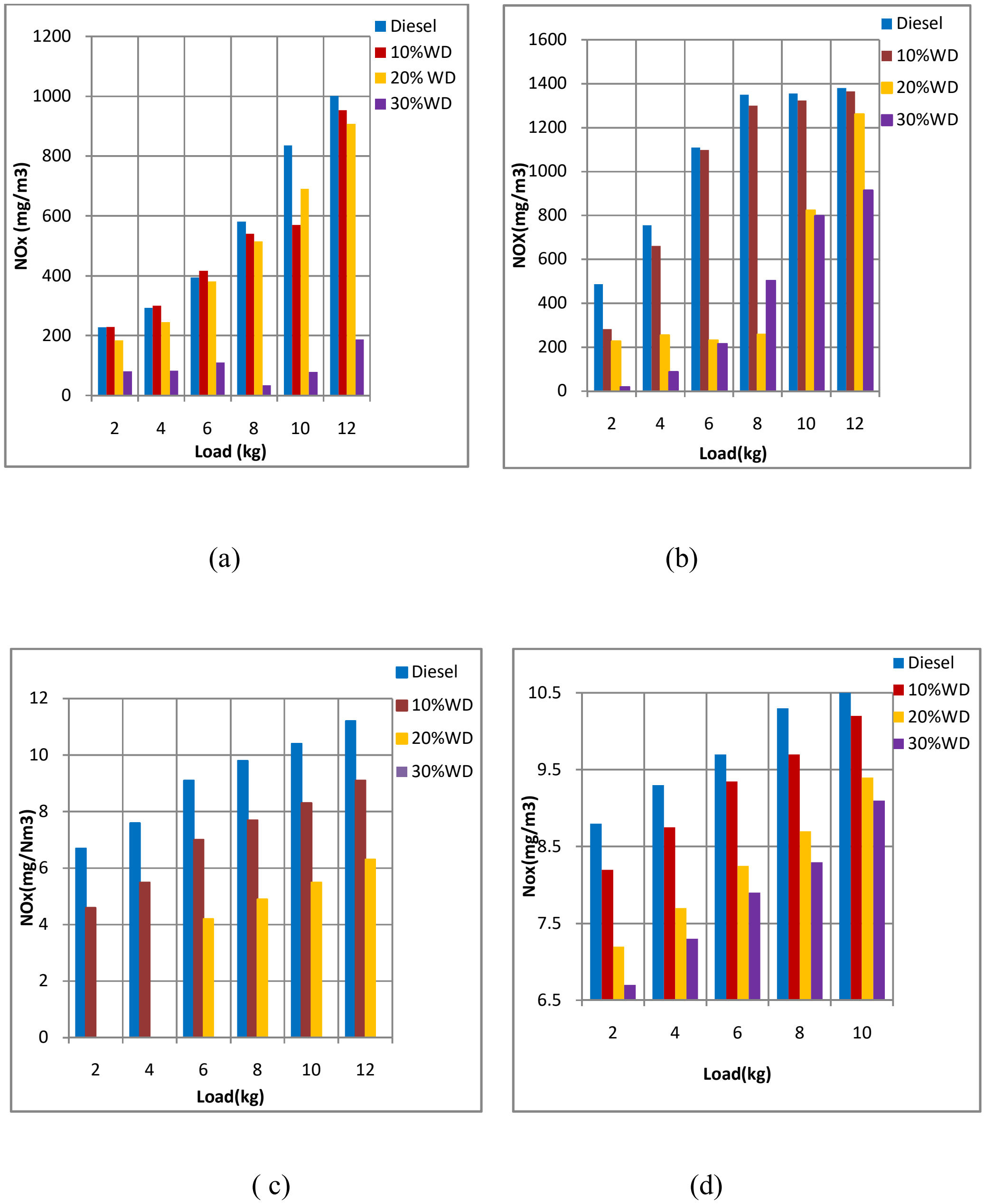


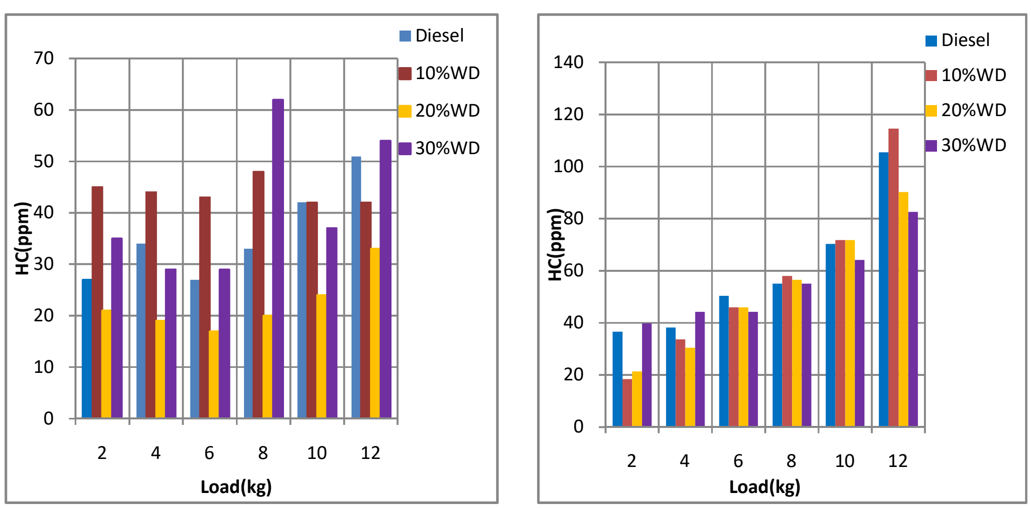
FIGURE 4.9 NOx emission rates for neat diesel and water emulsified diesel at different load conditions

The availability of water in WD30 is primarily responsible for this effect. The heat is absorbed as latent and basic heat nature by this attainable water content of WD30. Subsequently, there is a decrease in combustion chamber temperature and NOx formation. Consequently, the water contained in the emulsion and the combustion temperatures are the two most critical variables in NOx formation and reduction. The reduced NOx emission rate is also because of the minimal ignition delay. The water molecules in the emulsion fuel could consume more heat energy, resulting in a substantial decline in the temperature in the combustion chamber in this situation. The residence of oxygen in the surfactant is primarily accountable for the increased NOx formation in WD10. Figure 4.9(c) shows that WD30 produces no NOx emission for all load variations, while WD20 fuel only shows emissions in a higher load range.

4.10 Hydrocarbon (HC) Emission

Incomplete fuel combustion activity is the primary source of hydrocarbon emissions. Figure 4.10 depicts the hydrocarbon emissions emitted by the engine when it is run on water emulsified diesel and neat diesel.

The overall volume of fuel consumed results in the reduction of hydrocarbons. Because of the water drops in the diesel, the atomization increases, resulting in more complete and adequate combustion. Because of the entire mixture of fuel-air, hydrocarbon emissions rise as the load increase. The hydrocarbon emissions from water emulsion diesel are usually lesser than that of diesel fuel, as shown by numerous studies. This decrease in hydrocarbon is due to improved emulsion fuel combustion, the phenomenon of the micro explosion, and the formation of OH radicals from water. Figures 4.10(a) and (b) show that WD20 produces lower HC than diesel.



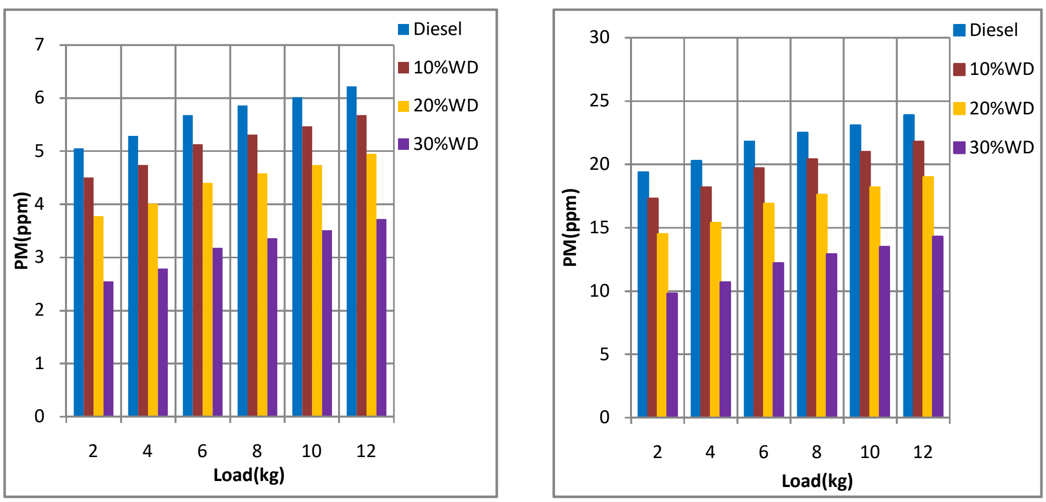
(a) (b)

FIGURE 4.10 Load conditions Versus Hydrocarbon emissions

4.11 Particulate Matter (PM) Emission

The emitted particulates from the engine involve a small amount of matter of carbon and inorganic substances. Figure 4.11 displays the PM emission from neat diesel and water-diesel emulsion at various load conditions.

Figure 4.11(b) shows that the particulate matter emission is greatly decreased by applying the WD30 for the load value of 12kg. Similarly, for all values of load condition, the emission of the particulate matter is less in the case of the water emulsion diesel in contrast to the neat diesel. The application of the WD20 for a load condition of 12kg shows less particulate emission than other water emulsions such as WD10 and WD30, respectively. The WD20 produces a reduced amount of 19ppm for a 12kg load. But for the same load condition, it is 23.9ppm for neat diesel.



(a) (b)

FIGURE 4.11 Particulate Matter emissions Vs Load

4.12 Carbon Dioxide (CO_2) Emission

The engine emits carbon dioxide due to fuel combustion in the combustion chamber. The complete combustion of the HC will produce water and carbon dioxide.

From figure 4.12, it is evident that the CO_2 emission is limited to 1.54%vol for the maximum load of 12kg by applying the WD30. But in the case of neat diesel, it is about 3.47%vol. The water emulsion diesel will produce a decreased CO_2 emission of 3.09%vol, 2.58%vol, and 1.54%vol for WD10, WD20, and WD30, respectively, compared to pure diesel.

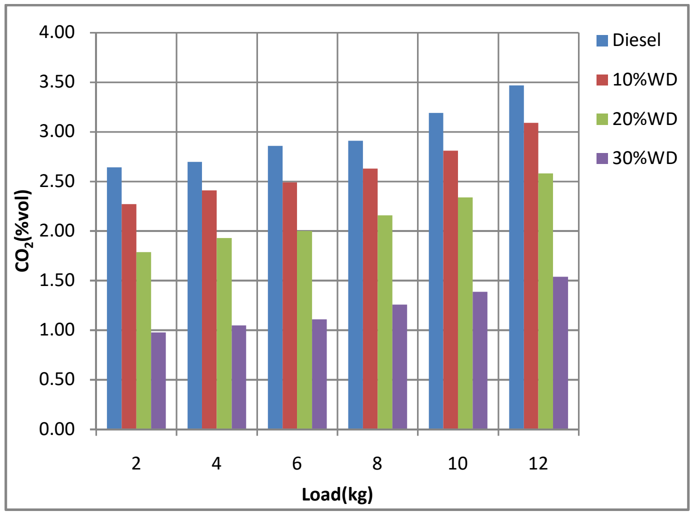


FIGURE 4.12 Carbon dioxide emissions at different load conditions

4.13 Smoke Emission

The emission of smoke over various engine load conditions is depicted in figure 4.13. The emissions of smoke for both pure diesel and WD are found to increase with the increase in load at constant engine speed. It is because of the higher fuel consumption rate at a higher engine load. As the engine speed is kept constant, sufficient time is not available for combustion of the increased fuel consumption at a higher load.

From figure 4.13, it can be revealed that there will be a maximum emission of smoke when water emulsion diesel is used in contrast to the neat diesel. In the case of neat diesel for load conditions of 10kg, the smoke emission is limited to 4% with WD20. WD10, WD20, and WD30 reduce as the load increases. For the 2kg load condition minimum, smoke emission was achieved with WD10 and WD20 compared to other water emulsion diesel and neat diesel. The smoke emission is found to be less with WD than that with pure diesel. This may be attributed to improved combustion of emulsified fuel due to the combined effect of micro explosion and secondary atomization.

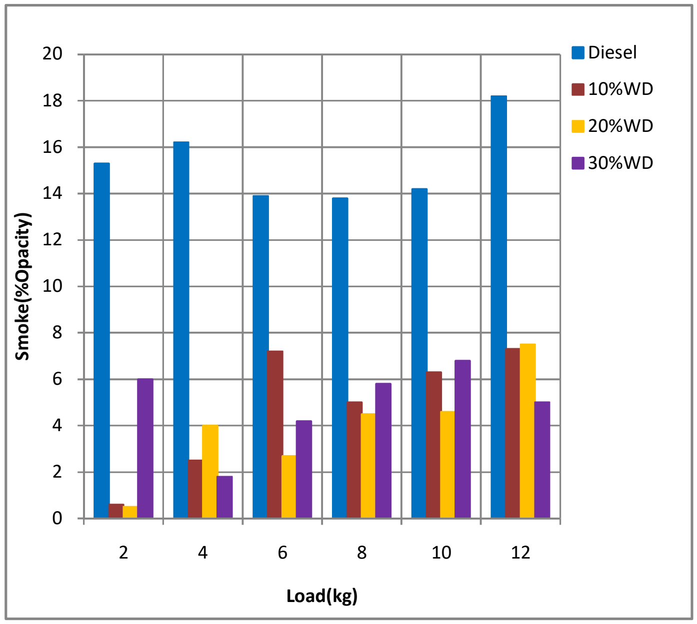


FIGURE 4.13 Load condition versus Smoke emission

4.14 Comparison of performance and emission characteristics:

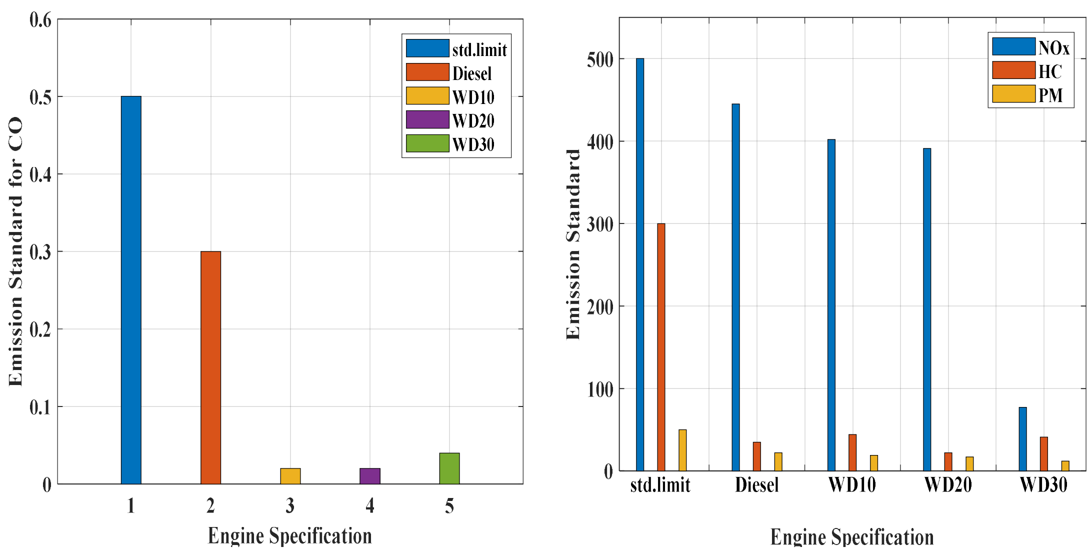


FIGURE 4.14 Comparison of emission standard and obtained emission result

Figure 4.14 represents the comparison of emission characteristics of water emulsified with diesel fuel standard values. The emission standard limit from Bharat stage four gives the carbon monoxide emission limit of 0.5% for diesel engine vehicles. In contrast, the engine fuelled by emulsion with diesel fuel, the maximum value of CO obtained is less than 0.01%. It ranges within the standard limits. The standard limit values of NOx, HC, and PM are 500, 300, and 50ppm. Comparing the emission concentration of the experiment with standard limits shows that the water emulsified fuel with 30% is better for reducing the exhaust emission than the diesel fuel.

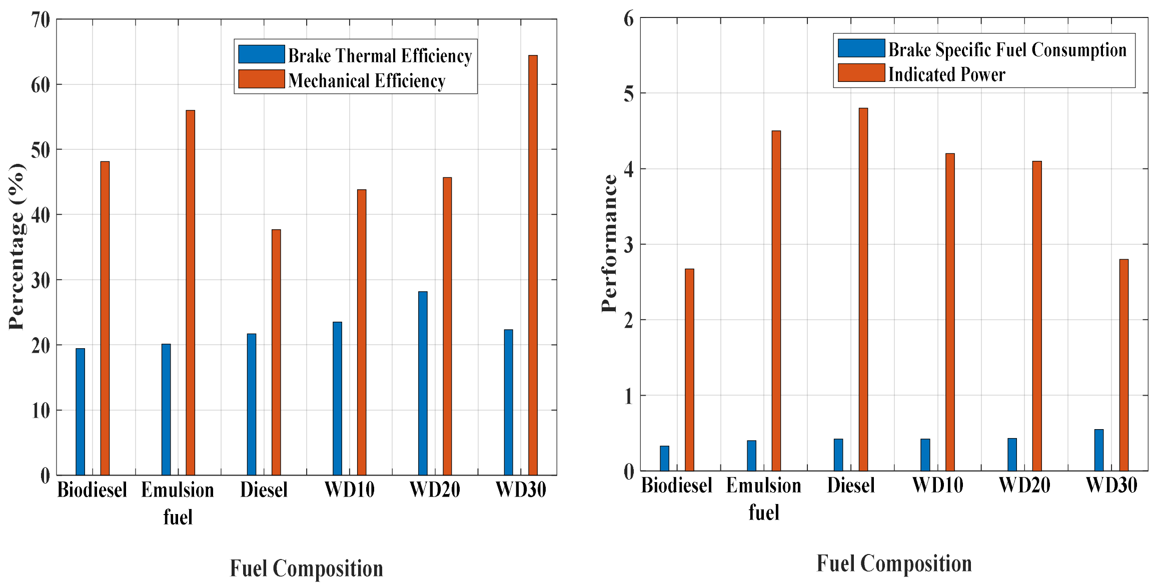


FIGURE 4.15 Comparison of Performance characteristics [68,69,72]

Figure 4.15 represents the performance comparison with reference biodiesel and emulsion fuel performance [68,69,72]. The graph clearly shows that emulsion fuel gives better outcomes of performance. Form experimental work, the WD30 gives the best results in mechanical efficiency and BSFC. The best results were obtained when compared to the reference performance. The thermal efficiency and indicated power also give good outcomes.

4.15 Summary

This chapter describes the performance characteristics obtained from the experimental results. The emission characteristics and performance of different concentration levels of water emulsion diesel-fuelled single-cylinder four-stroke diesel engines are evaluated with varying input load conditions. The emission characteristics and engine performance behaviors are measured in this study to decide the best water emulsion fuel proportion. The performance curves are plotted based on the experimental results. The uncertainty analyses of performance characteristics are performed, and the results are tabulated. The emissions characteristics are analyzed and graphs are plotted. Finally, the comparisons between the obtained performances and performance obtained in other works of literature are compared and results are plotted in a graph.

CHAPTER 5

Conclusions and Future Recommendations

5.1 Conclusion

At different engine load conditions, the research is carried out on a single cylinder four-stroke diesel engine with water emulsion diesel fuel at a speed of 1500 rpm. Different experiments are carried out with various load conditions of 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg, respectively. Brake thermal efficiency, indicated power, brake specific fuel consumption, and mechanical efficiencies are computed for various concentration levels of water emulsion and compared to diesel fuel performance characteristics in each test. The emission level of carbon monoxide, nitrous oxide, hydrocarbon, particulate matter, carbon dioxide, and smoke for each test are also computed. The key findings from the extensive study can be summarized as,

- Engine power decreases with water content; the leading cause is that the calorific value of emulsion fuel is inferior to diesel fuel.
- BSFC increases with WD emulsion, but using WD10 the BSFC is comparable with diesel fuel.
- Because of the micro explosion effect, brake thermal efficiency using emulsion fuel is similar to diesel and even more preferable at higher load. Higher brake thermal efficiency is observed using emulsion WD10 for all load conditions.
- Injector pressure increases with the amount of water, and nominal variation is observed for WD20 and WD30 emulsion.
- WD10 produces less CO emission compared to base fuel. Adding water to fuel increases oxygen presence in the fuel, demonstrating reduced CO emission.
- HC emissions are lower than diesel fuel due to a higher air-to-fuel equivalence ratio, as sufficient oxygen is present for the fuel to burn entirely. HC emission decreases noteworthy with WD20 emulsion.

- The emission of NOx is found to be significantly lower for WD30. NOx emission is reduced with emulsion fuel because of the heat sink effect.
- Reduction in PM can be attained with all propositions of emulsion fuel in all load ranges due to better mixing caused by micro explosion phenomena.
- Smoke emission is lower with the WD10 emulsion fuel than with diesel fuel due to the combined effect of secondary atomization and longer ignition delay.
- Using WD10 microemulsion fuel the emission characteristics, brake thermal efficiency are found to be better compared to WD20, WD30 and diesel fuel in the current experimental setup.

Overall, it is observed that emulsion fuel has proved to be a possible substitute fuel that can generate a better and greener exhaust emission and reduction in fuel consumption without much effect on the engine performance. This can be achieved without modifying the existing diesel engine using emulsion as an alternate fuel.

5.2. Future Scope

Although this work is reasonably extensive, there is scope for enhancements and additional diagnostics that can be carried out to move forward. Throughout this research, various challenges are experienced. A few of them are discussed here to continue this work and predict the root cause of the problems.

- This study can be expanded in the future using different nanoparticles and applying bio-oil to the diesel engine as a water emulsion fuel.
- The current study can be expanded to include a multi-cylinder engine.
- Studies can be carried out by changing diesel engine compression ratio, injection timing, and injection pressure.
- In order to study the effects of water on the combustion chamber, endurance tests with emulsified fuels can be conducted.
- Different fuel additives can be tested to see how they affect combustion, performance, and emissions.
- The water is highly economical; hence more investigation can be carried out for the enhanced water emulsified diesel.

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Annexure – A

Ultimate Analysis of Sample

सरदार वल्लभभाई राष्ट्रीय प्रौद्योगिकी संस्थान, सूरत
SARDAR VALLABHBHAI NATIONAL INSTITUTE OF TECHNOLOGY, SURAT
સરદાર વલ્લભભાઈ રાષ્ટ્રીય પ્રૌદ્યોગિકી સંસ્થા, સુરત
SVNIT

TEST RESULTS

Date: 02/07/2019

Client: M/s Patel Kintu R.

Ultimate Analysis of Samples (Instrument: **Leco TruSpec CHNS**)

Sample Name	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulfur (%)
Sample 1 (10% Diesel-Water Emulsion)	79.3	13.4	12.7	0.135
Sample 2 (20% Diesel-Water Emulsion)	71.1	12.7	13.0	0.215
Sample 3 (30% Diesel-Water Emulsion)	55.5	12.4	14.4	0.253

Gross Calorific Value of Samples (Instrument: Leco AC-350 **Bomb Calorimeter**)

Sample Name	Gross Calorific Value (kcal/kg)
Sample 1 (10% Diesel-Water Emulsion)	9575.2
Sample 2 (20% Diesel-Water Emulsion)	8700.3
Sample 3 (30% Diesel-Water Emulsion)	7215.7

Dr. S. A. Channiwala
Testing In-charge
Professor & Lab. In-charge

ICHCHHANATH, SURAT-395 007 (GUJARAT) INDIA
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Annexure- B

Fuel Analysis Report

Eindustries
Future Ready

Prism Test & Measure Private Limited

E-mail : Info@prismpharmatech.com, info@prismcalibration.com
Website : www.eindustries.in, www. prismcalibration.com

NABL Accrediated Environment Testing & Calibration Lab

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Since - 2004

Water Analysis Report

Format No.	7.8, F-01	Issue No.	01
JRF No.	EHS/NN/202012-14-2552	Reporting Date:	14/12/2020
Report No.	EHS/NN/202012-14-2552/02		
Name & Address of Client :	Mrs. Kintu Patel 694/2, Panchvati Park, Sector-23, Near GH-5, Gandhinagar, Gujarat, INDIA		
Sampling Date	08/12/2020	Sample Received Date	08/12/2020
Sample Collected by	Client	Sampling Method	Grab
Sample Type	Diesel-Water Emulsion Sample-2		
Date Of Analysis	Start 10/12/2020	End	12/12/2020

TEST RESULTS

Sr. No.	Parameters	Results	Unit	Method/Instrument Used	Method Used
1.	Density at 15°C	0.814	gm/ml	Density Bottle Method	IS 1448
2.	Flash Point	91.0	°C	Flash Point Apparatus Method	IS 1448
3.	Gross Calorific Value	10410.0	Kcal/Kg	Bomb Calorimeter	IS 1448
4.	Kinematic Viscosity at 40°C	2.39	Cst	U-Tube Glass Capillary Viscometer	IS 1448
5.	Sulphur (as S)	0.08	%	Gravimetric Method	IS 1448

*Remarks: Test report No- M/1001/20

Analysis Done By:	Approved by (Prism Test & Measure Pvt. Ltd.)

Remarks: - All the results are at the time of testing.
Any hand Written corrections or photocopies in the report invalidates this report.
Any legal liabilities subjected to ahmedabad jurisdiction only.
Prism Test & Measure is GPCB Approved Environmental Auditor and Issue No. is GPCB/EA- 244/493288, Dated 1st FEB 2019.

FILE NO: 41461 (Mrs. Kintu Patel)

Prism Group of Company

Inst. Supply & Calibration, Validation, GPCB Approved Env. Auditor

F/101, Rudraksh Complex-II, Beside Syndicate Bank, Nr. Jasoda Nagar Cross Road-III, GIDC, Vatva, A'bad-382 445.
Customer Care : 72039 56789, 9099062852, Tech. Help Desk 7878991188

Annexure- C

Sample Observation Table

Load (kg)	Fuel	IP (kW)	ME (%)	BTHE (%)	BSFC (kg/kWh)	CO%	NO_X (mg/m3)	HC (mg/m^3)	Smoke (%Opacity)	PM (mg/ Nm^3)
2	Diesel	2.86	19.34	8.66	0.99	0.011	487	24	15.3	19.4
	10%WD	3.1	19.98	9.69	0.88	0.01	283	12	0.6	17.3
	20%WD	3.11	18.81	9.16	0.94	0.012	228	14	0.5	14.5
	30% WD	3.21	18.67	7.37	1.16	0.027	19	26	6	9.8
4	Diesel	**3.69**	**31.92**	**15.6**	**0.55**	0.01	755	25	16.2	20.3
	10%WD	3.56	31.67	13.87	0.62	0.009	661	22	2.5	18.2
	20%WD	3.85	30.41	13.42	0.64	0.013	255	20	4	15.4
	30% WD	3.8	31.04	11.95	0.72	0.018	88	29	1.8	10.7
6	Diesel	4.14	41.33	19.65	0.44	0.011	1110	33	13.9	21.8
	10%WD	4.17	41.37	18.54	0.46	0.009	1098	30	7.2	19.7
	20%WD	4.22	40.27	15.41	0.56	0.015	232	30	2.7	16.9
	30% WD	4.34	38.98	14.56	0.59	0.014	216	29	4.2	12.2
8	Diesel	4.58	49.43	20.56	0.4	0.01	1350	36	13.8	22.5
	10%WD	4.69	48.38	21.67	0.42	0.009	1300	38	5	20.4
	20%WD	4.68	47.9	14.83	0.58	0.013	259	37	4.5	17.6
	30% WD	4.86	47.14	15.15	0.57	0.012	503	36	5.8	12.9
10	Diesel	5.06	55.24	22.91	0.37	0.015	1355	46	14.2	23.1
	10%WD	5.28	52.78	24	0.36	0.012	1325	47	6.3	21.0
	20%WD	5.19	53.32	16.42	0.52	0.012	824	47	4.6	18.2
	30% WD	5.17	53.57	17.03	0.5	0.011	798	42	6.8	13.5
12	Diesel	5.63	60.32	24.33	0.35	0.035	1318	69	18.2	23.9
	10%WD	6.01	54.86	23.64	0.36	0.04	1365	75	7.3	21.8
	20%WD	5.8	58.49	18.83	0.46	0.018	1262	59	7.5	19.0
	30% WD	5.53	57.04	18.1	0.47	0.012	915	54	5	14.3

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[2]. K R Patel, Vijay Dhiman, Research Study of Water- Diesel Emulsion as Alternative Fuel in Diesel Engine – An Overview, *International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137 Volume – 02, Issue – 09, September – 2017,* 37-41.

[3]. K. R. Patel, V. D. Dhiman, Water- diesel microemulsion as alternate fuel in a diesel engine -An overview, International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, February – 2017, Volume-6, Issue-NASET 17, 50-55.

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