CFD MODELLING AND ANALYSIS OF DUAL FUEL (DIESEL+ANIMAL FAT BIODIESEL) COMBUSTION ENGINE WITH VARIOUS ENGINE LOADS

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Hassan Chamas

ABSTRACT

M. Sc. Thesis

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The world's fuel reserves are decreasing day by day and it is expected that they will cease to exist in the future, therefore, an alternative fuel source must be discovered to be used inside the internal combustion engine (ICE). Biodiesel is a fuel made from animal fat waste or different kinds of oil. The purpose of this study is to analyze the animal fat biodiesel performance, combustion, and exhaust emission and compared it to diesel fuel. Since a large number of experiments are required for high accuracy analysis and these experiments can be both time consuming and costly, computer applications are preferred because high accuracy results can be obtained by reducing the number of experiments by using the Computational Fluid Dynamics (CFD) application. Contour plots are used to measure several factors such as density, temperature, and others. The viscosity and density of biodiesel are higher than diesel. The results indicate a decrease in smoke and carbon monoxide (CO) emissions but on the other side the nitrogen oxide (NO_x) and carbon dioxide (CO_2) emissions increase. Overall, animal fat biodiesel can be used as an alternate diesel fuel without concern.

Key Words : Animal fat biodiesel, diesel engine, exhaust emissions, computational fluid dynamics.

Science Code : 91413

ÖZET

Yüksek Lisans Tezi

ÇİFT YAKIT (DİZEL+HAYVANSAL YAĞ BİYODİZEL) YANMALI MOTORLARIN FARKLI MOTOR YÜKLERİNDE ANALİZİ VE CFD MODELLEMESİ

Hassan Chamas

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Dünyanın yakıt rezervleri her geçen gün azalmakta ve gelecekte de yok olacağı tahmin edilmektedir, bu nedenle içten yanmalı motorlarda kullanılmak üzere alternatif bir yakıt kaynağının bulunması gerekmektedir. Biyodizel, hayvansal yağ atıklarından veya farklı yağ türlerinden elde edilen bir yakıttır. Bu çalışmanın amacı, hayvansal yağ biyodizel performansını, yanmasını ve egzoz emisyonunu analiz etmek ve dizel yakıtı ile karşılaştırmaktır. Yüksek doğrulukta analiz için çok sayıda deney gerektiğinden ve bu deneyler hem zaman alıcı hem de maliyetli olabildiği için Hesaplamalı akışkanlar dinamiği (CFD) uygulamasını kullanarak deney sayısını azaltarak doğruluğu yüksek sonuçlar elde edilebileceği için bilgisayar uygulamalarına yönelinmiştir. Kontur grafikleri, yoğunluk, sıcaklık ve diğerleri gibi çeşitli faktörleri ölçmek için kullanılır. Biyodizelin viskozitesi ve yoğunluğu dizele göre daha yüksektir. Sonuçlar, duman ve karbon monoksit emisyonlarında gözle görülür bir azalma olduğunu, ancak diğer yandan nitrojen oksit ve karbondioksit emisyonlarının arttığını gösteriyor. Genel olarak, hayvansal yağ biyodizel, alternatif bir dizel yakıt olarak endişe duymadan kullanılabilir.

Anahtar Kelimeler : Hayvansal yağ biyodizel, dizel motor, egzoz emisyonları, Hesaplamalı akışkanlar dinamiği.

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SYMBOLS AND ABBREVIATIONS INDEX

SYMBOLS

W	: Watt
kg/m^3	: kilogram per cubic meter
K	: Kelvin
Pa	: Pascal
$[m.s^{-1}]$	: One meter per second
µm	: Micrometer
[Pa S]	: Pascal per second
J/kg-k	: Joule per kilogram kelvin
°C	: Celsius
kJ/kg	: kilo joule per kilogram
mm^2/s	: millimetre squared per second
ppm	: particules per million

ABBREVIATIONS

KOH	: Potassium hydroxide
NaOH	: Sodium hydroxide
FFA	: Free fatty acids
TAGs	: Triacylglycerol's
HC	: Hydrocarbons
CO	: Carbon monoxide
CO_2	: Carbon dioxide
N_2	: Nitrogen
H_2O	: Water
H	: Hydrogen
O_2	: Oxygen
PM	: Particulate matter
NO_x	: Nitrogen oxides
SO_2	: Sulfur dioxide
EGR	: Exhaust gas recirculation
BTE	: Brake thermal efficiency
NBB	: National Biodiesel Board
CFD	: Computational fluid dynamics
BSFC	: brake-specific fuel consumption
HHV	: Higher heating value
ICE	: Internal combustion engine
NO_2	: Nitrogen dioxide
SO_3	: Sulfur trioxide
CH_4	: Methane

PART 1

INTRODUCTION

The significant growth in the number of vehicles in recent years has resulted in a huge demand for petroleum products. With unrefined oil stocks expected to last only a few decades, there has been an active investigation for alternative fuels [1]. Researchers anticipate that fuel sources will be consumed during the next five decades as a result of rising energy consumption caused by an expansion in population numbers [2]. The world's energy consumption is increasing dramatically as a consequence of rapid industrialization, rising population, increased development, and economic expansion [3]. Aside from a shortage of fuel reserves, hazardous contaminants such as NO_x, CO_2, and hydrogen sulfide do significant harm to the environment and the for sure the human body. NO_x and particulate matter (PM) emissions are the two main pollutants generated by using the well known diesel engines [2,4].

ICE burns fuel within the engine. This type of engine has been discovered in automobiles as well as other engine vehicles. The engine operates in a succession of processes that are constantly repeated. The discovery of the ICE was possibly the most astounding success in human history, signaling the start of new mobility. Since then, this mentioned engine has seen several advances. Typically, the primary goal was to overcome the lower thermal efficiency associated with bigger engines.

Throughout 1892, the German engineer Rudolf Diesel-powered developed a concept known as the Compression Ignition power plant, or CI engine, which was first operated by converting liquid fuel into hot pressured air. This invention was watershed moment in the automobile industry, and the CI engine has dominated the on- and off-road transportation markets ever since [5].

Combustion engines are classified into numerous categories based on use, ignition method, and more other characteristics. ICE are typically fuelled by petroleum-derived liquid fuels or by the normal fuel [6]. While internal combustion became famous for all of its benefits, such as great thermal efficiency, it also became infamous for having a negative and horrible impact on nature [5].

The National Biodiesel Board (NBB) provides two major definitions for biodiesel. The first is that biodiesel is a residential, renewable fuel for diesel engines derived from common oils such as soybean oil and meeting the specifications of ASTM D 675, while the second is "a fuel composed of mono-alkyl esters of long-chain greasy acids derived from vegetable oils or animal fats and meeting the specifications." In engine testing, when biodiesel is compared to normal diesel fuel, the energy and fuel consumption are nearly proportional to the fuel's strength contents. We can observe that biodiesel emits fewer hydrocarbons (HC), PM, and CO than diesel fuel. CO_2 is utilized in photosynthesis to increase oilseeds, producing biodiesel that is nearly LASER neutral. When using 100% biodiesel, NO_x will increase by 10% to 15%. Biodiesel fuels are beneficial for the environment since they are easily biodegradable, which is useful in the case of irrigation water (H_2O) [7].

Biodiesel has several advantages over diesel fuel, such as reduced sulfur and aromatic content, better emission profile and safer handling, higher cetane number, greater efficiency, higher viscosity density, higher flash point, and renewability. One significant advantage is that the alternative fuel has an energy content that is approximately 12% lower than petroleum-based diesel fuel on a mass basis [7–9].
Biodiesel also has some important disadvantages:

- Alternative fuel is approximately one and a half times more costly than oil diesel fuel.
- Power is required to produce biodiesel gas from soya plants, as well as the energy required for planting, fertilizing, and harvesting.
- Another downside of biodiesel fuel is that it might damage rubberized housing in certain engines.

- Because biodiesel cleans the specific dirt engines, this dust and dirt might collect in the fuel filter and produce a clog. As a result, filter systems must be updated on a regular basis [10].

Biodiesel's thermo-physical properties influence its quality, which is expressed in its performance, combustion, and emission properies during the main usage of the engine [11]. The major thermophysical parameters that signal the quality of biodiesel and have a significant impact on its combustion are density (ρ), kinematic viscosity (v), cetane number (CN), and higher heating value (HHV) [12]. Triglycerides are the building blocks of both fats and oils. Although numerous animal components and secretions can provide oil, in commercial practice, petrol is often recovered from rendered muscle fats from animals such as sheep, chickens, pigs, and deer [13].

In 2014, the European Association murdered 328 million pets (cattle, sheep, swine, and also goats) and 6 billion poultry (mostly hens and turkeys). This large number of slain pets or animals generates massive amounts of waste animal residue, including additional fat, which must be handled to prevent pollution or repurposed to provide some added value [14]. Given that animal fats are damaging to human health, they are more advised and suited for usage in a variety of applications such as fuel rather than in the food business. Animal oils have a limited application as diesel engine fuel since they are solid and viscous at room temperature. Low pressure, ineffective combustion, poor vapor-air mix, inadequate atomization, and even harmful chemical accumulation are caused by animal oils [13]. One crucial feature to remember is that animal fats are low-cost biodiesel feedstock [10].

1.1. THEORETICAL BACKGROUND

1.1.1. History of the diesel engine

The inventor Rudolf Diesel requested a patent for a "new rational heat engine" on February 27, 1892, at the Imperial Patent Office in Berlin. He received the DRP 67207 patent, dated February 28, 1892, for a "Working Method and Design for Combustion Engines," on February 23, 1893. On March 18, 1858, Rudolf Diesel was born in Paris to German parents. As may be deduced from his backstory, Diesel had set himself a goal that had been bothering him ever since he was a college student. This was a significant initial step toward that aim. When the 1870–1871 Franco–Prussian War began, he was still in school and traveled through London to Augsburg, where he was raised by foster parents. Young Rudolf Diesel was obligated to take control of his life and rely on himself by, among other things, providing individual classes, because he lacked the support from his family and a lack of money [15].

In the end, scholarships allowed him to join the Polytechnikum München, subsequently known as the Technische Hochschule, where he earned his diploma in 1880 as the program's top test taker. During Professor Linde's lectures on the theory of caloric machines, Diesel discovered that the steam engine, the dominating heat engine at the time, used a lot more energy than the ideal energy conversion cycle predicted by Carnot in 1824. Additionally, with an efficiency of only approximately 3%, the boiler furnaces of the time emitted annoying smoke that severely contaminated the air. According to lecture notes that have remained, the Carnot cycle may be accomplished, if practical, by directly utilising the energy available in coal without steam as an extra medium. While employed for Lindes Eismaschinen, he ambitiously explored the idea of a rational engine, which took him from Paris to Berlin. He hoped that his design would grant him extra income as well as social development. Finally, he applied for and was awarded the aforementioned patent with claim 1 and also that electric cars with conventional internal combustion engines may achieve considerable pollution reductions in a short period of time [16].

Operating method for combustion engines that utilizes pure air or another balanced gas (or steam) with a working piston compressing the air so intensely in the cylinder that the heat created as a result is much higher than the ignition temperature of the fuel being used, which stage burning happens without oxygen because fuel is delivered progressively from dead center outward. A second claim also is stated that multiple stage compression and expansion are protected by an invention. A three-cylinder compound engine was proposed also by Diesel. Two high-pressure cylinders, numbers 2, and 3, are functioning with an offset of 1808, experience adiabatic compression, and the fuel, diesel initially mentioned coal dust supplied by the second conveyor B in top dead center automatically ignites to cause isothermal combustion and expansion, which turns adiabatic after burning is complete. In relation with the isothermal precompression by water injection or the earlier intake of the fresh charge for the second engine cycle that runs parallel, The double-acting center cylinder one receives the combustion gas, which completely expands to atmospheric pressure before being discharged once the motion is modified. Thus, each spin is followed by one cycle. Diesel went back to the four-stroke cycle that has been called "state-of-the-art" since Nikolaus Otto's time in order to run the Carnot cycle. Keeping the thermal load of the engine low enough would allow him to operate it without cooling, he reasoned, using isothermal combustion at a maximum temperature of 8008°C. Diesel considerably outperformed the "state-of-the-art" at compressions of about 250 at this limitation temperature: Also on the one hand, this provided "outsider" Diesel with the naivete needed to put his vision into action. On the other hand, industries with a history in engine manufacturing, such as the Deutz gas engine manufacturer, ignored Diesel's initiative [17].

In order to spread his ideas and gain support from industry, From around turn of the 1892–1893 academic year, Diesel prepared a paper titled "Theory and Design of a Rational Heat Engine" and delivered it to Deutz and other professors. Diesel understood that "the concept and its implementation are the two halves of a discovery": In actual operation, he predicted maximum losses of 30 to 40%, which would correspond to a net efficiency of 50% and a Carnot efficiency of around 73% at 8008°C. Diesel ultimately signed a contract with the renowned Maschinenfabrik Augsburg AG, run by Heinrich Buz, a top steam engine maker, in early 1893 after nearly a year of work and planning. The contract included concessions made by Diesel to an ideal engine, including a maximum pressure reduction from 250 at to 90 at and later 30 at, cutting away with coal dust as a fuel, and reducing the compound engine's three cylinders to one high pressure cylinder. The deal, which was beneficial for Diesel, was engaged into by two other producers of heavy machinery, Krupp and Sulzer shortly after. a new study demonstrates that ambient conditions have an impact on engine power: A diesel engine operating at 1,000 meters above sea level is unable to provide the same amount of electricity, this is a new diesel equation [18].

1.1.2. History of biodiesel

The phrase "biodiesel" wasn't initially used until 1988, utilizing vegetable oil as a fuel substitute goes back to 1900. The invention of the diesel engine by Rudolf Diesel served as the foundation for what later came to be known as "biodiesel." At the Paris World's Fair in 1900, the diesel engine made its debut. When study was done to assess cottonseed oil as a diesel fuel, it was also clear that biodiesel was popular in the USA [19].

Those who are unfamiliar with the history of bioethanol could mistake this for a development from the 20th century. People who lived through the Arab oil embargos of the 1970s recall this time as the beginning of the outspoken demand for a local renewable energy source to fight the sharp rise in oil prices that has remained into the beginning of the twenty-first century. However, the truth is that ethanol was created as a biofuel before Edwin Drake discovered petroleum in 1859. Prior to this year, the energy crisis was focused on finding a replacement for whale oil, which was frequently used as lamp oil and was running low. Whale oil was desired, although other lamp oils made from plants and animals were also utilized. By the end of the 1830s, whale oil had been replaced by ethanol blended with turpentine, which was refined from pine trees [20].

In recent years, Brazil has seen a significant increase in the hunt for a sustainable, technically feasible, and economically viable alternative fuel source. There was no obligation on the percentages of blending between fossil diesel and 100% pure biodiesel (B100) back in 2005, right after the start of the new program, when the biofuels sector in Brazil started producing biodiesel through the end of 2007. However, the 2% blend was already in existence. However, the Brazilian government made adding B100 to diesel necessary in the following percentages at the beginning of 2008: from January to June of that year, 2% (B2); 3% (B3); 4% (B4); and 5% (B5) from July to December 2009, as well as from January 2010 to June 2014. Brazil was then the world's fourth-largest producer of biodiesel due to increased production and consumption [21]. As is shown in Fig. 1.1. the biodiesel production from 2005 to 2014.

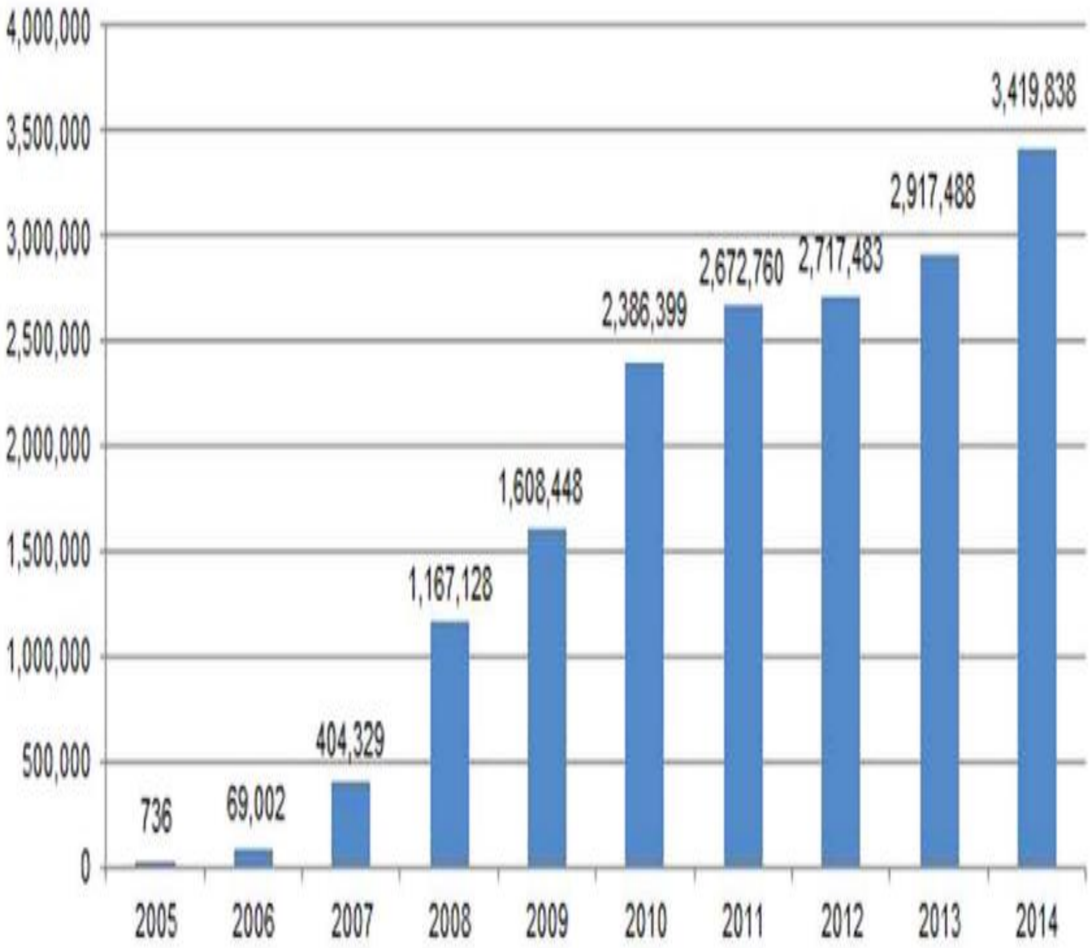

Figure 1.1. Biodiesel production 2005-2014 [22].

1.2. PROBLEM STATEMENT

The difficulties of utilizing regular diesel fuel in engines may result in negative outcomes such as:

- increase the impact of pollutants produced in the environment such as an NO_x and more
- the high price of diesel fuel in comparison to other types
- As a result of a range of high-flammability chemicals, corrosion on the engine's surface is increasing, and it makes a huge amount of noise during operation.

1.3. SIGNIFICANCE OF THE RESULTS

Diesel fuel is applied widely in the automotive sector, trucks, and all vehicles that include diesel engines. Since diesel fuel is used for transportation, it offers a wide variety of performance, efficiency, and safety benefits. Consequently, diesel machining is obviously of major significance. But the fuel is running out through the years. accordingly, finding an alternative fuel as a replacement for the normal diesel and inspecting its performance to check if it can be used also totally or as a blend inside the engine cylinder became a significant study subject in the past years.

1.4. RESEARCH QUESTIONS

- Is animal fat biodiesel suitable to use in diesel engines?
- Is biodiesel more expensive than diesel fuel?
- Which parameter affects the fuel inside the cylinder?
- Is it possible to reduce the effects of emissions?
- What is the best way to produce biodiesel?
- Does biodiesel have a significant disadvantage?

1.5. ASSUMPTIONS

- Biodiesel engine performance results should be great and work better than diesel, alternative fuel is a wise choice as a replacement inside the engine's cylinders.
- Pollution is low and the emissions emitted liked CO and smoke reduce while using animal fat biodiesel.
- Compared to diesel fuel, alternative fuel prices should be high and expensive.

1.6. LIMITATIONS

The tests during this study were directed by two cylinders, each cylinder is for a specific type of fuel. The first cylinder is 100% pure diesel and the second is 100%

biodiesel. The tests took place using CFD two dimensions Ansys software with specific properties and boundary conditions.

1.7. RESEARCH PURPOSE

The research's key purpose was to conduct an experiment on animal fat biodiesel to check if it can be used inside a fuel engine. To achieve this, the subsequent characteristics were investigated.

- Inspect the most important properties results, such as density, velocity, and more.
- Evaluate the most significant biodiesel emission that affects humans from animal fat like CO_2 and more
- While using alternative fuel check the engine performance. Like brake thermal efficiency (BTE) and more.
- Investigate a pure diesel cylinder performance and emissions to be compared at the end with the animal fat cylinder, using the data collected from CFD Ansys.

PART 2

LITERATURE REVIEW

Due to the importance of diesel fuel in various mechanical engineering sectors such as machines, automotive, and a lot of further industrial fields, in addition to its excellent and important characteristics, several types of research are written and various studies happened by researchers concerning the usage of animal fat biodiesel as an alternative fuel. Each test was done under different circumstances.

Kleinova et al. [23] carried out research to study the difference between diesel oil and chicken fat biodiesel on many parameters like emission and performance. The type of engine used in the experiment plays a significant role. As a result, the maximum power and maximum torque are decreased using pure diesel compared to biodiesel due to the lower energy content of triacylglycerol TAGs.

In this article, Nader [24] examined and evaluated a range of fuels, including methanol (10%), diesel (40%), ethanol (20%), biodiesel (45%), and others. Those mixes are evaluated under the same operational conditions in compression-ignited engines. Methanol, ethanol biodiesel, and biodiesel are all alternatives to diesel fuel (BMD and BED). As a result, while biodiesel fuel initially suggests increased fuel consumption, CO and HC emissions also increase.

Varuvel et al. [25] investigated how waste fish fat may be converted into biofuel for diesel engines using the pyrolysis method and a catalyst. The authors came to the conclusion that emissions performance has significantly improved. Compared to neat diesel (29.98%), neat biofuel has a very high BTE of 32.4% at 80% load. Clean biodiesel is used in place of diesel, however, because of the high premixed combustion, NO_x emissions are extremely high with biodiesel compared to diesel .

Kavon et al. [26] undertook preliminary research to produce an animal fat alternative. In the presence of CO_2, we can make biodiesel. As a result, it is obvious that temperature, rather than pressure, drives the non-catalytic transesterification process. Finally, charcoal is used to convert cow tallow and lard fat into biodiesel.

Bankovic et al. [27] researched strategies to manufacture alternative fuel from animal fat waste, due to the high expense of utilizing plants on the one hand and human consumption on the other. Researchers employ a variety of techniques, including the transesterification process, enzyme catalysis, and others. Biodiesel has not spread widely because it cannot compete on in price with petroleum fuel.

Rajak and Verma [3], did a study to look into the impact of alcohol and waste oil, as well as edible and non-edible vegetable and animal fat emissions from ethylic biodiesel in CI engines. They concluded that the lowest level of NO_x pollutant emission was seen for edible soybean, non-edible jojoba curcas, animal fats from chicken, and greasy oil (waste oil). as a result the higher level of NO_x pollutant emission is for (edible) 3050 ppm, then (non-edible) 3003 ppm, and after this the chicken fat with 2680 ppm, then the grease oil with 3280 ppm and finally the alcohol with the lowest NO_x emission 212 ppm.

Dixit et al. [28] examined the CFD analysis of biodiesel fuel compared to diesel fuel on many parameters like the temperature of combustion and other parameters. In this process methyl or what we can call biodiesel is refined from animal fat. The biodiesel type name here is B100 (pure biodiesel). As a result, biodiesel shows better lubrication properties than diesel.

Uslu and Simsek [29], looked explored how biodiesel made from animal fats (AFBD) affected a single-cylinder, four-stroke engine's performance, and emissions. A variety of fuels, including D100 (100% diesel + 0% animal biodiesel), AFBD100 (0% diesel + 100% animal fat biodiesel), and AFBD50 (50% diesel + 50% animal fat biodiesel), were also used. Therefore, it appears that using AFBD100 resulted in a drop in BTE value but an increase in brake-specific fuel consumption (BSFC). NO_x emissions increased due to the high oxygen (O_2) of AFBD fuel compared to diesel and also with the usage of AFBD fuel the CO_2 emissions have risen.

Maksom et al. [30] did a CFD Study on the Impact of Biodiesel Composition on the Density and Viscosity of Diesel-Biodiesel Blend. The diesel and biodiesel are mixed together inside a mixing tank, result are shown using the CFD application. They concluded volume friction contour shows this blade design cannot mix the diesel biodiesel phases uniformly and suitable blade design can help diesel biodiesel mix uniformly.

Mora et al. [14] researched the method of making as well as creating biodiesel from cheap fat leftovers. Since it is less costly, utilizing animal fat waste to offer alternative fuel is preferable to using vegetable oil leftovers. There are several ways to gain animal waste, for example. Pretreatment comes first, then separation, and lastly purification. With the rise of technology, numerous new techniques for manufacturing animal fat biofuel will indeed be developed in the future.

PART 3

EMISSIONS FROM DIESEL ENGINES

Diesel exhaust contains substances of a full air and carbon (C) combustion (nitrogen, H_2O, and CO_2), additionally as products of incomplete combustion (CO, NO_x, various HC, and partially oxidized HC such as aldehydes, ketones, phenols, and a lot of sulfur compounds). Submicron particles released by diesel engines damage surfaces and affect eyesight. For the most part, however, the existence of mutagens and carcinogens adsorbing on particulates has increased worries about diesel exhaust and its potential to induce lung cancer, even though these particles have been regarded to cause low health risk.

Recently, the potential consequences of fine particles below 10 µm on respiratory morbidity and death have been discussed, particularly in people with preexisting chest illness [31]. The dangers of diesel exhaust to human health have received more attention nowadays. Numerous investigations have been released, some of which suggest to establish a connection between diesel fumes and respiratory ailments such bronchitis, asthma, and lung cancer [32,33]. Many studies indicate that diesel emissions play an significant role in some major and well known human diseases that will lead to bad results and also may lead to death, this emissions should be taken in consideration and human should reduce there usage of normal diesel engine.

The involvement of microscopic particles smaller than 10 micrometers in diameter, which are typically found in diesel emissions, certainly deserves further exploration because there is some weak evidence indicating that they may be partially to blame for some asthma exacerbations [34]. The diesel is a lot of gases that effect the human body, those gases can't be shown in the human eye but thet are toxic and harmful for human health and environment. The compositions of diesel exhaust gas With a detailed and clear explanation are shown in Fig. 3.1.

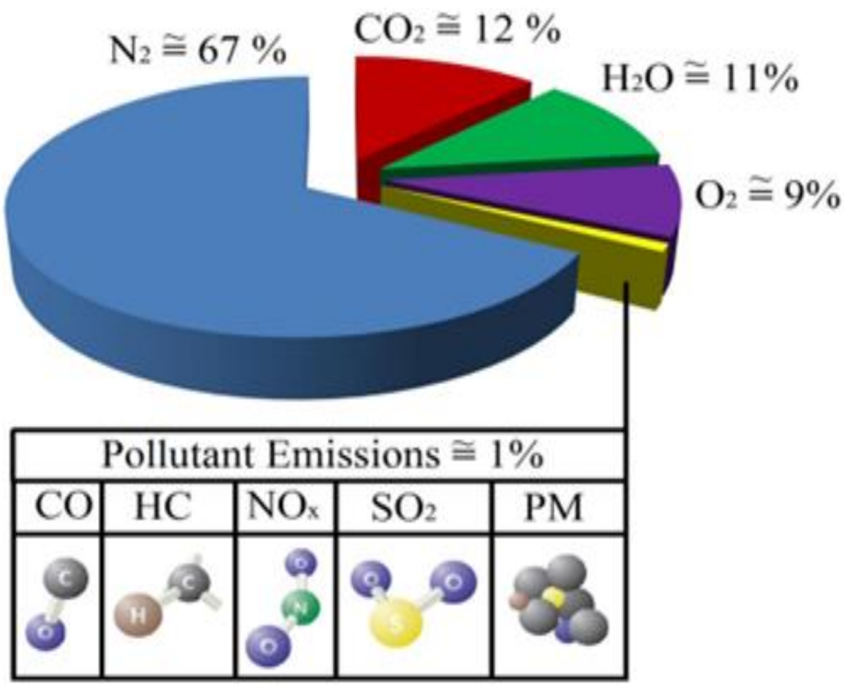

Figure 3.1. The compositions of diesel exhaust gas [35].

Because diesel exhaust particles and gases are floating in the air, a person is exposed to this pollutant anytime he or she breathes in air that includes these compounds. The predominance of diesel-powered vehicles makes it nearly difficult to escape exposure to diesel exhaust or its metabolites, whether you live in the country or the city. On the other side, those who exists or work in urban and industrial areas are more likely to become exposed to this pollutant. People who spend time loading and unloading trucks, operating diesel-powered equipment, or working close to diesel equipment are exposed to higher levels of diesel pollution and are at increased risk for health problems [36].

3.1 HC EMISSIONS

Because of the low temperature near the cylinder wall, unburned fuel is included in HC emissions. The temperature of the air-fuel combination is now significantly smaller than that of the cylinder middle [37]. Type of fuel, engine modification, and design all have an impact on HC concentration in diesel engines. Additionally, variable operating conditions have an impact on HC emissions in exhaust gas. High levels of rapid engine speed change, sloppy injection, high nozzle cavity volumes, and injector needle bounce can all cause considerable amounts of unburned fuel to enter the exhaust [38]. There are a large and wide number of HC, containing the alkanes, alkenes, and aromatics. They are quite often described in form of similar methane (CH_4) content [39]. Both the environment and human health are at risk from HC. Together with other pollution sources, they provide a major contribution to the production of ground-level ozone. About half of the contaminants that cause ozone formation come from vehicles. HC are poisonous and might cause pain in the respiratory system [40]. As stated in the preceding paragraph one of the principal organic contaminants in diesel exhaust is HC, which are released as gaseous and DPM-bound molecules. The phase of HC in diesel exhaust (gas, condensed liquid, or solid) is determined by its molecular weight, temperature, and concentration. Formaldehyde, methanol, acrolein, benzene, 1, 3-butadiene, and low-molecular-weight PAHs and their oxygenated and nitrated derivatives are among the vapor phase molecules that may have an impact on human health [41].

3.2 NO_x EMISSIONS

The amount of NO_x emitted depends on the cylinder's maximum temperature, O_2 concentrations, and residence duration. The majority of the NO_x released is generated early in the combustion phase, when the piston is still close to the top of its stroke. The flame temperature reaches its highest point at this time. The amount of NO_x released triples for every 100 ºC increase in combustion temperature. The percentage of NO_x created depends on the maximum temperature of the cylinder, concentrations of O_2, and residence duration. The majority of NO_x is created early in the combustion phase, while the piston is still close to the top of its stroke. The flame is at its highest temperature at this pointThe amount of NO_x generated can increase by up to three times for each 100 ºC increase in combustion temperature [42].

NO_x are also known as (NO) and nitrogen dioxide (NO_2). NO accounts for 85-95% of NO_x. In the atmosphere, it progressively reduces to NO_2. While NO and NO_2 are categorized with each other as NO_x, these two pollutants have fundamental distinctions. NO_2 is a red-brown gas with a distinct odor, whereas NO is a colorless and odorless gas [43,44].

NO and NO_2 are both hazardous; however, NO_2 has a toxicity level five times that of NO and is thus a direct issue for human lung illness. NO_2 has the potential to irritate the lungs and reduce resistance to respiratory infections, such as influenza. NO_x emissions are important precursors to acid rain, which can have a negative impact on both terrestrial and aquatic ecosystems. NO_2 and nitrates in the air also contribute to pollution haze, which reduces vision [45,46].

3.3 CO EMISSIONS

incomplete combustion results in CO production, This happens when the oxidation process is incomplete. The mixing of air and fuel has a significant impact on this concentration, and it is largest when the excess-air factor (k), a sign of a rich mixture, is less than one [47]. CO is a tasteless, transparent gas. People breathe in CO from the air, which is then absorbed into their bloodstream. Hemoglobin absorbs it and loses some of its capacity to carry O_2. The performance of various organs may be impacted depending on the CO amount in the air, which can cause asphyxiation and result in diminished focus, slow reflexes, and anxiety [48–50].

Hemoglobin changes shape when CO attaches to it, the capacity of hemoglobin reduced and it’s now harder to carry the O_2 [51]. The function of various organs, especially those with high O_2 requirements, such as the brain and heart, can be affected by this decreased O_2 availability, which can cause poor focus, slow reflexes, and disorientation. In addition to causing pulmonary inflammation, CO also affects the inflammatory balance throughout the body, impairing blood coagulation [52]. Incomplete combustion will produce CO, humans will inhale it as a results of its exit from the engine , humans can’t see this emissions in their eyes so they enter their bodies and respiratory system without noticing, but unlike its effect which will be very obvious and clear.

3.4 PM EMISSIONS

PM emissions are created during combustion and are found in exhaust gases. Extremely small particles of partially burned fuel, partially burned lubricating oil, fuel oil's ash content, cylinder lube oil, or sulfates and H_2O may have accumulated to make them [53]. The majority of PM is produced by the incomplete combustion of HC in gasoline and lubricating oil. According to one experiment, the usual particle composition of a heavy-duty diesel engine is 41% C, 7% unburned fuel, 25% unburned oil, 14% sulfate and H_2O, 13% ash, and a lot of more components [54].

To figure out the impact of PM emissions on the environment and human health, several research are being done. These studies suggest that breathing in these particles might result in major health issues like early death, asthma, lung cancer, and other cardiovascular issues. These emissions contribute to air, H_2O, and soil pollution; building soiling; reduced visibility; decreased agricultural production; and global climate change [55,56]. The transport of PM is shown in Fig. 3.2.

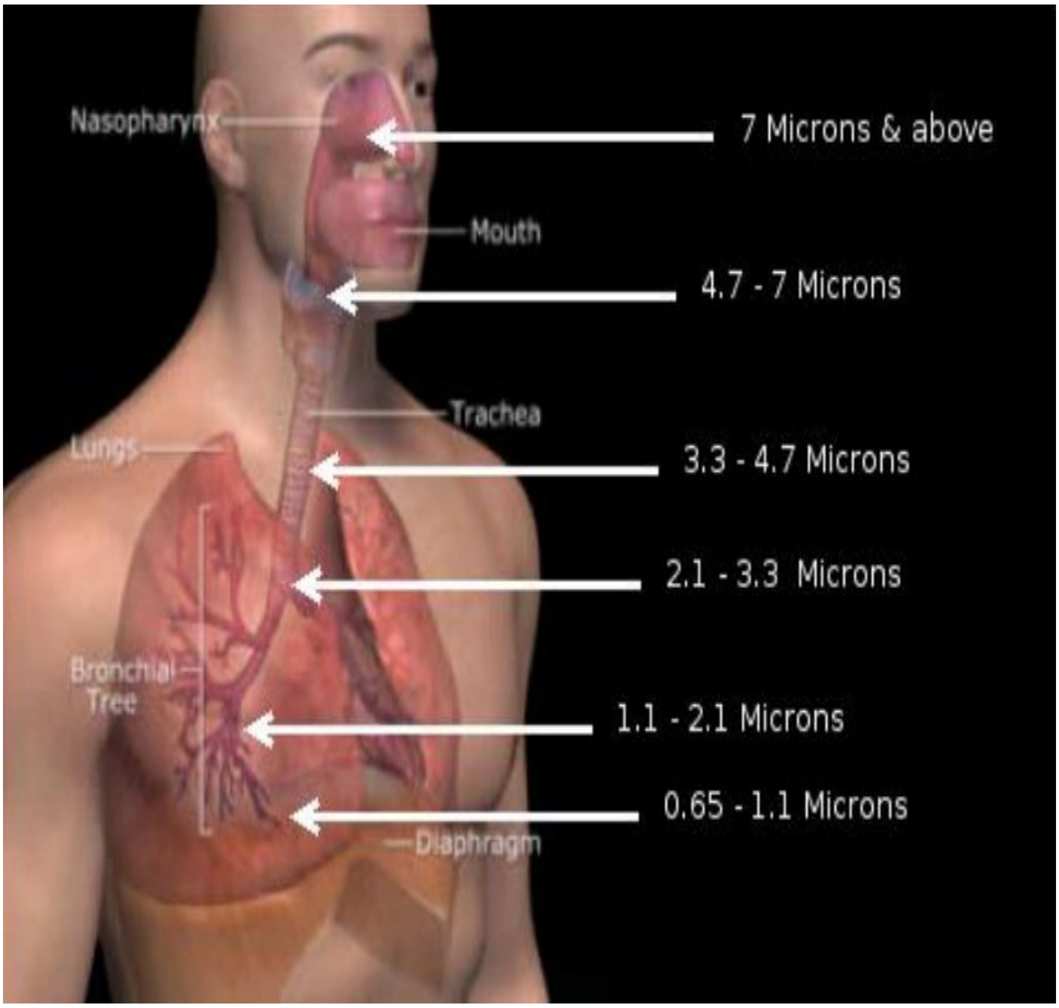

Figure 3.2. Transport of the PM with breath according to their size [41].

3.5 CO_2 AND SO_2 EMISSIONS

Diesel fuel emits the most CO_2 into the environment when driven at high engine speeds. The key advantage is that CO_2 emissions from the usage of biodiesel may be considered C credits because it is a biofuel produced by photosynthesis. Because of incomplete combustion, the CO_2 emissions from utilizing rubber seed oil as fuel are reduced. The burning of fossil fuels emits CO_2, which accumulates in the atmosphere and causes a slew of environmental issues. The burning of biofuels emits CO_2, but crops rapidly absorb it, thus CO_2 levels remain stable [57]. The most significant effect of CO_2 emissions is global warming. When opposed to CO concentrations, CO_2 concentrations exhibit the opposite effect, which is owing to the O_2 content in ethanol boosting the combustion process.

Individuals' reactions to the same sort of those pollutants exposure may differ. The more sensitive population group is likely to react more aggressively than the average healthy person. Children, the elderly, and those with heart and lung conditions, such as emphysema and asthma, are more sensitive to exhaust exposure and at increased risk for health problems [58].

Sulfur dioxide (SO_2) is an uncontrolled diesel emission caused by sulfur in gasoline and engine lubricant. SO_2 is a colorless gas with a distinct, unpleasant odor. Only around 2% to 4% of the sulfur in the gasoline is released as sulfure trioxide (SO_3) by the engine. SO_2 emissions contribute to global warming. SO_2 this component is released during the combustion process in power systems that use petroleum fuels. In terms of environmental impact, such emissions play a significant part in global warming potential, which has grown year after year [59]. Based on the sulfur emissions the huge and bigger portion emitted from the diesel engine while using diesel fuel is SO_2 but on the other side the small quantity is the SO_3 .Those emissions effect the human body for sure but the most effected part of those emissions is the environment, because one of the bigger effect of the SO_2 is the global warming. Problem like this should be reduced because the global warming situation increase year after year.

The health impacts of these emissions are both acute and chronic, resulting from both short-term and long-term or repetitive exposure. Specific health concerns and their severity are determined by the number of chemicals exposed as well as the length of exposure. Acute diesel exhaust exposure can induce eye, nose, throat, and lung discomfort, as well as lightheadedness.

A variety of more serious impacts from long term exposure to diesel pollutants may have a negative impact on human health. Chronic exposure and bad effects is more likely to happen if a person works in a field that often employs diesel or is exposed to diesel fumes on a routine basis for an extended length of time. Studies on human health relate inhaling in diesel exhaust to an increased risk of developing lung cancer [60]. Each type of emission to which humans are exposed from the use of diesel engine effect human health and the environment in a very bad way. All the mentioned toxic emissions should be reduced quickly.

PART 4

MATERIALS AND METHODS

4.1 PRODUCTION OF BIODIESEL

Due to the high viscosity inside the animal fat oil, it can't be used inside the diesel engine. There are a lot of methods to reduce the viscosity [61].

- The blending of oils: using fats, magnesium is added to the blend result a reduction in viscosity and flash point [62].
- Micro emulsion: two liquids that can't be mixed together such as oil and H_2O, with a diameter in the range of 0.001-0.15 µm [63]. it results in a decrease of the viscosity and an increase of H_2O inside the fuel [64].
- Thermal cracking: this process can happen in two methods the thermal type which happens at high temperature and catalytic cracking which happen at a lower one [65].

Those methods reduce the viscosity but only one method is used to create pure biodiesel and it's called transesterification.

4.1.1 Transesterification

The transesterification process is used to produce biodiesel. Using oil derived from vegetable oil (palm, Jatropha, and others) or animal fat waste (chicken, lard, and more). To produce pure biodiesel, a catalyst is used in this process. This process can employ either potassium hydroxide (KOH) or sodium hydroxide (NaOH). Biodiesel is made up of a lengthy chain of C and hydrogen (H) atoms linked together. An ester functional group is also included in the chain, making it distinct from standard diesel chains (shown in the red circle) [28]. The chemical formula of biodiesel is shown in Fig. 4.1.

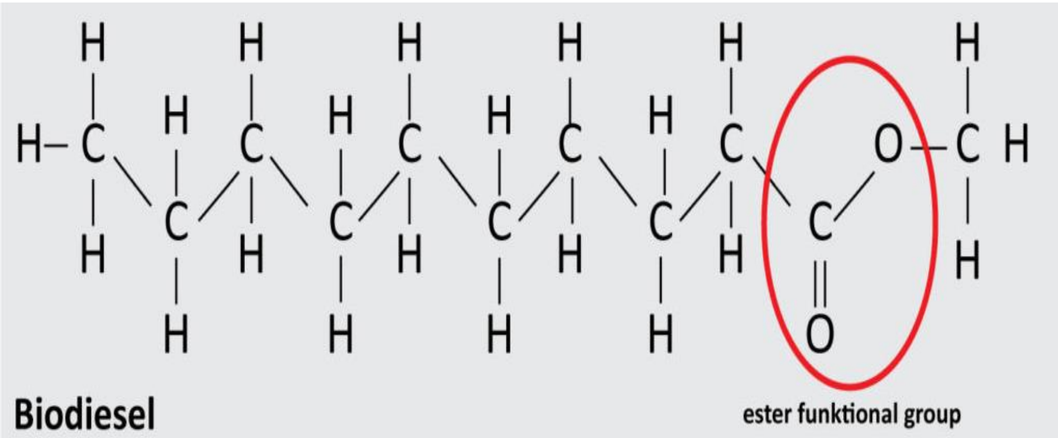

Figure 4.1. Biodiesel chemical formula [66].

TAGs is found in animal fat. They are chemically converted into acid alkyl esters in the presence of alcohol by an acid or base inside the transesterification process [27]. Triglycerides are transformed into monoglycerides, diglycerides, and glycerol during the transesterification process [67]. Because of the development of soap content, transesterification of animal waste with a high concentration of free fatty acids (FFA) is challenging [68]. The production of animal fat biodiesel is a long process, for example in the case of beef tallow production several steps are happening. The producing of biodiesel is shown in Fig. 4.2.

Figure 4.2. Producing biodiesel [69].

In this research, beef tallow was transesterified with methanol in one step using KOH as a catalyst. The beef tallow was purchased from an Indian slaughterhouse in Tamilnadu, whilst a close Indian Oil fueling station provided the diesel fuel. Base-catalyzed transesterification with methanol and KOH as a catalyst was used to transform beef tallow into methyl esters. Beef tallow should be boiled for a total of one hour to a temperature of between 100 and 120 °C prior to transesterification. Then, a cotton filter was used to filter out the particles and other impurities. Following this, 500 g of beef tallow, 95 g of methanol, and approximately 2 g of the well-known KOH were added to a 1000 ml flat-bottom flask that was equipped with a magnetic stirrer heater and a digital thermometer.

Finally as an important and final step, This mixture was vigorously blended, boiled for three hours at 70°C, and then allowed to cool to room temperature for twelve hours. In a separatory funnel, the ester and glycerol layers were separated. Finally, the beef tallow methyl ester was purified with distilled water H_2O before being dried at room temperature [70].

4.1.2 Benefits of using animal fats as biodiesel

When consumers buy chicken or any other species of animal used for food production in numerous nations such as India they ask for it without the skin and the store owners throw the skin down the public drain as a result there is hazardous solid waste in the environment the major feedstock for biodiesel manufacturing is chicken oil which is made from waste skin with a high-fat content When compared to vegetable feedstock, the extraction of animal fats by the heating processes yields increasing quantities of non-edible oil after the well-known rendering process [71]. The cetane number, density, heating value, and all other fuel parameters are excellent and great [72].

Biodiesel generated from animal fat can be used to improve the properties of alcohol and diesel combinations. The lubricating qualities are superior to standard petrol diesel. Most importantly, animal skin may be acquired for free or at a cheap cost and has the highest biodiesel yield [73]. Other than chiken, pork and cow, biodiesel can be produced from fish waste and this is a great idea to benefit from fish waste like head, skin and more. Same process is used on the fish waste, after the purification and filtration we can achieve the biodiesel produced from fish oil, each liter of fish oil will produce 0.9 liter of biodiesel, its almost the same. Alternative fuel can be produced also from plants but using animal fat is better because plant could be used in medicine and hospitals but on the other side animal fats are considered as waste and will not be used in anything else. The biodiesel is produced from several and many feedstocks as is shown in Fig. 4.3. it's possible to say that using animal fat is a great option, also waste and all fish parts like head, bones and all the part of chiken, also the incomplete eggs and feather, because even from the feather it's possible to create alternative fuel but this depend on the type and size of feather.

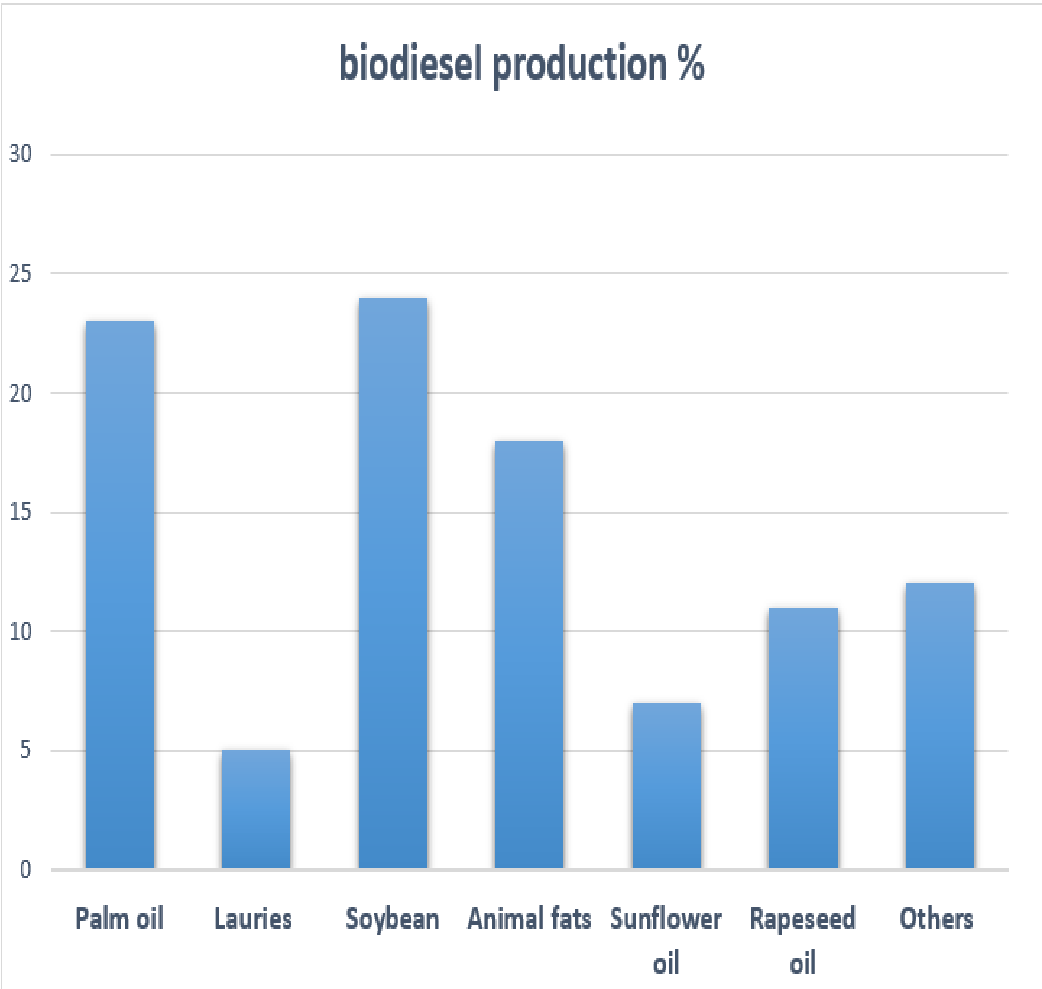

Figure 4.3. Production of biodiesel from various feedstocks [61].

4.2 MATERIALS

For the work of this test, it is required every thermal parameters utilized in the combustion analysis shown in Table 4.1. Each species have different properties used. In this experiment pure diesel and animal fat, biodiesel properties are used.

Table 4.1. Properties of diesel and biodiesel.

Properties	Diesel	Animal fat
Chemical formula	$C_{10}H_{22}$	$C_{18,45}H_{35,01}O_2$
Density at 15°C (kg/m^3)	883.5	887.0
Kinematic viscosity 40°C (mm²/s)	4.24	4.241
Flash point (°C)	174	180
Upper heating value (kJ/kg)	46105	39640.62
Lower heating value (kJ/kg)	43199	38547.86
Cetane number	54	58
Sulfur count (mg/kg)	5.5	1.1
Cold filter clogging point	-13.89	-2
Specific heat (J/kg-k)	-	2.5154
Ester content %(m/m)	-	96.8
Cloud point (°C)	-6	-1
Sulphated ash content	0.0016	0.005
Freezing point (°C)	-15	-3
Molecular weight (kg/k mol)	-	28.966

4.2.1 Modeling of the problem

The diesel enters the cylinder through a small nozzle. This mentioned nozzle is placed on the corner of the cylinder. All the measurement and cylinder geometry used in the experiment is shown in Fig. 4.4. The same measures and design of the cylinder are used also on the animal fat biodiesel side. The size of the cylinder and all the other measurements like inlet and more should be 100% the same so we can have a fair comparison between the two cylinders. If the measurement are not the same, results for sure will be different because the dimensions of the cylinder have a huge effects on the properties of the fuel. Each type and size cylinder have a different results depending on their measurement so this why in this experiment dimensions should be 100% the same.

Figure 4.4. Cylinder design.

4.2.2 CFD analysis of biodiesel using ANSYS fluent

The problem is examined with the usage of ANSYS fluent, as [74] mentioned CFD is a fast-expanding field that uses computer-based numerical analysis and methods to numerically solve fluid motion equations in order to anticipate and/or analyze fluid flow events. Fig. 4.5. below show the CFD ansys software and the 2 selected species.

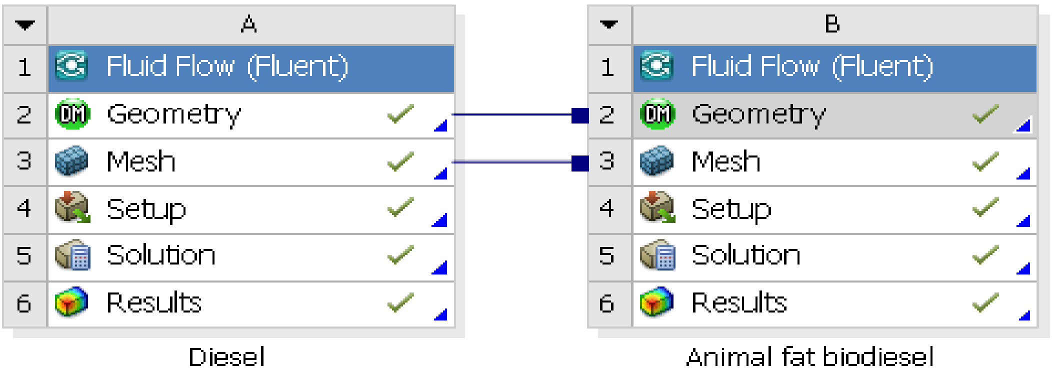

Figure 4.5. CFD application.

The design has been drawn. Utilizing a fine mesh generation on the geometry, the entire domain is discretized. The first analysis is happen for normal diesel fuel on many parameters (density, temperature, and more). The same analysis and mentioned steps are used again but this time on the animal fat biodiesel side. Analysis steps and boundary conditions are summarized and explained in the below part.

4.2.3 Analysis steps

First of all the setting should be changed to 2D because the experiment will happen on it, it will two-dimension simulation, not 3D. The fluid flow (fluent) must be selected. Open the geometry section and draw the required design with the needed measurement. Design and cylinder measurement is shown in Fig. 4.4. Open the mesh section, select the edges so the mesh is good and improved, and then define the boundary condition. They are shown in Table 4.2. summarized.

Table 4.2. Bounderies conditions of CFD.

Boundaries conditions
a) Fuel; 80 m/s from the selected nozzle and at a 300 k temperature
b) Air; 0.5 m/s and at a temperature of 300 k and a 1 species mass fraction
c) Walls; constant temperature at 300 k

Now it's possible to generate the mesh, the result is updated and shown in Fig. 4.6. The mesh is one of the most important steps during CFD simulation.

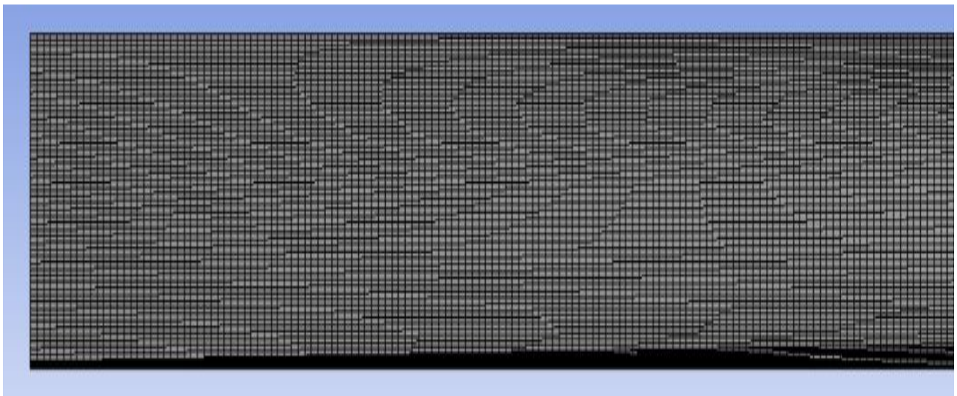

Figure 4.6. CFD mesh.

Now it's the role of the third main section, the setup. Add the properties of each boundary selected above. Then determine the specific species that are chosen for this experiment (pure diesel and animal fat biodiesel). The diesel species and properties are founded in the ANSYS but the animal fat biodiesel is missing so as a solution, a new fluid material with specific properties should be added. The reference properties of animal fat biodiesel and pure diesel were referred to based on the previous studies and analyzed by [14,29,75]. The final selected and used fuels properties are shown in Table 4.1. Some properties changed because inside the Ansys some parameters needed in this experiment are missing and based on a proper study parameters are selected and used inside the animal fat side in this experiment.

Then the cell zone conditions should be checked to define the aluminum as solid, and the animal fat biodiesel as fluid, and the boundary conditions are defined (pressure, velocity, and temperature). Before the calculation, the solution method should be changed to the couple and also turn on the pseudo in order to improve the stability while processing the results. Finally, initialize the data and activate the calculation on 200 iterations. The result will be discussed in the result part.

PART 5

RESULTS AND DISCUSSIONS

After applying the alternative fuel animal fat biodiesel in a diesel engine CFD experiment, function and exhaust emission results must be examined and analyzed. As a result, this study conducts two major tests, exhaust emissions and engine efficiency testing.

5.1 PERFORMANCE RESULTS

To determine the lubricating characteristic of fuel. Fig. 5.1. and Fig 5.2. shows the chemical formula of diesel ($C_{10}H_{22}$) and the chemical formula of biodiesel made from animal fat is ($C_{18,45}H_{35,01}O_2$). Biodiesel is more viscous than pure diesel. Animal fat biodiesel has a lubricating quantity, therefore it flows more smoothly inside the combustion chamber than diesel. As a result engine life improves, benefiting biodiesel applications.

Depending on the amount of time for biodiesel and diesel to burn the combustion time in the biodiesel cylinder is shorter than in the diesel cylinder. To generate the same amount of power using diesel, more fuel is required. As a result, more fuel is injected, extending the duration of combustion and perhaps leading to incomplete combustion. Another important point that should be studied is the BSFC, the ratio of mass fuel consumption to braking power is BSFC. This mentioned is a significant characteristic for comparing the various fuels inside the engine's cylinder.Several studies predict that the BSFC will rise throughout using animal fat biodiesel and will be greater than diesel. For example, Yilmaz et al. [76] discovered that BSFC rises at low engine load, falls at medium load, then rises once again at high load. As a result, the BSFC rise as the amount of biodiesel in the gasoline increases.

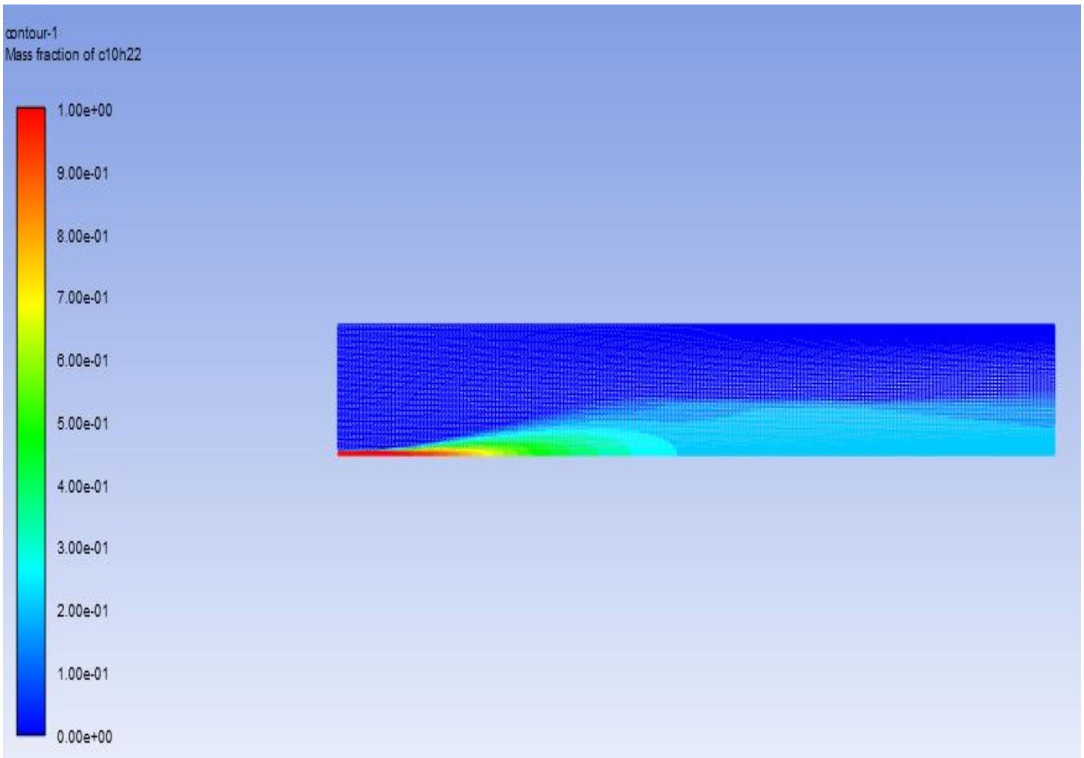

Figure 5.1. Diesel Contour chemical formula.

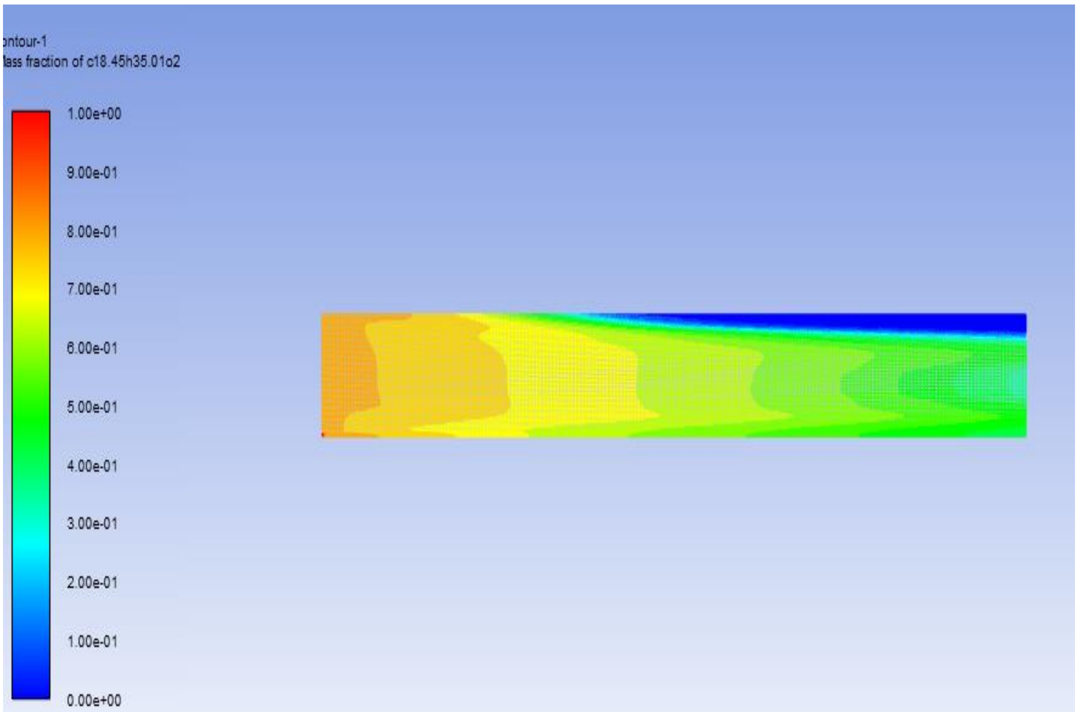

Figure 5.2. Biodiesel contour chemical formula.

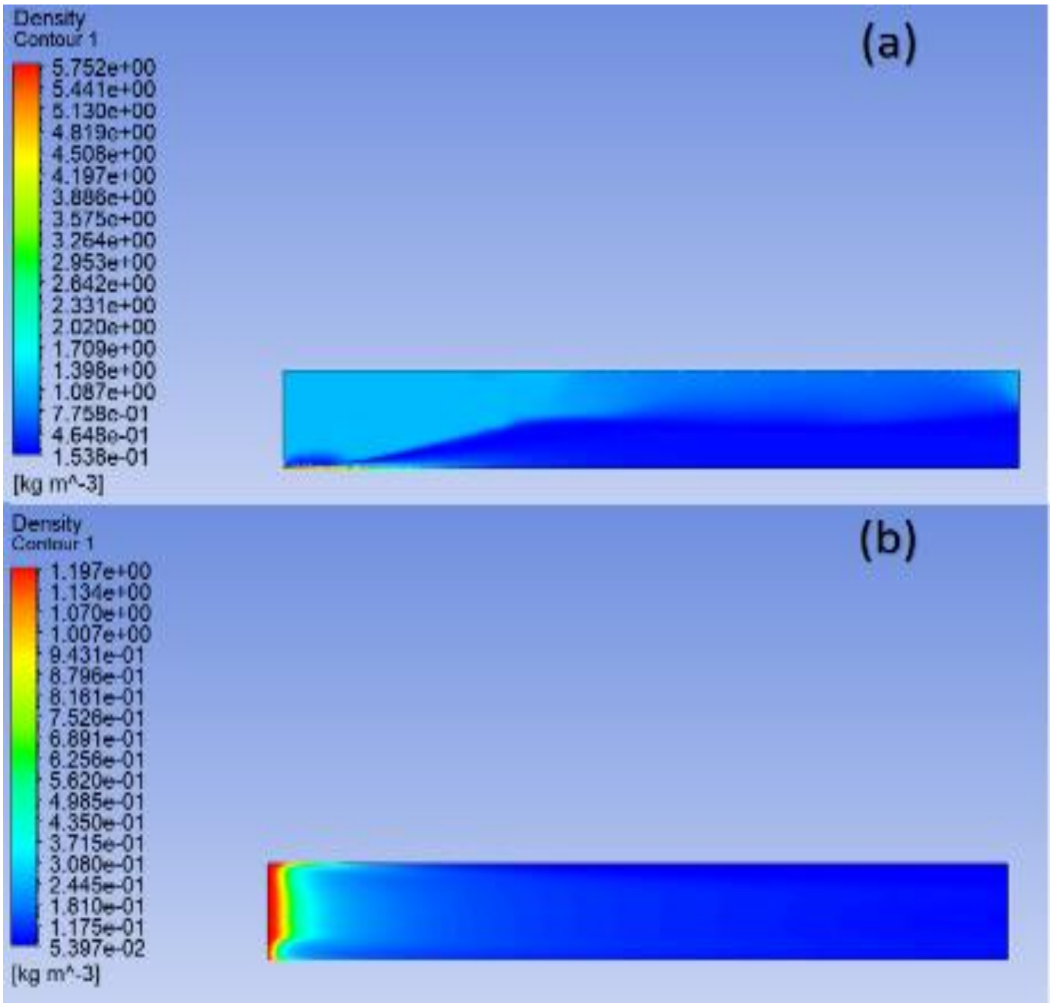

Figure 5.3. Contour profile for density (a) diesel, (b) biodiesel.

Density defines the amount of fuel that may be used per unit volume and fluctuates correspondingly as the temperature and the pressure change. Furthermore, density controls fuel injection in CI engines, with denser fuel requiring more fuel to be injected for the same volume than less dense fuel. The density of biodiesel produced from animal fat was estimated by weighing it against a given volume and was found to be 8837 kg/m^3 [77].

The density of biodiesel regulates the amount of fuel injected into the cylinder and serves as a precursor for managing the fuel injection system to ensure full combustion. Animal fat biodiesel seems to be more effective than pure diesel, the Fig. 5.3. represents the difference of density while using alternative fuel. The high density is detected in the biodiesel, it reaches the maximum in the red color above.

Because of the high concentration of O_2 in biodiesel, its density is higher than that of diesel. The easiest technique to lower the density within biodiesel is to raise the temperature. As demonstrated by the results of this experiment. Biodiesel has a greater density than diesel. This will reduce BTE, but the high density of animal fat will result in a considerable increase in fuel consumption. Greater density can interrupt the ignition process during biodiesel combustion, resulting in lower engine performance and greater NO_x emissions. Fuel density has an impact on exhaust emissions as well. The density is related to the amount of PM and NO_x emitted. High-density fuel typically causes an increase in PM and NO_x emissions in diesel engines.

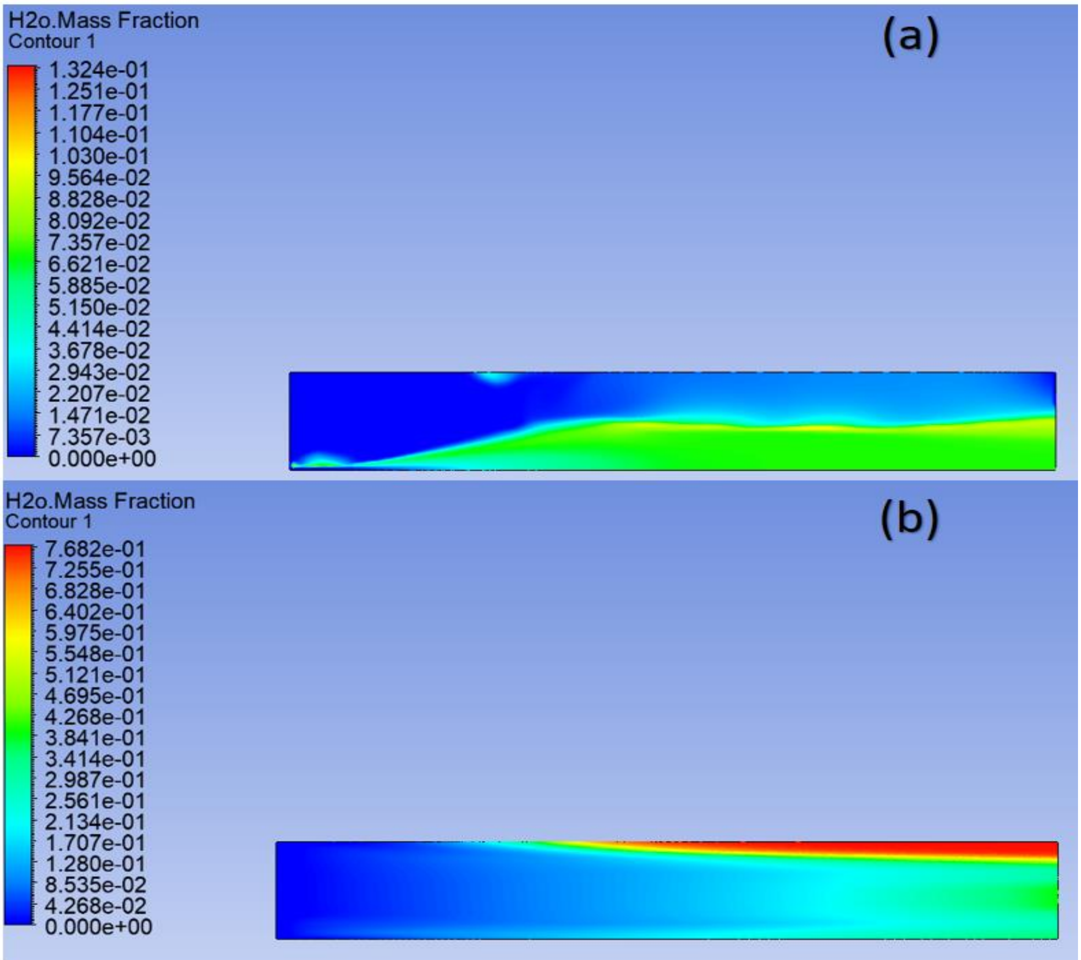

Figure 5.4. Contour of H_2O, (a) diesel, (b) biodiesel.

The H_2O content in fuel is an essential factor in fuel quality. H_2O may be incorporated into fuels during manufacturing, transit, and storage. In fuels, there are three sorts of H_2O: free water, emulsion-rated water, and soluble water [78]. According to the Fig.

5.4. that the animal fat biodiesel has much more H_2O inside than the diesel fuel cylinder. The H_2O inside the alternative fuel is 0.772071 but the H_2O inside the diesel is 0.13309. The main reason for the huge amount of H_2O while using the alternative fuel is that the O_2 and H increase inside the biodiesel during the chemical reaction and the combustion process, so they create more H_2O than diesel fuel.

During the production of biodiesel, H_2O is utilized to wash away catalysts, soap, and leftover glycerol. Either a vacuum drier or an evaporator must be used to remove the remaining H_2O. The high content of H_2O inside diesel and biodiesel can lead to huge problems. For example like, microbiological overgrowth, transportation equipment, and H_2O accumulation Additionally, H_2O is harmful to the manufacture of biodiesel since it results in the generation of soap when FFA and H_2O are present and found inside the cylinder.

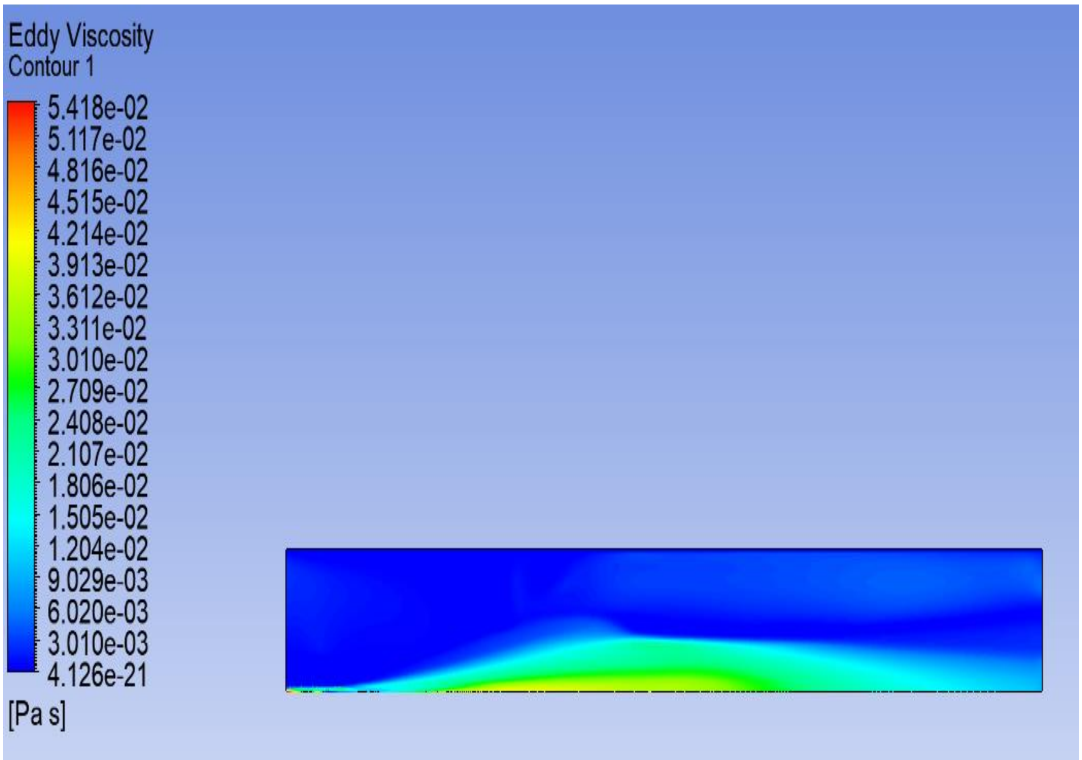

Figure 5.5. Contour of diesel viscosity.

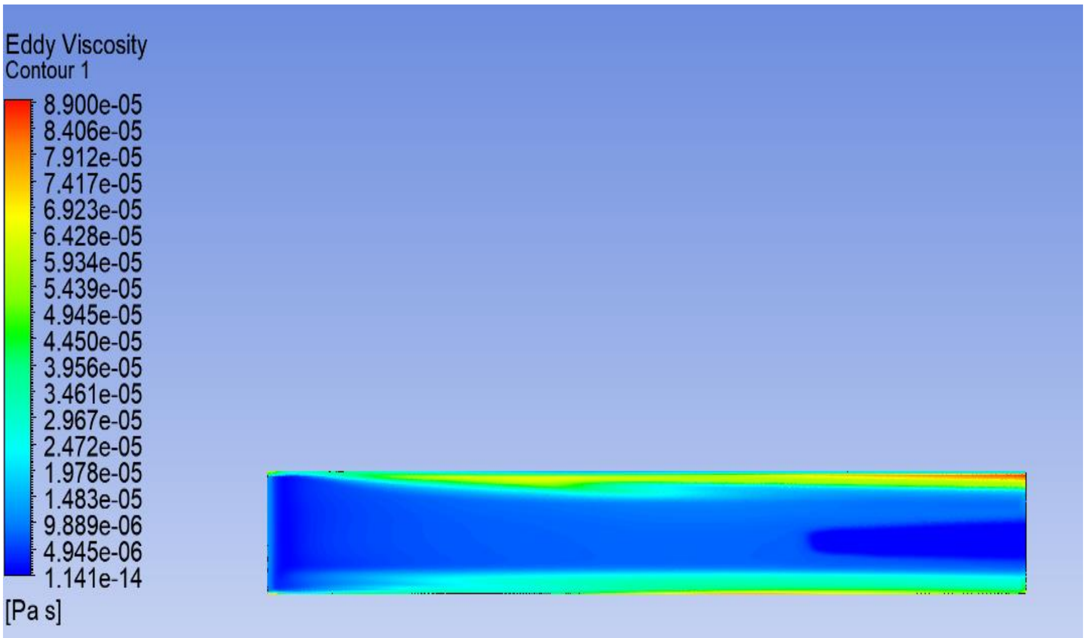

Figure 5.6. Contour of biodiesel viscosity.

The viscosity is one of the most important parameters while testing any type of fuel because it has a major effect on engine performance. The temp affects the viscosity in the opposite way, in other words, the decrease of temperature will result in the elevation of viscosity. Viscosity is one of the most crucial properties of engine fuel. It is important in the fuel spray, mixture formation, and combustion processes. As is known that biodiesel is more viscous than diesel fuel. Fig. 5.5. and Fig. 5.6. result that biodiesel has a higher viscosity (b) than pure diesel (a), the high viscosity is shown on the edge in the red color. The viscosity of animal fat biodiesel is high due to its high fatty acid composition. The maximum viscosity of biodiesel is $8.9454e^{-5}$ [Pa S] but on the other side, the maximum viscosity of diesel is 0.0544504 [Pa S].

Because of the high viscosity, the specific fuel consumption increased with increasing biodiesel content in the tested fuels under all loading circumstances. Additionally, it decreases atomization, fuel vaporization, and combustion, therefore biodiesel has a poorer thermal efficiency than diesel fuel. Since the high viscosity of biodiesel, there will be an increase in CO emissions with high load. As said before Viscosity influences fuel atomization after injection into the combustion chamber, and therefore the production of engine deposits. The higher the viscosity, the more likely the fuel is to produce such issues. So in other words, a high viscosity can cause poor fuel atomization, inefficient combustion, injector choking, ring carbonization, and fuel buildup in lubricating oils.

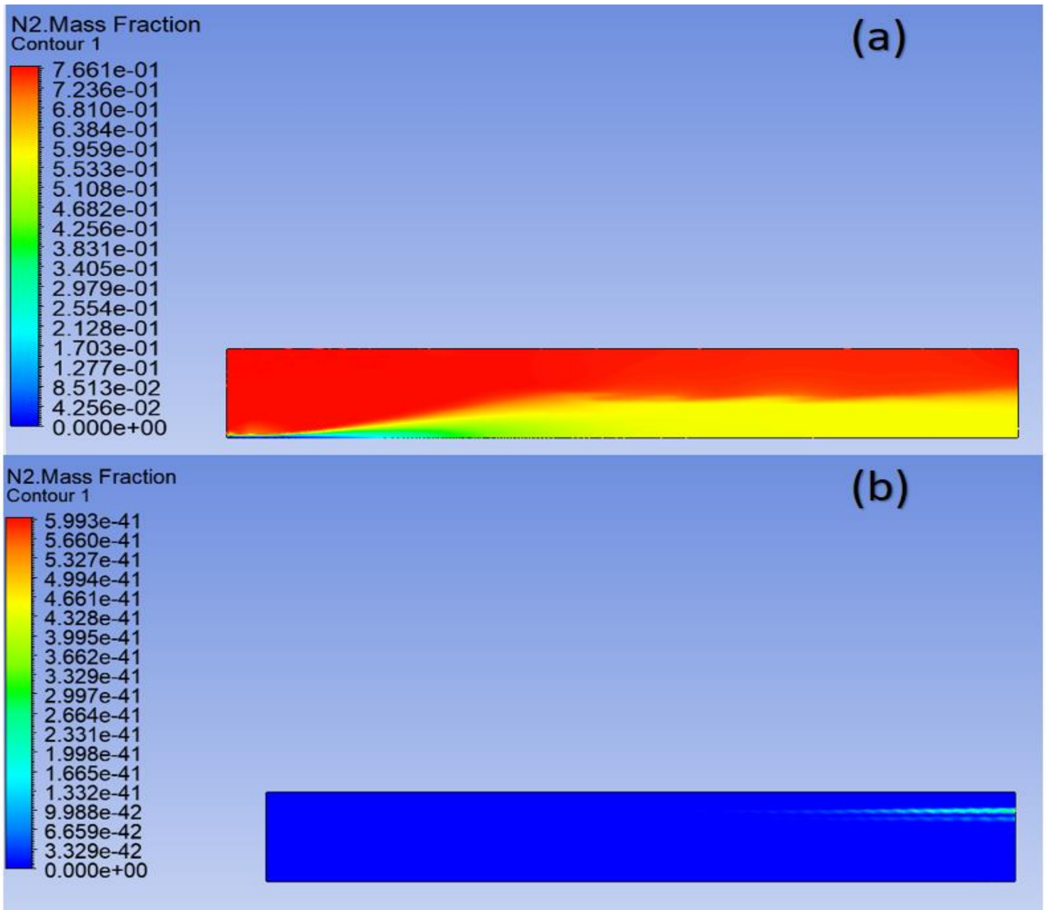

Figure 5.7. Contour of N_2 (a) diesel, (b) biodiesel.

N_2 (nitrogen) is the shortcut of nitrogen but in this experiment, the nitrogen is formed from two molecules so it will be called N_2. This emission occurs in the greatest metal catalysts (palladium and rhodium) catalyzed NO reduction through either N_2O(a) intermediate degrading to N_2(g) + O(a) or nitrogen association as N(a) + N(a)N_2 (g) [79,80]. Fig. 5.7. illustrates the N_2 result between the diesel and biodiesel cylinders. As is shown and obvious In the CFD picture, the N_2 in the biodiesel is higher than in diesel, also as is seen the maximum N_2 inside the biodiesel is 6.01199 e^{-41} but on the other side, it is 0.77 inside the diesel cylinder. Because of the N_2 decrease caused by the presence of water inside the fuel, biodiesel has lower levels of NO_2 than pure diesel. Because the H_2O content of biodiesel is larger than that of diesel, its N_2 content will be lower than that of diesel in this situation.

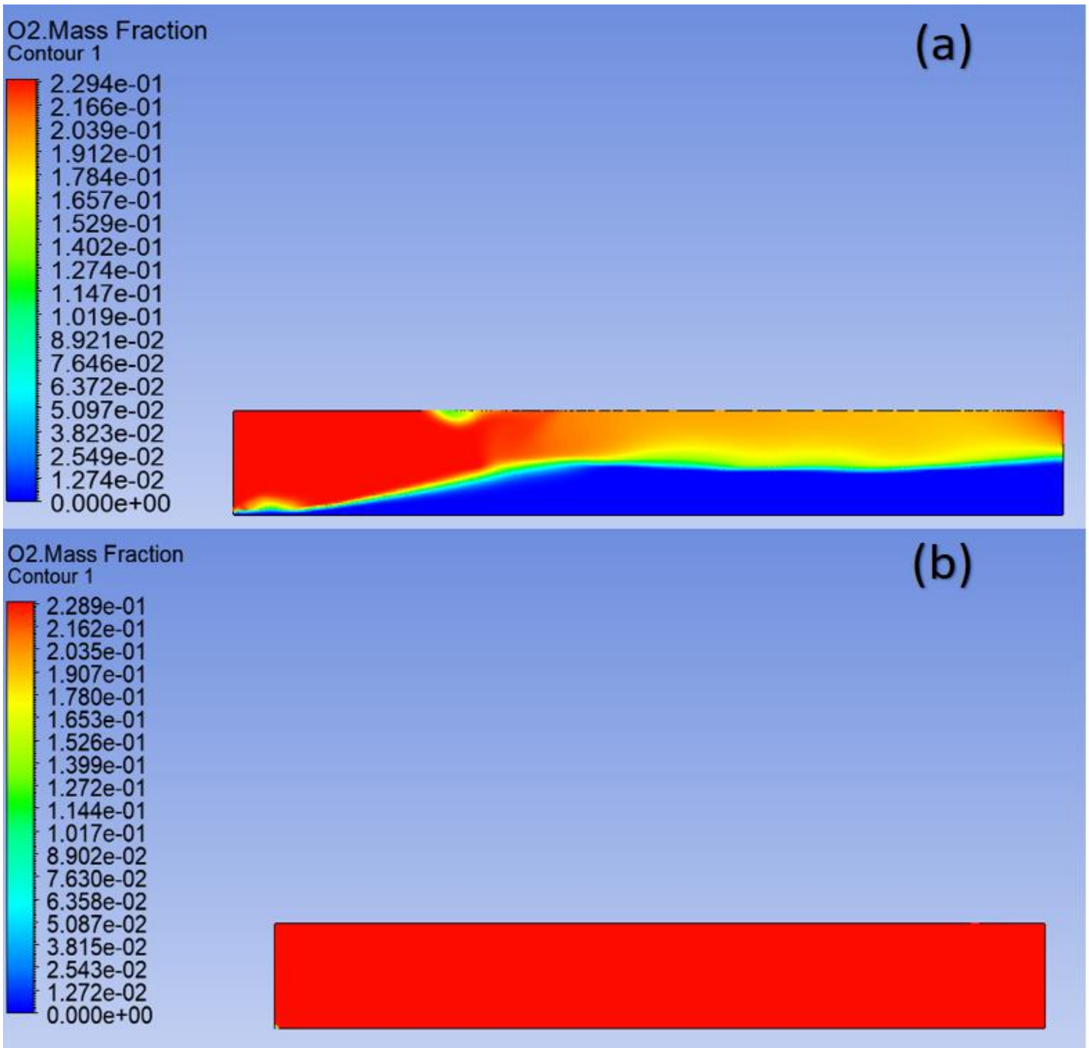

Figure 5.8. Contour of O_2, (a) diesel, (b) biodiesel.

Because O_2 is essentially created within biodiesel, it will undoubtedly be there. This experiment showed that after burning, the animal fat biodiesel had a greater O_2 content than diesel., as shown in Fig. 5.8. Biodiesel burns more completely than regular diesel because it includes more O_2. This eliminates HC and CO emissions. Because of the increased O_2 within the biodiesel cylinder, the air-fuel mixture rate increases, reducing the physical delay and allowing the ignition to occur sooner. However, because regular diesel fuel contains less O_2 than animal fat biodiesel, the ignition delay increases.

The maximum O_2 mass fraction in diesel fuel is 0.230544, which is more than the maximum O_2 mass fraction in biodiesel fuel 0.230056. As a result of the lower quantity of O_2, the data show that diesel will take longer than alternative fuel. As noted in the pressure research, in the case of blended fuels, as the concentration of diesel in the blend increases, so does the ignition delay. Several other studies discovered the same thing, for example, [81] revealed that biodiesel had more O_2 than normal fuel. In a conclusion, as compared to diesel and other mixes, the ignition delay with animal fat biodiesel is shorter.

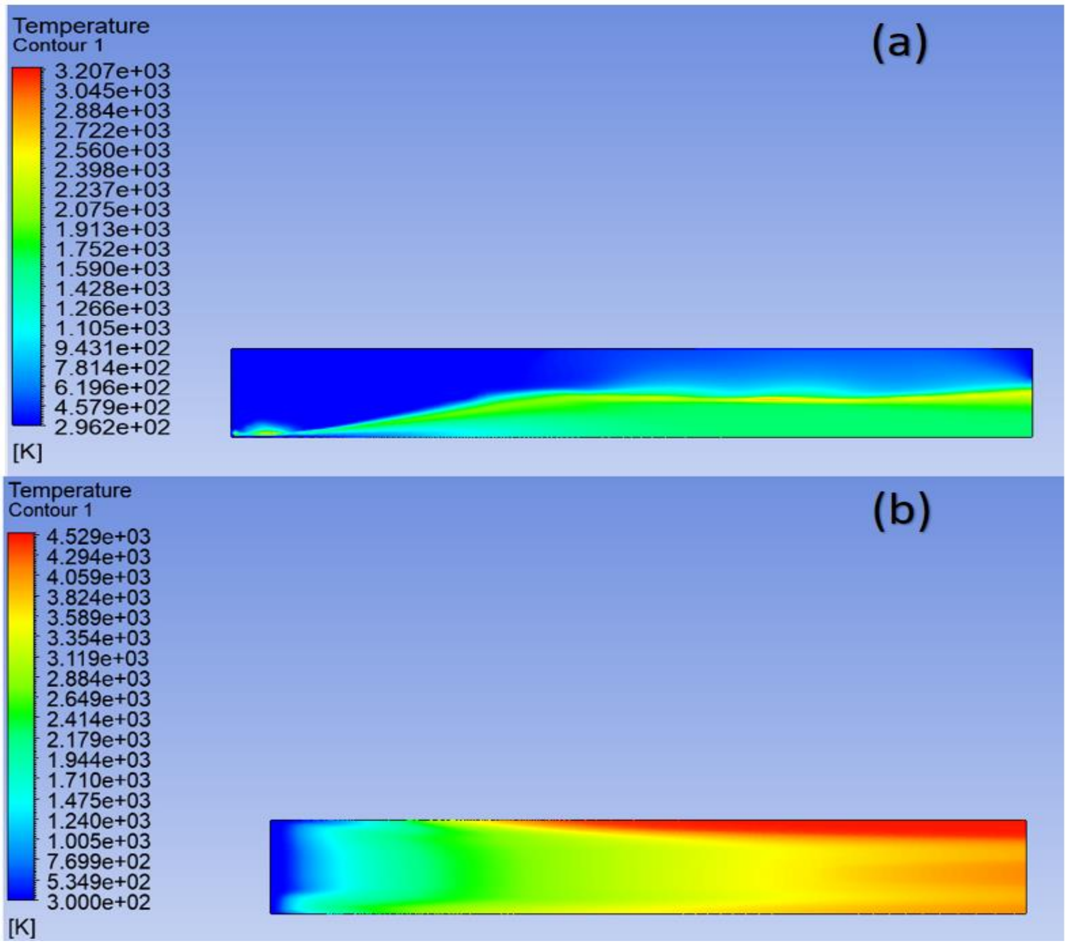

Figure 5.9. Contour of temperature (a) diesel, (b) biodiesel.

Fig. 5.9. shows the result of temperature in diesel and biodiesel. As was expected the temperature rise in the animal fat side (b) probably happen because of the shortened combustion duration in biodiesel the elevation of temperature is noticeably clear in the image, thanks to the distribution of colors in the CFD application.

As it's crystal clear, the temperature in animal fat biodiesel is higher than diesel, because the color of diesel is blue and baby green, this is the lowest color to determine the temperature in the CFD application, but on the other hand in the biodiesel side, the diversity of color that results in the high temperature is shown, such as yellow, orange and the maximum is the red. From resultswe can see that the maximum temperature of biodiesel is 4550.04 K but on the other hand, the maximum temperature of the diesel cylinder is 3221.74 K. Biodiesel fuels are inappropriate for usage in colder climates because they contain a higher amount of saturated fatty acid methyl esters. The major explanation for these results is that biodiesel has a bigger flash point than diesel fuel. The flash point, as the name implies, is the exact temperature at which a fuel will catch fire. And also the temperature is higher because the biodiesel has a higher cetane number. As a result, in terms of temperature, biodiesel is safer to handle at greater temperatures than standard diesel.

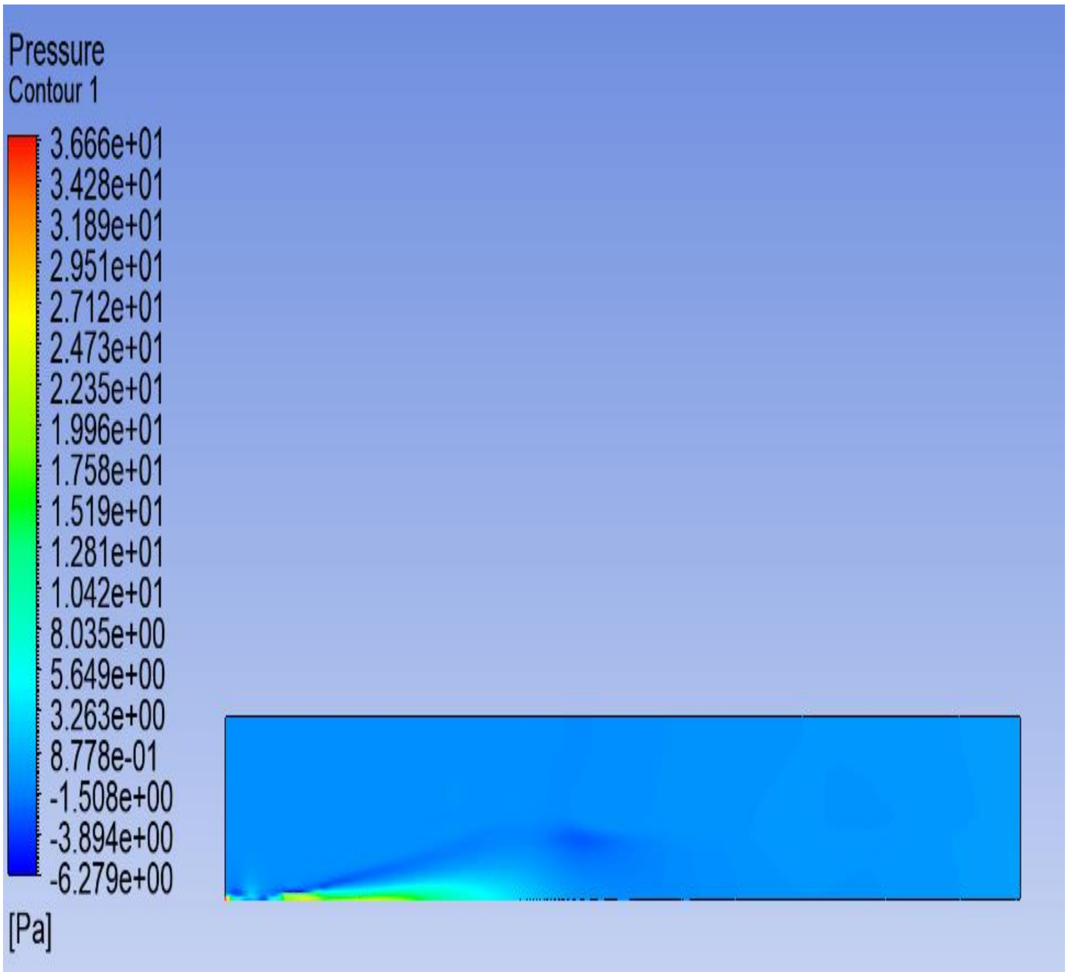

Figure 5.10. Contour of diesel pressure.

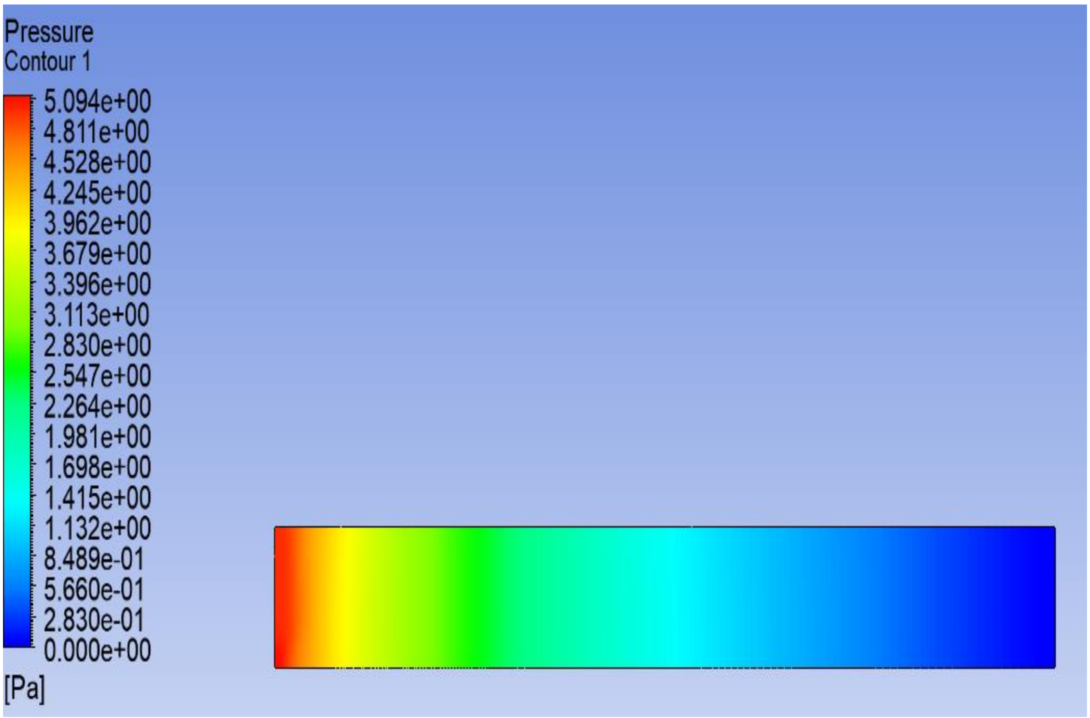

Figure 5.11. Contour of biodiesel pressure.

The pressure in the biodiesel cylinder is higher than in the standard diesel cylinder, as indicated in Fig. 5.10. and Fig 5.11. the chemically bonded O_2 in the animal fat biodiesel causes the cylinder pressure to rise. When the fuel combines with the O_2 inside the combustion chamber, the pressure inside the cylinder rises. Furthermore, pressure is one of the most vital factors affecting the creation of methyl esters. in the case of blends (biodiesel + diesel), many researchers [25] predict that the pressure will reduce with the decrease of pure diesel inside the mixture. More studies result that the pressure value is reduced. This problem is associated with the reduction of fuel atomization when animal fat is used [82].

As a result, it is reasonable to conclude that the fall in pressure in the diesel cylinder or, in the case of blends is a result of the lag in O_2 concentration during combustion affects the rate of combustion. According to the experiment, the maximum pressure occurred extremely early with animal fat biodiesel 5.1194 [Pa] and late with regular diesel fuel 36.8801[Pa]. This demonstrates that heat energy is discharged relatively late, reducing BTE and increasing exhaust gas temperature

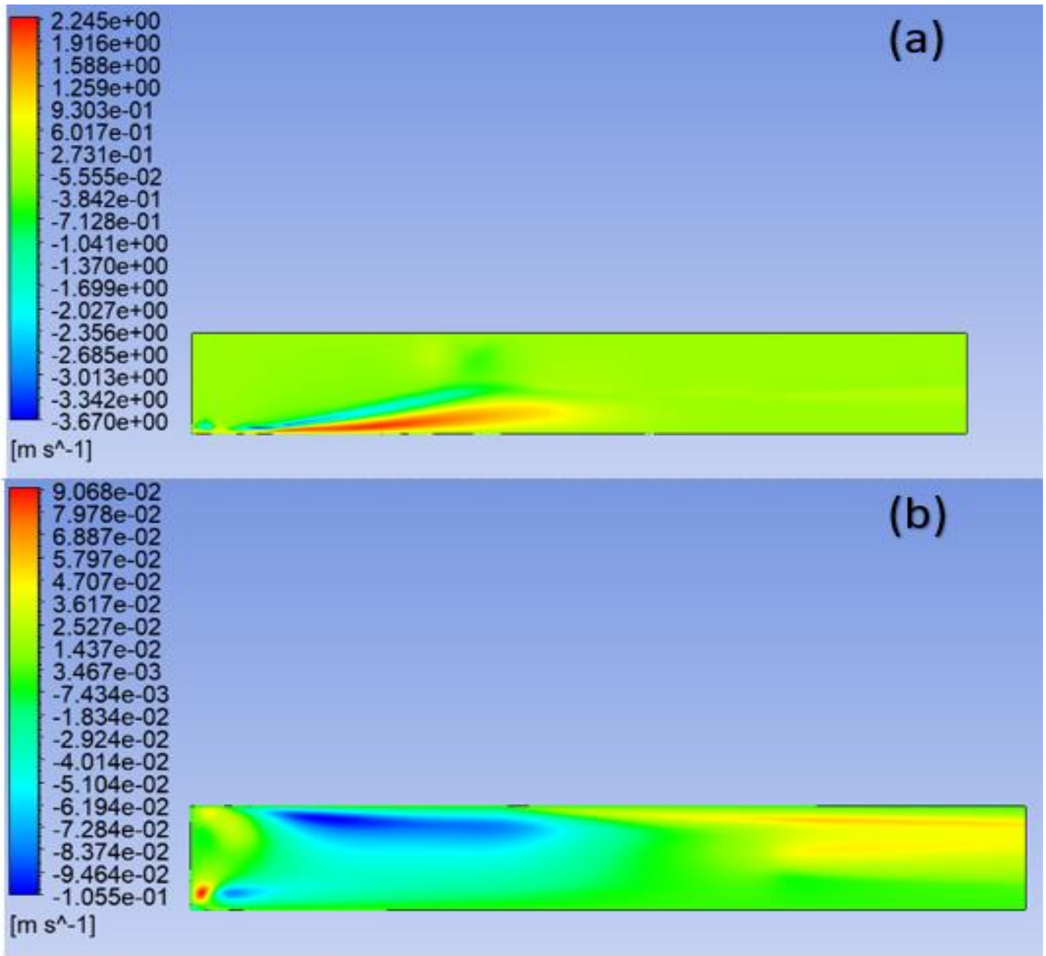

Figure 5.12. Contour of velocity (a) diesel, (b) biodiesel.

As is well known, velocity is the rate at which something moves. The examined speed in this experiment is referred to the fuel and combustion. The major parameters influencing velocity are density, viscosity, and pressure. Fig. 5.12. shows the compared result of velocity between the diesel and animal fat biodiesel. Based on the results, the maximum velocity of pure diesel is 2.27474 $m.\mathrm{s}^{-1}$ but on the other side, the maximum velocity inside the biodiesel cylinder is 0.09166 $m.\mathrm{s}^{-1}$

Due to the CFD application we can easily compare the velocity contour of diesel and biodiesel based on the color resulted inside the cylinder or also it can be compared based on the number resulted and showed on side inside the axe that show all the values so it's easier and more simple to compare the two cylinders. It was obviously noticed that the average velocity within the diesel cylinder is more than 15% higher than the alternative fuel. This is because diesel and biodiesel have differing effects on the liquid flow forms inside the nozzle aperture. Finally as a final result, after the experiments, several studies come to the same conclusion. For instance, [83] inferred that velocity is related to viscosity. In other words, lower viscosity diesel fuel causes an increase in velocity, whereas higher viscosity biodiesel causes a drop in velocity when compared to diesel fuel and also it's acceptable to say that velocity is one of the most important parameters while testing which type of fuel is better to use, in this experiment it's obvious that the diesel fuel have higher velocity than biodiesel because it have less viscosity. The relation between velocity and viscosity is opposite as is obvious and showen inside those results above.

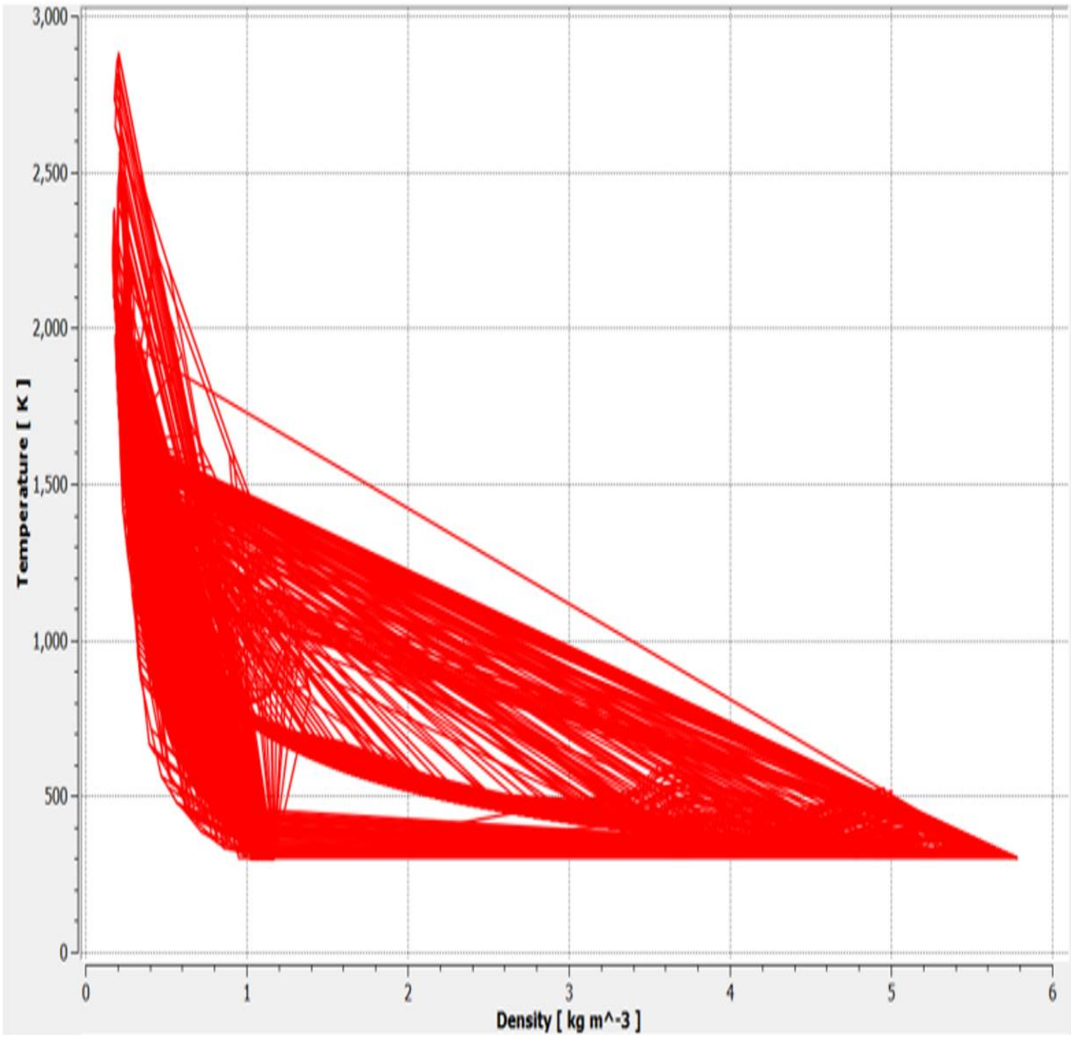

Figure 5.13. Diesel temperature with density.

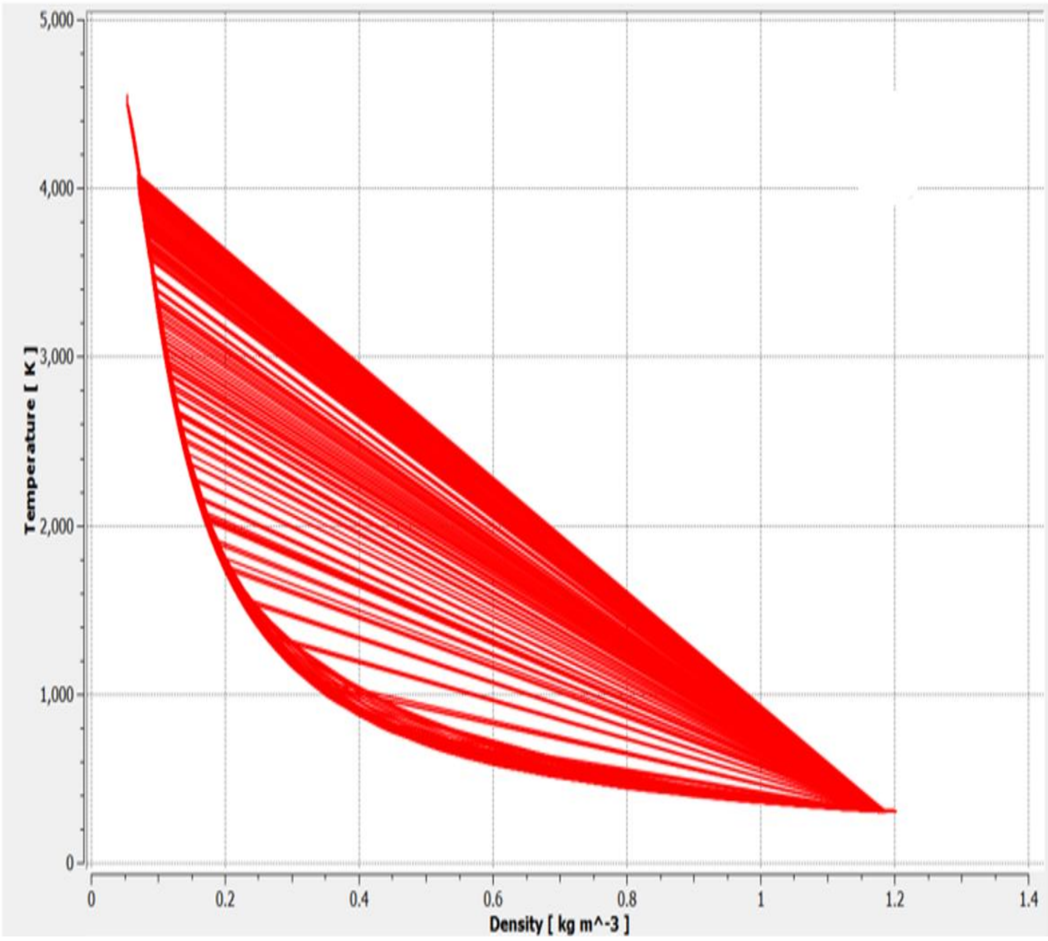

Figure 5.14. Biodiesel temperature with density.

The connection between temperature and density is really simple to describe and comprehend. The relationship is inverse. The density of the fuel changes with temperature; for example, if the fuel is cold, it has more density than warmer or higher-temperature fuel. When a liquid is warm (at a high temperature), it has a low density. For example, if two fuels with identical qualities are compared, the fuel with the lowest temperature will result in an increase in density during the experiment. Fig. 5.13. and Fig 5.14. shows the variation of temperature with respect to the density between diesel and biodiesel.

As can be seen from both sides, as the temperature drops, the density rises during the combustion process. The temperature in the biodiesel reaches a maximum of (4550.04 K) with a density of (0.0539736 kg/m^3), whereas the density of diesel was (0.15384 kg/m^3) with a temperature of (3221.74 K). When the experiment ends, the density of biodiesel reaches a maximum of (1.2029 kg/ m^3) with a temperature of (300 K), which is still higher than normal diesel (296.22 K). It is well known that biodiesel is denser than diesel after combustion. The above-mentioned results and graph demonstrate that the hypothesis is correct.

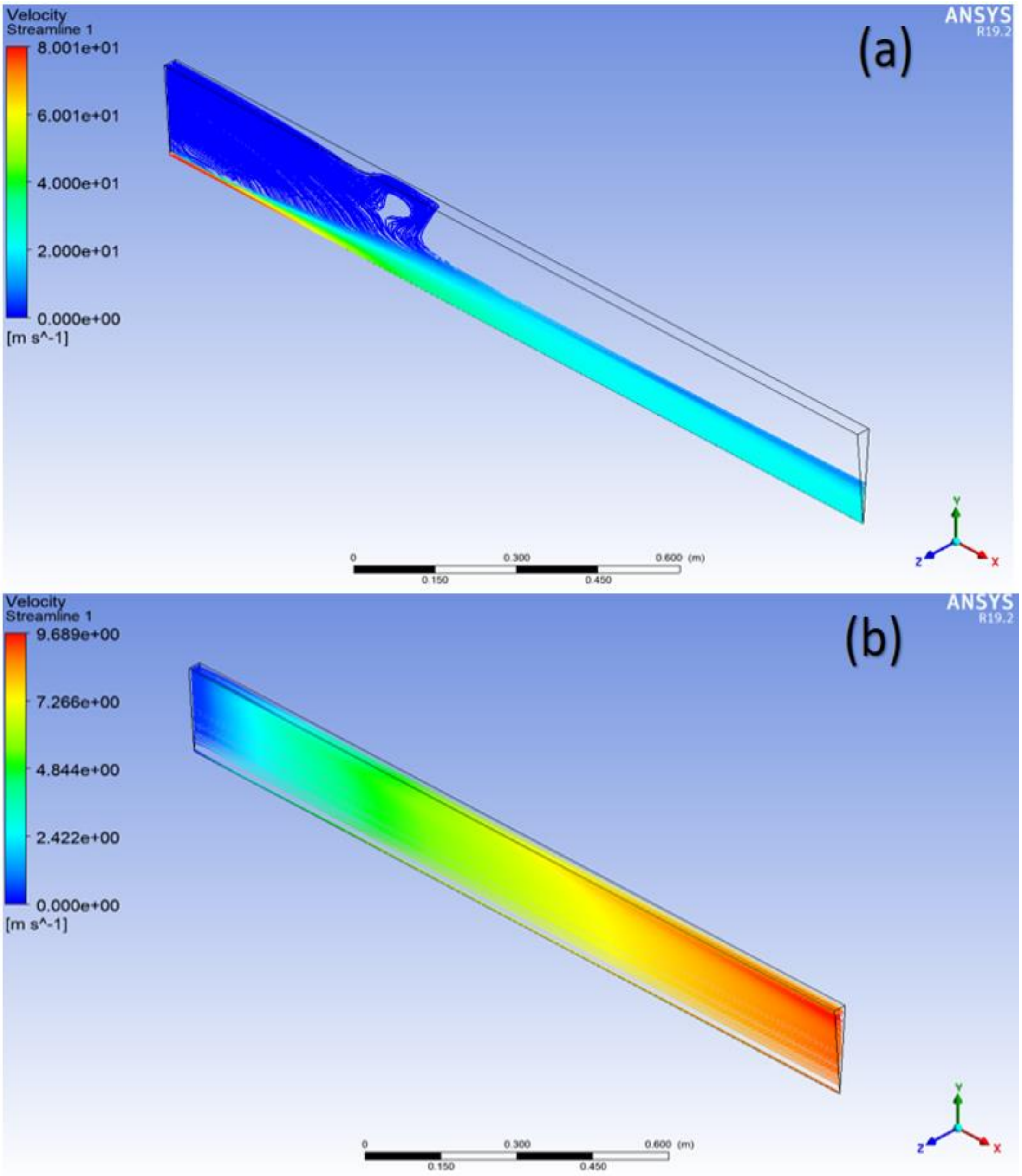

Figure 5.15. Streamline of air and fuel inlet (a) diesel, (b) biodiesel.

A streamline is a flow trajectory. Fig. 5.15. demonstrates the streamlining and air/fuel distribution inside the cylinder. As illustrated in the (a), the air and fuel enter quickly at first due to the low density, and afterward the distribution and velocity decrease. On the other hand, because of the high density of the biodiesel, the air/fuel enters slowly, as represented by the CFD colors, before becoming rapid owing to the high temperature, which increases the viscosity. The streamline velocity is one from the most important parameters while testing any type of fuel and not only the biodiesel, because it have a huge impact on the engine performance.

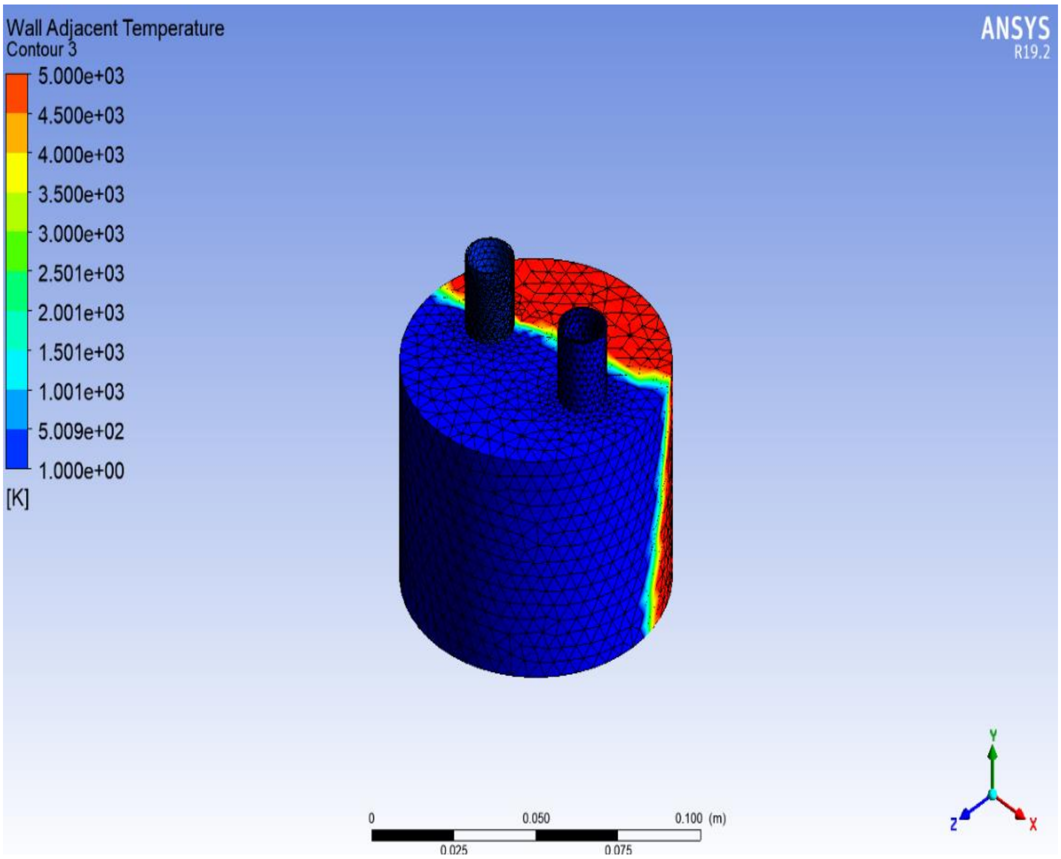

Figure 5.16. Contour of wall adjacent temperature diesel in 3D design.

The temperature of the cell close to the wall is the total temperature after all reactions, and it may also be defined as the temperature of the cell near the wall and seen on the wall. Normal temperature results are explained above in the comparison with the animal fat biodiesel, but Fig. 5.16 shows the result of temperature in three dimensions. 3D is better, more professional, and will show the results more clearly and studies can be conducted better than 2D simulation. As previously stated, diesel has a lower flash point and cetane number than biodiesel, hence the temperature in the cylinder will undoubtedly be lower

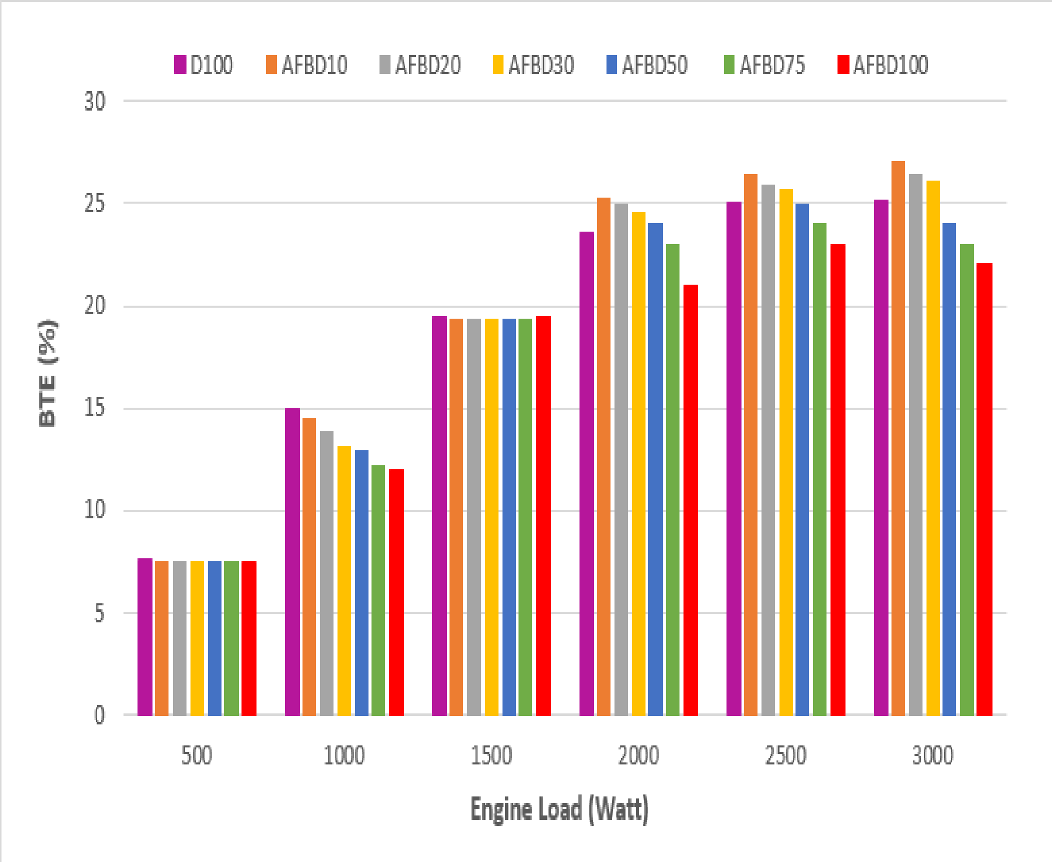

Figure 5.17. BTE according to AFBD percentage and engine load [2].

Thermal efficiency is defined as the ratio of power production to energy introduced by fuel injection, with the latter being the product of the injected fuel mass flow rate and the lower heating value [84]. BTE is defined as the ratio of usable power extracted from the engine to energy provided to the engine. Cetane number, evaporation rate, density, fuel optimization, flash point, calorific value of the fuel, compression ratio, injection advance, and spray pressure are some of the factors that impact a diesel engine's ability to burn fuel efficiently [2].

In Fig. 5.17. the results of the BTE values are shown. When the BTE values are compared to engine load, it is clear that the values of BTE grow as the engine load increases, but once the load reaches 2500 watts, the animal fat biodiesel values begin to drop. This is because torque and power levels have decreased. Now, when compared to diesel, the value of animal fat blends (10, 20, and 30%) has grown greatly; however, when animal fat blends (50, 75, and 100%) are used, the BTE values decline. The high quantity of O_2, the big cetane number, and the high viscosity inside the biodiesel fuel play an important role in the results. Due to the high viscosity inside the animal fat fuel, the BTE values show as obvious decreasing after the usage of the 30 % biodiesel blend. The high O_2 content, high cetane number, and high viscosity of the biodiesel fuel all play a part in the result. Because of the high viscosity of animal fat fuel, the BTE ratings clearly decrease after using a 30% biodiesel blend. In other words, it can be said that the BTE increase with the decrease of animal fat biodiesel fuel inside the blends.

5.2 EXHAUST EMISSIONS RESULTS

5.2.1 NO_x emissions Results

The combustion chamber temperature and the air-fuel ratio are two critical factors that determine NO_x production. NO_x is created when the combustion chamber's temperature exceeds 1800 K due to a chemical reaction involving nitrogen and O_2 in the air, which are hazardous to human health and the environment. Nitric acid is produced when NO_x reacts with moisture in the lungs, which causes respiratory disease exhaust gas recirculation (EGR) is one of the most effective methodes to minimize NO_x emissions while maintaining fuel efficiency [85].

In Fig. 5.18. the variation of NO_x emission using animal fat biodiesel with respect to several engine loads is shown. As it is obvious in the graph the oxide of nitrogen emission rise with the increase of engine load. the main reasons for NO_x elevation are first the high cetane number of biodiesel and second that over time and with the engine load running high, this leads to the increase of the cylinder temperature which results in the elevation of oxide of nitrogen. As indicated in the graph, because of its high viscosity, animal fat biodiesel produces greater nitrogen emissions in all mixes and engine loads. Numerous research have revealed that diesel engine NO_x emissions are affected by the cetane number. Lower cetane numbers imply longer ignition delays and more accumulated fuel/air mixture, which leads to high temperatures and the generation of NO_x as well as a rapid heat release at the beginning of the combustion process [86].

During the internal combustion process, the engine needs a percentage of O_2 to burn the fuel. This O_2 is achieved from the air that contains 21% O_2 and the remaining part is almost 79% and this percentage is formed from pure nitrogen. The NO_x emissions are a result of nitrogen and O_2 reaction together during the internal combustion process [87,88]. Some researchers in their studies result in the NO_x emission increase while using animal fat biodiesel due to the high amount of O_2 that results in a huge reaction with nitrogen that creates a huge amount of NO_x. As long we add more animal fat biodiesel as long that the NO_x emission will get higher [29]. According to other authors [89,90]. The higher the iodine content, the more unsaturated the biodiesel, so the oxide of nitrogen will increase. It's acceptable to say that the NO_x emission will keep elevate with the engine load as long that the animal fat is increasing inside the mixture because the mixture that have the minimum amount of biodiesel have the lowest emissions.

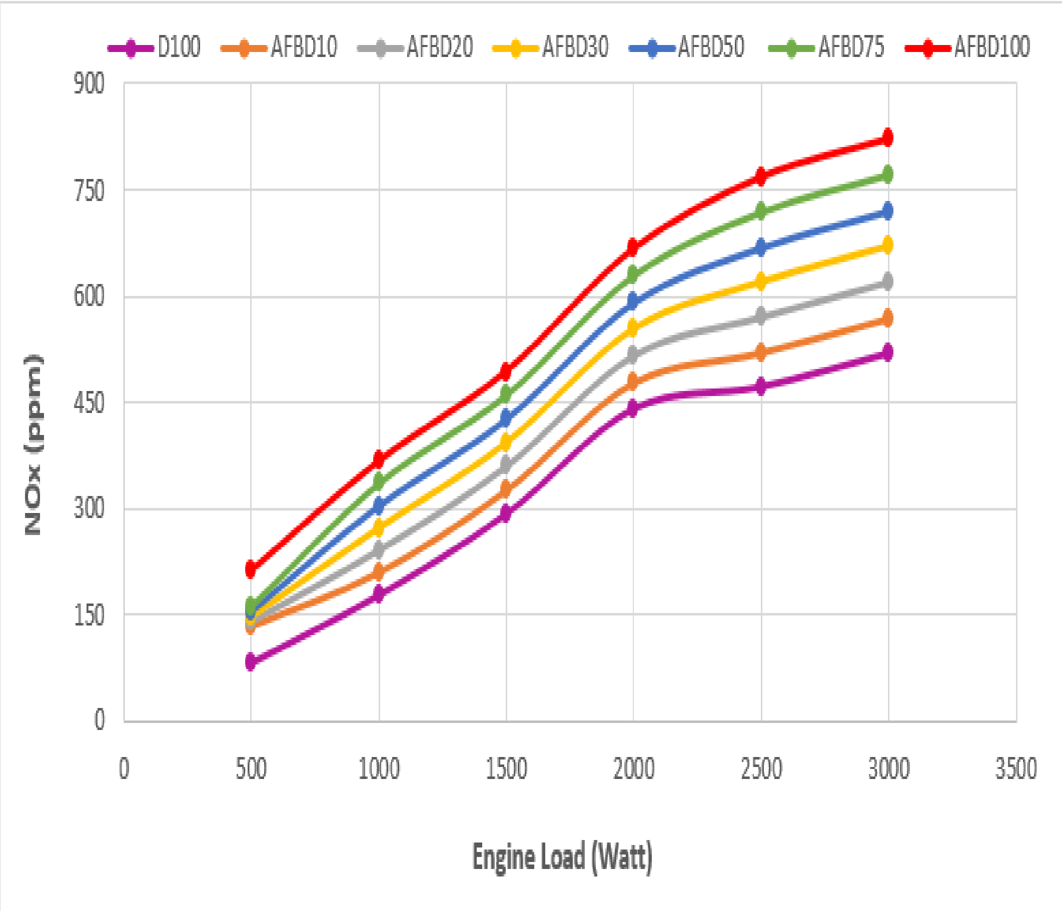

Figure 5.18. NO_x emission according to AFBD percentage and engine load [2].

5.2.2 CO emissions results

The presence of CO in combustion products is caused mostly by a lack of O_2. Combustion engine emissions influence fuel type and properties, atomization rate, combustion chamber design, engine speed, air-fuel ratio, and other engine operating variabls [91]. CO from diesel engines is a fundamental element of emission regulations. CO indicates wasted chemical energy losses in engines and increases in emissions, which have a negative impact on the engine performance and work [62]. In Fig. 5.19. the variation of CO emission using animal fat biodiesel with respect to several engine loads is shown. On the first hand, CO emission reduce at low engine load due to the high cetane number while using animal fat biodiesel, but on the other hand when the engine load become 2500 watt and more, the emission boost again. CO emissions for all fuels reduce with low engine load. They then grow during high-load conditions. Because of the high viscosity. When compared to pure diesel emissions, CO emissions from animal fat decreased significantly at high loads. This part of emission is related to other emissions like CO_2, in other word CO have a different and opposite result than the CO_2 emissions, when the CO emission increase the CO_2 emission will drop and decrease. The relation between this two emissions is easy to explain, it's opposite and reverse because with the elevation of one the second will drop and reduced with the elevation of engine load.

This is because biodiesel has a high amount of O_2. All biodiesel mixes release less CO than diesel, while 100% animal fat emits the least. In many researchers' studies, it results that with the use of animal fat biodiesel C emissions decrease [92], A study found that under greater loads, CO emissions from biodiesel fuel were lower than those from diesel fuel. This is due to the improved burning properties [93], as showing also during several studies The CO emissions in animal fat biodiesel were lower than for diesel fuel, and the degree of reduction in CO emissions did not rely on the quantity of animal fat biodiesel inside the fuel [94,95]. A study found that under greater loads, CO emissions from biodiesel fuel were lower than those from diesel fuel. Because of the O_2 concentration, in this case it's acceptable to say that alternative fuels emit less CO and the normal diesel emit a higher amount [96].

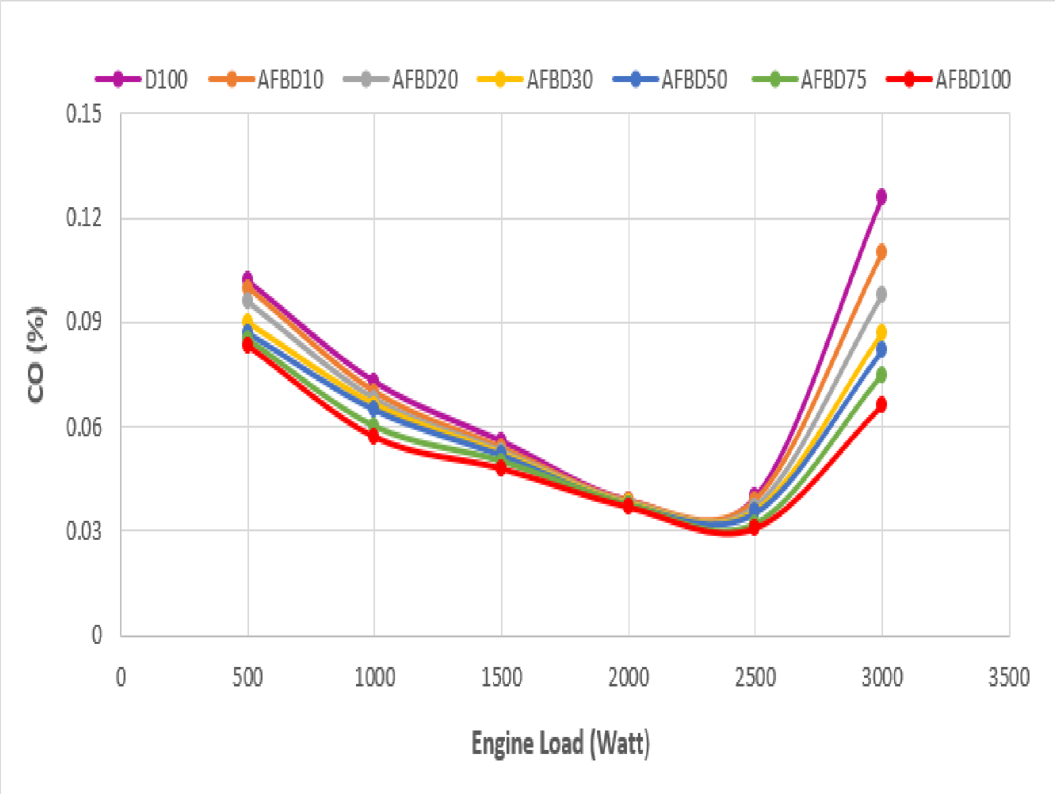

Figure 5.19. CO emission according to AFBD percentage and engine load [2].

5.2.3 HC emissions results

HC emissions arise in areas with incomplete combustion. Engine speed or load have no effect on HC emissions. The design of the combustion chamber and the injection technique are more important factors. When movement rises, so do air motions (turbulence), and therefore will be less unburned HC emissions [97]. HC contain a variety range of organic chemical compounds and have no harmful impact under typical air circumstances. They are considered pollutants, although they play a role in the responses of other pollutants in the atmosphere. In areas where there is a high rate of motor vehicle use, there is a significant increase in the number of HC [98,99].

In Fig. 5.20. the variation of HC emission using animal fat biodiesel with respect to several engine loads, as it was obvious that the emission rise with the increase of engine load. It is conceivable to state that the higher the HC content of exhaust emissions, the worse the engine will perform.

The graph clearly shows that HC emissions from all fuels are increasing. At low loads, the fuel with the highest proportion of diesel has the largest percentage of HC emissions, which is definitely attributable to the low viscosity of pure diesel. The HC emissions drop as engine load increases, and the pure animal fat biodiesel produces the lowest value of emissions. This is due to the high combustion temperature in biodiesel and the high amount of O_2, which leads to the massive oxidation of the HC emissions. All of the above results indicate that diesel has the highest HC emissions.

Some researchers' like Simsek results that the HC emission decreased by almost 20% but it will increase more if we add more biodiesel [92]. Another study by Shahir et al. [93] at greater loads, biodiesel fuel operation provides reduced HC emissions. The HC emission from animal fat biodiesel is kind of greater than that from pure diesel. A study by Alptekin and Canakci [100], result that when comparing the results of biodiesel fuel which is created from various raw materials with diesel fuel, some emissions like HC decrease.

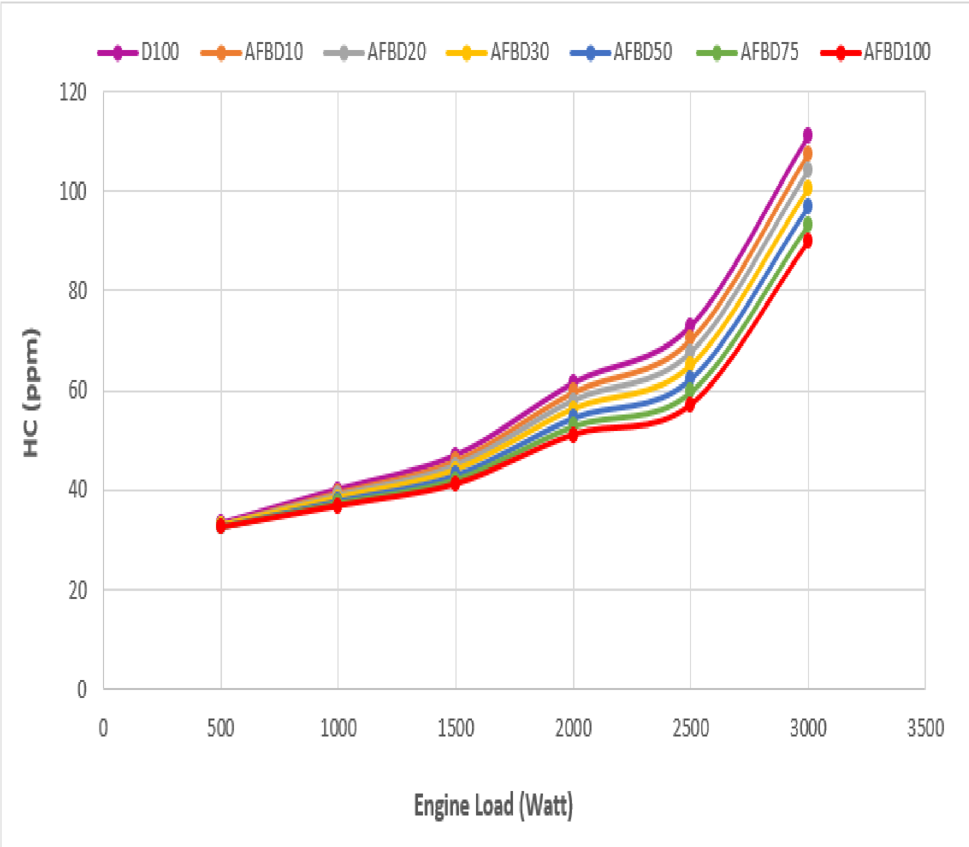

Figure 5.20. HC emission with AFBD percentage and engine load [2].

5.2.4 SO_2 and smoke emissions results

The quantity of smoke in the exhaust gas determines the amount of PM in the exhaust gas. The O_2 usually included in biodiesel mixes, which removes any potential local O_2 deprivation, is said to have aided in the reduction of smoke levels. When the fuel particles cannot locate sufficient O_2 in the cylinder, they are released as smoke [2,101,102]. In Fig. 5.21. the variation of smoke emission using animal fat biodiesel with respect to several engine loads is shown. The percentage of smoke emission decrease with the elevation of engine load, this happens because the animal fat biodiesel has the needed quantity of O_2 in the combustion place so this will increase the oxidation which decreases the smoke emission. It's important also to say that animal fat biodiesel has a low sulfur matter, this is an important factor for smoke reduction.

The density of the smoke decreases with any biodiesel fuel, particularly with 100% animal fat. This reduction in smoke emissions is related to the decreased C content of the alternative fuel. Pure biodiesel has the lowest proportion of smoke because of the higher quantity of O_2, which reduces smoke formation during the combustion process. Diesel fuel produces more smoke than all animal fat biodiesel mixes combined.

Some researchers like Lapuerta et al. [103] show that utilizing animal fat biodiesel reduces the proportion of smoke emissions; the best reason for this reduction is the high O_2 content. According to several researchers like Öner et al. [104] investigate that biodiesel produced the least amount of SO_2 emissions of all test fuels. However, in other trials like Lin et al. [105] discovered that utilizing biodiesel resulted in the lowest SO_2 concentration at all higher engine speeds, whereas diesel fuel resulted in the highest SO_2 concentration. Biodiesel's decreased sulfur concentration is significant for one key reason. Biodiesel, as a low-sulfur fuel, emits little or no SO_2. This emissions causes respiratory sickness, aggravates existing heart and lung problems, contributes to acid rain generation, can impair sight, and can travel vast distances [106].

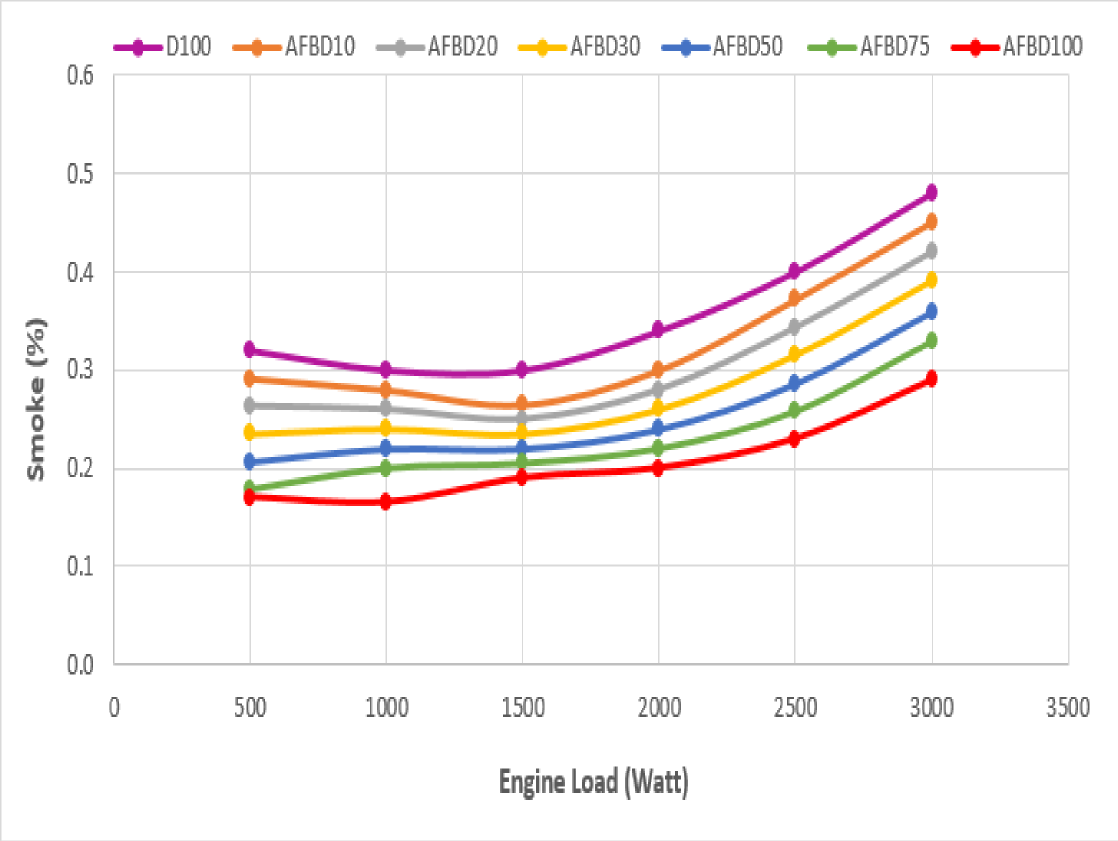

Figure 5.21. Smoke emission with AFBD percentage and engine load [2].

5.2.5 CO_2 emissions result

CO_2, which generates the greenhouse effect in the atmosphere, is one of the primary drivers of global warming and the world's most serious environmental crisis. Using alternative fuels instead of fossil fuels is one strategy to minimize CO_2 emissions created by the burning of fossil fuels. According to a study, automobiles account for around 28 percent of CO_2 emissions, with road vehicles accounting for 84% of these emissions. Some researchers have investigated the use of biodiesel inside the diesel engines [57,98,107,108]. In Fig. 5.22. the variation of CO_2 emission using animal fat biodiesel with respect to several engine loads is shown. As it is obvious that the CO_2 emission is rising with the rise of engine load. The result of CO_2 is the opposite of CO, The excess of biodiesel-derived O_2 in the cylinder is thought to be the reason why CO_2 emissions continue to rise. Increasing CO_2 means increasing the rate of full combustion in the cylinder. This is one of the disadvantages of utilizing biodiesel as a fuel.

The CO_2 emissions result in increase due to the high cetane number as shown in the graph result, due to the opposite relation between CO_2 and monoxide. The result of CO_2 emissions increases as was expected. 100% percent animal fat when compared to diesel operation, biodiesel produces more CO_2. The presence of more CO_2 in exhaust emissions indicates that the fuel was completely burned.

According to the researchers, the low C and H content of biodiesel accounts for the reduction in CO_2 emissions during full combustion. The air-fuel ratio in engines has a considerable impact on the quantity of CO_2 produced at the conclusion of this interaction. As long as the rate of air-fuel ratio remains constant, the rate of CO_2 grows proportionally [109,110]. With the adding of animal fat biodiesel the CO_2 emissions have increased in some research due to the improvement of the combustion [92].

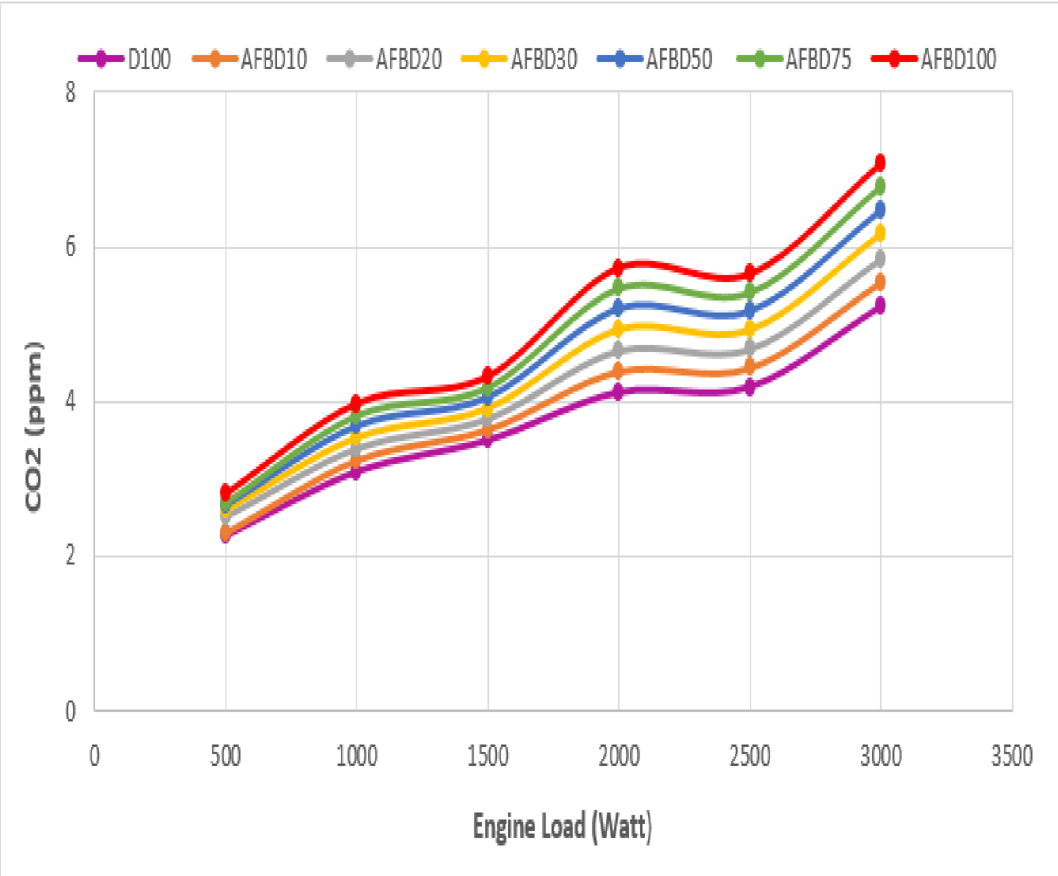

Figure 5.22. CO_2 emissions with AFBD percentage and engine load [2].

The maximum and minimum results of parameters inside the two fuel cylinders are shown in Table 5.1 above, due to the Ansys CFD, not only by the color change in the pictures but also by using those results it's much easier to compare parameters such as pressure, temperature, and more. Sometimes using computer technology is better than real work because in this way the results are excellent and very accurate. This table results in all the differents that happened during this experiment.

Table 5.1. Paramteres results

Parameters	Diesel		Biodiesel	
	min	max	min	max
Densisty Kg/m^3	0.15384	5.77994	0.0539736	1.2029
H2O mass fraction	----	0.13309	----	0.772071
Viscosity [Pa s]	4.12624e^{-21}	0.0544504	1.14149e^{-14}	8.9454e^{-5}
N2 mass fraction	----	0.77	----	6.01199 e^{-41}
Temperature [K]	296.22	3221.74	300	4550.04
Pressure [Pa]	-6.27928	36.8801	----	5.1194
O2 mass fraction	----	0.230544	----	0.230056
Velocity $[\boldsymbol{m.s^{-1}}]$	-3.670	2.27474	-0.105	0.09166

PART 6

CONCLUSION

Every problem ends with a particular solution obtained from a proper study. The main aim of this research is to compare engine performance and emissions between diesel fuel and animal fat biodiesel using the CFD Ansys application. The following are some of the significant findings obtained from this computational study.

- BTE increases with the engine load but on the other hand, it decreases with the addition of animal fat biodiesel inside the blend.
- In the density and velocity study, results show that both properties increase while using animal fat biodiesel due to several parameters.
- The addition of animal fat biodiesel was shown to be highly successful in reducing HC and CO emissions. Both engine emissions are significantly decreased.
- It was observed that the addition of animal fat biodiesel had no impact on NO_x emissions. Nitrogen emissions increase, causing the cylinder temperature to rise, but on the other side the smoke emission decrease due to the higher quantity of O_2, which reduces smoke formation during the combustion process

The obtained results were compared with earlier results obtained by others authors, this comparison showed accepted conformity. As a result using animal fat biodiesel as an alternative fuel within a diesel engine is suitable. Because it reduces the amount of animal waste in the environment and as well as the exhaust emissions are good for the environment.

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RESUME

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