MATHEMATICAL MODELLING ON THE EFFECT OF EQUIVALENCE RATIO IN EMISSION CHARACTERISTIC OF COMPRESSION IGNITION ENGINE WITH BIODIESEL FUEL

MOHAMAD NAFEZ AZZAM BIN KHALID

A report submitted

in fulfillment of the requirements for the degree of

Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this project report entitled “The mathematical modelling on the effect of equivalence ratio in emission characteristic of compression ignition engine with biodiesel” is the result of my own work except as cited in the references

Signature : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : .....

Name of Supervisor : .....

Date : .....

DEDICATION

To my beloved mother and father

ABSTRACT

In this study, the mathematical modelling on the effect of equivalence ratio in emission characteristic of compression ignition engine with biodiesel fuel is discussed in the methodology section. The increasing needs for fuel in everyday life, as well as the dangers associated with it, pose a severe threat to the world. Attention must be paid to this issue in order to recognise it. This study is performed to prove that the biodiesel fuel has many advantages compare to the diesel fuel. In the literature review section, the general knowledge about the biodiesel are explain including the production of biodiesel, the technique used to produce the biodiesel and all the costing need to produce the biodiesel fuel. There will be a simulation using a MATLAB and Microsoft Excel software to calculate the mole fractions of the product in the chemical reaction of the biodiesel fuel. Then, every graph of the mole fraction of every product will be explained briefly in Chapter 4. The emission of combustion product like carbon dioxide, carbon monoxide and nitrogen oxide that may affect the environment will be discussed.

ABSTRAK

Dalam projek ini, pemodelan matematik mengenai kesan nisbah kesetaraan dalam pelepasan ciri-ciri enjin penyalaan mampatan dengan biodiesel terdapat dalam bahagian metodologi. Keperluan bahan api yang semakin meningkat dalam kehidupan seharian serta bahaya yang berkaitan dengannya telah menimbulkan ancaman yang teruk kepada dunia. Perhatian mesti diberikan kepada isu ini untuk mengenalinya. Kajian ini dilakukan untuk membuktikan bahawa bahan api biodiesel mempunyai banyak kelebihan berbanding dengan bahan api diesel. Dalam bahagian kajian literatur, pengetahuan am tentang biodiesel diterangkan termasuk penghasilan biodiesel, teknik yang digunakan untuk menghasilkan biodiesel dan semua keperluan kos untuk menghasilkan bahan api biodiesel. Akan ada simulasi menggunakan perisian MATLAB dan 'Microsoft Excel' untuk mengira pecahan mol produk dalam tindak balas kimia bahan api biodiesel. Kemudian, setiap graf pecahan mol setiap produk akan diterangkan secara ringkas dalam bab 4. Pembebasan produk pembakaran seperti karbon dioksida, karbon monoksida dan nitrogen dioksida yang boleh menjejaskan alam sekitar akan dibincangkan.

ACKNOWLEDGMENTS

To begin, I'd want to take this opportunity to convey my heartfelt appreciation to my supervisor Dr. Adnan Bin Roseli from the Faculty of Mechanical Engineering in Universiti Teknikal Malaysia Melaka (UTeM) in order to provide the necessary guidance, assistance, and motivation in order to complete this project task on time.

Special thanks to both my parents Mr. Khalid bin Hassan and Mrs. Azlina Binti Khamis as they always support me throughout this project. They were continued patience, understanding and give moral supports from the begin. They also provide me a financial support in order to complete my research in this project.

Special thanks to all my friends for their moral support in completing this degree. Lastly, thank you to all who contributed to the successful completion of this project throughout its critical stages.

TABLE OF CONTENTS

ABSTRACT ..... **i**
ABSTRAK ..... **ii**
ACKNOWLEDGMENTS ..... **iii**
LIST OF TABLES ..... **vii**
LIST OF FIGURES ..... **ix**
LIST OF ABBREVIATIONS ..... **xi**
LIST OF APPENDICES ..... **xii**

CHAPTER 1 INTRODUCTION **1**
1.1 Background 1
1.2 Problem Statement 3
1.3 Objective 4
1.4 Scope of the Project 4
1.5 General Methodology 5

CHAPTER 2 LITERATURE REVIEW **6**
2.1 What is biodiesel 6
2.2 The production of biodiesel 8
2.3 Techniques to produce biodiesel 10
2.3.1 Rapeseed oil as the main source 10
2.3.2 Production of biodiesel from plant oils that are both edible and non-edible. 10
2.3.3 Biodiesel with used of palm oil 11
2.4 Biodiesel yield 13
2.5 Operating Cost 14

CHAPTER 3 METHODOLOGY **16**
3.1 Introduction 16
3.2 Combustion Modelling Approach 18
3.2 Governing Equation 19
3.3 Newton Raphson Method 23
3.4 MATLAB input 26

CHAPTER 4 RESULT AND ANALYSIS **27**

4.1 The mole fraction of every combustion product with variation of equivalence ratio 28

4.1.1 Carbon Dioxide (CO_2) 28

4.1.2 Water (H_2O) 29

4.1.3 Nitrogen gas (N_2) 30

4.1.4 Oxygen gas (O_2) 31

4.1.5 Carbon Monoxide (CO) 32

4.1.6 Hydrogen gas (H_2) 33

4.1.7 Hydrogen atom (H) 34

4.1.8 Oxygen atom (O) 35

4.1.9 Hydroxide (OH) 36

4.1.10 Nitrogen Oxide (NO) 37

4.2 The mole fraction of every combustion product with variation of temperature ... 38

4.2.1 Carbon Dioxide (CO_2) 38

4.2.3 Nitrogen gas (N_2) 40

4.2.4 Oxygen gas (O_2) 41

4.2.5 Carbon Monoxide (CO) 42

4.2.6 Hydrogen gas (H_2) 43

4.2.7 Hydrogen atom (H) 44

4.2.8 Oxygen atom (O) 45

4.2.9 Hydroxide (OH) 46

4.2.10 Nitrogen Oxide (NO) 47

4.3 The mole fraction of every combustion product with variation of pressure 48

4.3.1 Carbon Dioxide (CO_2) 48

4.3.2 Water (H_2O) 49

4.3.3 Nitrogen gas (N_2) 50

4.3.4 Oxygen gas (O_2) 51

4.3.5 Carbon Monoxide (CO) 52

4.3.6 Hydrogen gas (H_2) 53

4.3.7 Hydrogen atom (H) 54

4.3.8 Oxygen atom (O) 55

4.3.9 Hydroxide (OH) 56

4.3.10 Nitrogen Oxide (NO) 57

4.4 Discussion 58

4.4.1 Emission of combustion product 58

CHAPTER 5 CONCLUSION AND RECOMMENDATION 61

5.1 Project Conclusion 61

5.2 Area of Improvement 63

APPENDICES 65

REFERENCES 68

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	The differences between all the techniques	8
Table 4.1	Mole fraction of CO_2 with variation of equivalence ratio	28
Table 4.2	Mole fraction of H_2O with variation of equivalence ratio	29
Table 4.3	Mole fraction of N_2 with variation of equivalence ratio	30
Table 4.4	Mole fraction of O_2 with variation of equivalence ratio	31
Table 4.5	Mole fraction of CO with variation of equivalence ratio	32
Table 4.6	Mole fraction of H_2 with variation of equivalence ratio	33
Table 4.7	Mole fraction of H with variation of equivalence ratio	34
Table 4.8	Mole fraction of O with variation of equivalence ratio	35
Table 4.9	Mole fraction of OH with variation of equivalence ratio	36
Table 4.10	Mole fraction of NO with variation of equivalence ratio	37
Table 4.11	Mole fraction of CO_2 with variation of temperature	38
Table 4.12	Mole fraction of H_2O with variation of temperature	39
Table 4.13	Mole fraction of N_2 with variation of temperature	40
Table 4.14	Mole fraction of O_2 with variation of temperature	41
Table 4.15	Mole fraction of CO with variation of temperature	42
Table 4.16	Mole fraction of H_2 with variation of temperature	43
Table 4.17	Mole fraction of H with variation of temperature	44
Table 4.18	Mole fraction of O with variation of temperature	45
Table 4.19	Mole fraction of OH with variation of temperature	46
Table 4.20	Mole fraction of NO with variation of temperature	47
Table 4.21	Mole fraction of CO_2 with variation of pressure	48
Table 4.22	Mole fraction of H_2O with variation of pressure	49
Table 4.23	Mole fraction of N_2 with variation of pressure	50

Table 4.24 Mole fraction of O_2 with variation of pressure 51
Table 4.25 Mole fraction of CO with variation of pressure 52
Table 4.26 Mole fraction of H_2 with variation of pressure 53
Table 4.27 Mole fraction of H with variation of pressure 54
Table 4.28 Mole fraction of O with variation of pressure 55
Table 4.29 Mole fraction of OH with variation of pressure 56
Table 4.30 Mole fraction of NO with variation of pressure 57

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1	Transesterification Process	8
Figure 3.1	Flow chart of the methodology	13
Figure 4.1	Mole fraction of CO_2 with variation of equivalence ratio	28
Figure 2.2	Mole fraction of H_2O with variation of equivalence ratio	29
Figure 4.3	Mole fraction of N_2 with variation of equivalence ratio	30
Figure 4.4	Mole fraction of O_2 with variation of equivalence ratio	31
Figure 4.5	Mole fraction of CO with variation of equivalence ratio	32
Figure 4.6	Mole fraction of H_2 with variation of equivalence ratio	33
Figure 4.7	Mole fraction of H with variation of equivalence ratio	34
Figure 4.8	Mole fraction of O with variation of equivalence ratio	35
Figure 4.9	Mole fraction of OH with variation of equivalence ratio	36
Figure 4.10	Mole fraction of NO with variation of equivalence ratio	37
Figure 4.11	Mole fraction of CO_2 with variation of temperature	38
Figure 4.12	Mole fraction of H_2O with variation of temperature	39
Figure 4.13	Mole fraction of N_2 with variation of temperature	40
Figure 4.14	Mole fraction of O_2 with variation of temperature	41
Figure 4.15	Mole fraction of CO with variation of temperature	42
Figure 4.16	Mole fraction of H_2 with variation of temperature	43
Figure 4.17	Mole fraction of H with variation of temperature	44
Figure 4.18	Mole fraction of O with variation of temperature	45
Figure 4.19	Mole fraction of OH with variation of temperature	46
Figure 4.20	Mole fraction of NO with variation of temperature	47

Figure 4.21	Mole fraction of CO_2 with variation of pressure	48
Figure 4.22	Mole fraction of H_2O with variation of pressure	49
Figure 4.23	Mole fraction of N_2 with variation of pressure	50
Figure 4.24	Mole fraction of O_2 with variation of pressure	51
Figure 4.25	Mole fraction of CO with variation of pressure	52
Figure 4.26	Mole fraction of H_2 with variation of pressure	53
Figure 4.27	Mole fraction of H with variation of pressure	54
Figure 4.28	Mole fraction of O with variation of pressure	55
Figure 4.29	Mole fraction of OH with variation of pressure	56
Figure 4.30	Mole fraction of NO with variation of pressure	57
Figure 4.31	Number of moles vs equivalence ratio	59
Figure 4.32	Number of moles vs temperature	60
Figure 4.33	Number of moles vs pressure	60

LIST OF ABBREVIATIONS

PM	-	Particulate Matter
KOH	-	Potassium Hydroxide
SO_2	-	Sulphur Dioxide
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
NO_2	-	Nitrogen Oxide
N_2	-	Nitrogen gas
OH	-	Hydroxide
H_2O	-	Water
O_2	-	Oxygen
GHG	-	Greenhouse Gas
FAME	-	Fatty Acid Methyl Ester
CI	-	Compression Ignition
FFA	-	Free Fatty Acid
GCFID	-	Gas Chromatography-Flame Ionisation Detector
GCMS	-	Gas Chromatography-Mass Spectroscopy Detector
ASTM	-	American Society for Testing and Materials
EN	-	European Union

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A1	MATLAB coding for the mole fraction of every combustion product with variation of equivalence ratio.	65
A2	MATLAB coding for the mole fraction of every combustion product with variation of temperature.	66
A3	MATLAB coding for the mole fraction of every combustion product with variation of pressure	67

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, people are really taking care the importance of the used of energy and technology that are not harmful to the environment. There is some renewable energy that has been identified as a good resource that can replaced the old source that has been used for a long time. Biodiesel can be said as the alternative fuel that can be used to replace the used of the diesel that are not eco-friendly to this world. Biodiesel can be made by some methods of production, and it will be discussed and explained briefly in the next chapter. The process to make this biodiesel is also quite expensive for some methods because of their operating costs and the processing time that are longer. Those method are known as biocatalyst and supercritical fluid processes and this method has rarely been used in the industrial. The other factor is because of the enzymes use has higher cost besides it also has slow rate of reaction. The developments of the catalysts in the biodiesel production are still investigated by the researcher around the world.

In the transportation sector, diesel is the most used as the source of energy and this scenario has led to the pollution of air and water. Thus, the researchers are now focused on to how to make a biodiesel fuel that are appropriate to the engine that are used in the most automobiles. A various resource of feedstock which has edible or non-edible along the methyl esters are investigated in order to find the most suitable for biodiesel fuel. There are some advantages of using biodiesel instead of other types of petroleum that has been researched such as it has better lubricity, has low sulphur content and it also a biodegradable which helps in improve the aquatic ecosystem. Biodiesel also helps to clean the engine of

the automobiles and it can reduce the greenhouse gas (GHG) emission. The most important thing if we want a biodiesel to be widely used is every country need to have their own biodiesel production in their industrial and make sure every resource is sufficient to be used in a long term or else these alternative fuels cannot be used in future.

The combustion process in the engine will be much early when biodiesel is used as the major source of energy because it has higher number of cetane number. Biodiesel can be compared with diesel that are now has been widely used in term of the cetane number and it can reduce the ignition delay period and it will make the pressure inside the cylinder engine higher.

Most of the article that has been used as references are discussing more about the biodiesel and the effects of using biodiesel in the compression ignition engine. Due to the difficulties involved in the experiment that are conducted by the researcher, they are also used a predictions and suggestions methods although it is not preferred but it is also helps to give a better data and results of their researched. Most of the analysis of the project are using a software such as Microsoft Excel and MATLAB and more data can be obtained by using different input to get various results to be compared with each other. MATLAB program also assist in giving the graphs that are needed for this research and from the graph, the difference of mole fractions of the substances or components with variation of equivalence ratio will be seen.

1.2 Problem Statement

People nowadays are preferred to used automobiles in their daily life as it can make their daily affairs becomes easier and there are about 550 million of automobiles used by people around the world and this scenario will be continuously used from time to time. This scenario has led to some others major problems where the source of energy in this world are decrease and it also has led to the environmental pollution like air and water pollution. All the professional person around the world that has related to this problem are now think to reduce the greenhouse gas emission and proactive steps have to be taken so that it can be stopped before it is too late to handle the problems. The other solution that can help to reduce the problems is by finding a new source of energy that is cleaner and does not give any pollution to the environment.

Most of the researcher around the world are now preferred to used biodiesel as the new source of energy to replaced old diesel fuel that has been proved are not eco-friendly to this world. This biodiesel fuel is actually has been used nowadays and there are some advantages that can obtained by using this fuel such as it helps to increase the water quality and the aquatic ecosystem. All the source that are used to make biodiesel such as corn oil, palm oil and rapeseed oil has been proved that all of it can give a high biodegradation rate in the water ecosystem. The biodegradation level also can be increased through the co-metabolism with the presence of biodiesel. There is also a researcher that do an experiment and it showed the primary molecules in the biodiesel which is the fatty acid methyl ester has been degraded so much faster than the diesel in a sea water.

1.3 Objective

There are some objectives that has been targeted for this project like:

1. To solve all the equation from the chemical equation of biodiesel by using mathematical modelling method assist by MATLAB program.
2. To study the other alternative of renewable fuel that can be used in the future.
3. To illustrate the engine performance, fuel properties and the emission characteristics of biodiesel fuel at different conditions.
4. To study the number of moles of every combustion product at variation of equivalence ratio, temperature and pressure.
5. To analyse the emission of the combustion products that cause the environmental pollution of the air.

1.4 Scope of the Project

The scope of the project that will be discussed are:

1. This research has been specific to use the biodiesel as a main substance that is used in the compression ignition engine.
2. This research is only required to solve the unknown in the chemical equation based on the substances in the biodiesel product.
3. All the calculation can be calculated manually by using every step that needed in a curtain formula that is used to solve the unknown.
4. MATLAB program is another platform that can be used to solve all the calculation and some graph can be obtained from it that may be help in the research purpose.

1.5 General Methodology

For this semester, there are some methods that are chosen to be used and the other will be continued on the next semester. To accomplish the objective of this project, the actions are listed below.

1. Literature review

   There is about 50 journals and articles that have been used as the guidelines and references in order to complete these researched. Most of the articles were discussed related to the title of the project.

2. Calculation

   All the governing equations need to be calculated by following all the steps in the article or any other references. There will be some other formula that needed to solve the equation like Newton Raphson method.

3. Simulation

   Simulation of the compression ignition engine will be made based on the chemical equation of biodiesel components and products.

4. Analysis and proposed solution

   Analysis will be presented on how the effect of equivalence ratio in emission characteristic of compression ignition engine with biodiesel fuel. Solutions will be proposed based on the data that has been collected and analysed.

5. Report writing

   A full report will be written and all the calculation and data that has been achieved will be discussed briefly in this report.

CHAPTER 2

LITERATURE REVIEW

2.1 What is biodiesel

As previously stated, biodiesel can be defined as alkyl fatty acid esters such as ethyl fatty acid esters, methyl ester of fatty acid esters, and propyl esters of fatty acid esters that can be obtained through the reactions of the transesterification process of animal fats or plant oils using short chain fatty acids such as methanol and ethanol. The use of alternate solution or renewable fuels can play a significant role in lowering fossil fuel usage and, thus, in reducing carbon dioxide emissions.

An example of a renewable element that may be added to gasoline and result in a reduction in fossil fuel usage is ethanol, which is created from biomass from food crops that is commonly thrown away. Similarities exist for compression ignition engines, where fatty acid methyl ester, also known as FAME, is created from vegetable oil, generally generated from seeds, and has been added to diesel fuel for a long period of time to prolong the life of crude oil-derived fuels. Because it offers engine efficiency that is equivalent to regular diesel, biodiesel is expected to be employed in diesel engines in the future. When utilised in conjunction with diesel, biodiesel may be utilised in both blended and pure form.

In addition to its non-explosive, non-flammable, non-toxic, and recyclable qualities, biodiesel also has the ability to reduce a variety of harmful exhaust emissions. With no sulphur oxide pollutants, no particle or soot emissions are produced, and heavy hydrocarbons emissions can be reduced. However, there are some downsides to using biodiesel, such as the fact that it can enhance nitrogen oxide emissions, has poor low temperature flow

qualities, and is subject to more stringent environmental laws when compared to traditional diesel fuel (Rashedul et al., 2014). Because it includes double bond bonds in the free fatty acid, biodiesel fuel has a low chemical stability, which is another drawback of the fuel.

With the presence of bio-based fuels, there is an additional hurdle in the usage of these fuels, for which a variety of additives can bring significant advantages. All of the aspects, including the reduction of the possibility for enhanced injector deposit development, oxidation stability, bad influence on cold flow characteristics, corrosion during long-term storage, and enhanced microbiological contamination, are taken into account. This is an example of where additives serve a valuable and extremely expensive function in reducing the likelihood of operating difficulties and achieving fuel specification standards, which can be difficult or impossible to do without the use of additives.

Additional chemicals should be used to enhance the characteristics of fuel, which are then mixed with fuel such as biodiesel, diesel, aviation oil, natural gas as well as other fuels to optimize the effectiveness of the fuel and the economy as a whole. Additives are used to promote the properties of fuel and are used in a variety of fuels, including biodiesel and diesel. In addition, additives increase the fuel's ability to fulfil environmental pollution control standards as well as the performance of the vehicle's engine. The economic feasibility, blending property, toxicity, additive solubility, viscosity of the fuel blend, solubility of water in the blend, flash point of the fuel blend, and water partitioning of the addition are all factors to consider when selecting additives for biodiesel fuel on gasoline. The usage of biodiesel in the modern world has provided us with a promising option. Not only does it have the potential to minimise reliance on traditional diesel fuel, but it is also a clean energy source that may be utilised for an extended length of time if handled properly.

2.2 The production of biodiesel

There are many various manufacturing procedures used in the production of biodiesel as CI diesel engines across the world today, and each one should be recognized and made accessible to those who are just starting out in their careers in the industry (Datta & Mandal, 2016). Each country's raw resources requirements differ from one another in a manufacturing environment. Researchers are working hard to develop new ways to make biodiesel from a variety of feedstock, including vegetable oil (neither edible nor non-edible), excess cooking oil, animal tallow, and algae, among other things.

There is much increased in number of viscosities in the oils and fats that have been formed from the material that has been acquired, and they are thus unsuitable for use in conventional CI engines. In order to lower the viscosity number, the first and most crucial step is to use a chemical process known as transesterification to accomplish this. During this reaction, the triglyceride contained in the oil or fat combines with an alcohol like as methanol and ethanol, while also there are the catalysts that is alkaline in nature is available to accelerate the reaction. This method requires the use of a catalyst, such as sodium or potassium hydroxide, as the examples. Glycerol, commonly known as glycerin, is formed as a byproduct of the production of other substances. The equation below depicts the total response of the transesterification reaction.

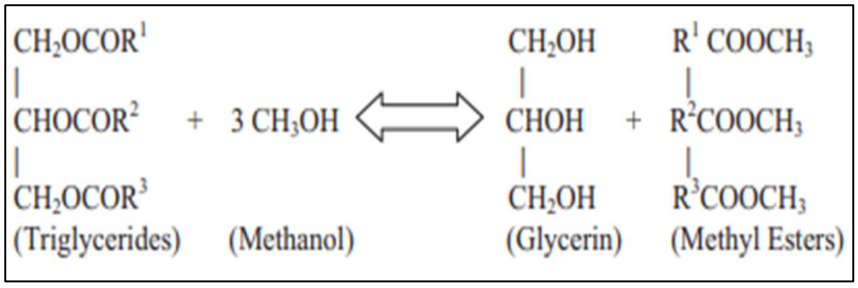

Figure 2.3 Transesterification Process