CHARACTERISTIC OF PALM OIL METHYL ESTER AS ALTERNATIVE FUEL

MUHAMMAD RIZUAN BIN MUSA

BACHELOR OF ENGINEERING
UNIVERSITI MALAYSIA PAHANG

2010

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **CHARACTERISTIC OF PALM OIL METHYL ESTER AS ALTERNATIVE FUEL**

SESI PENGAJIAN: 2010/2011

Saya **MUHAMMAD RIZUAN BIN MUSA (870203-23-6005)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda/~~Sarjana~~ /~~Doktor Falsafah~~)* ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:

NO. 6709, JALAN NURI 26,
BANDAR PUTRA,
81000 KULAI,
JOHOR

DR. RIZALMAN BIN MAMAT
(Nama Penyelia)

Tarikh: **6 DISEMBER 2010**

Tarikh: : **6 DISEMBER 2010**

CATATAN:
* Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai atau TERHAD.
♦ Tesis dimaksudkan sebagai tesis bagi Ijazah doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

CHARACTERISTIC OF PALM OIL METHYL ESTER AS ALTERNATIVE FUEL

MUHAMMAD RIZUAN BIN MUSA

Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “*Characteristic Of Palm Oil Methyl Ester As Alternative Fuel*“ is written by *Muhammad Rizuan Bin Musa*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive.

(AHMAD BASIRUL SUBHA BIN ALIAS)
Examiner   Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive.

Signature

Name of Supervisor : DR. RIZALMAN BIN MAMAT

Position : LECTURER

Date : 6 DECEMBER 2010

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature

Name : MUHAMMAD RIZUAN BIN MUSA

ID Number : MH07047

Date : 6 DECEMBER 2010

IN THE NAME OF ALLAH, THE MOST BENEFICENT, THE MOST MERCIFUL

A special dedication of This Grateful Feeling to My…

Beloved parents, Musa B Yacob and Siti Hamdanah Bt Hj Ahmad for giving me full of moral support and financial support. It is very meaningful to me in order to finish up my degree's study. Do not forget also to my loving sister, brother and my two little brothers, and also to my beloved one. Lastly to all my lovely friends.

Thanks for giving me Love, Support and Best Wishes.

ACKNOWLEDGEMENT

I want to express my sincere appreciation to my supervisor, Dr Rizalman Bin Mamat for his germinal ideas, invaluable guidance, continuous encouragement and constant support in completing this thesis. Without his guidance, I would not be able to finish this thesis completely. I also would like to express very special thanks to Mr. Mohd Idzwanrosli Bin Mohd Ramli, Instructor Engineer for his suggestions and co-operation throughout the study. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways during this thesis writing. I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. Without your support I feel that there is no inspiration for me to keep moving in my journey of life. I am also indebted to all my friends and anyone who helped me during my completion of this thesis.

ABSTRACT

The purpose of this work is to define the relationship between the fuel physical properties and the atomization characteristic of biodiesel. The spray atomization behavior was analyzed through spray parameters such as the spray tip penetration, cone angle and droplet size. Besides that, the specific heat capacity, viscosity, specific heat profile and liquid property profile is determined to define the characteristic of palm oil and also to prepare the database of palm oil. These parameters were obtained from an injector tester system and accurate prediction of spray atomization. In addition, the experimental results of biodiesel were compared with the diesel and cooking oil. It was revealed that the increase of the pressure supply (from 100 bar to 400 bar) little affects the spray liquid tip penetration. The increase of the pressure supply also increases the complete combustion. Also, biodiesel fuel evaporation actively occurred due to the increase in the pressure supply. Besides that, palm oil methyl ester possesses a high boiling point compare to diesel and this has showed that the fuel chemical structure and critical properties significantly influences the fuel properties.

ABSTRAK

Tujuan laporan ini adalah untuk menentukan hubungan antara sifat fizikal bahan bakar dan ciri-ciri atomisasi biodiesel. Perilaku semburan atomisasi dianalisis melalui parameter spray seperti penetrasi hujung semburan, sudut kon dan saiz titisan. Selain itu, kapasiti panas khusus, kelikatan, panas khusus profil dan profil hotel cair bertekad untuk menentukan ciri-ciri minyak sawit dan juga untuk menyediakan pangkalan data kelapa sawit. Parameter ini boleh diperolehi dari sistem pengujian penyuntikan dan ramalan yang tepat dari semburan atominasi. Selain itu, keputusan eksperimen antara biodiesel telah dibandingkan dengan diesel dan minyak masak. Terbukti bahawa peningkatan tekanan yang diberikan (dari 100 bar sehingga 400 bar) sedikit mempengaruhi tembusan hujung semburan cair. Kenaikan kadar tekanan juga meningkatkan pembakaran yang sempurna. Juga, pengewapan bahan bakar biodiesel aktif berlaku kerana peningkatan kadar tekanan. Selain itu, kelapa sawit metil ester mempunyai takat didih yang tinggi berbanding dengan diesel dan hal ini menunjukkan bahawa struktur kimia bahan bakar dan sifat kritikal nyata sekali mempengaruhi sifat bahan bakar.

TABLE OF CONTENTS

		Page
SUPERVISOR'S DECLARATION		iii
STUDENT'S DECLARATION		iv
SPECIAL DEDICATION		v
ACKNOWLEDGEMENT		vi
ABSTRACT		vii
ABSTRAK		viii
TABLE OF CONTENTS		xi
LIST OF TABLES		xii
LIST OF FIGURES		xiii
LIST OF ABBREVIATIONS		xiv
CHAPTER 1	**INTRODUCTION**	
	1.1 Project Background	1
	1.2 Problem Statement	2
	1.3 Scope of Study	2
	1.4 Objectives of the Project	3
CHAPTER 2	**LITERRATURE REVIEW**	
	2.1 Biodiesel	4
	2.1.1 Introduction To Biodiesel Concept	4
	2.1.2 History of Biodiesel	6
	2.1.3 Definition Of Biodiesel	8
	2.1.4 Biodiesel As An Alternative To Diesel Fuel Engine	9
	2.1.5 Advantages And Disadvantages Of Biodiesel	11
	2.1.6 Transesterification Process	12
	2.2 Fuel Properties Of Biodiesel	13

2.2.1 Critical Properties 13

2.2.2 Viscosity, Density And Flash Point 15

2.3 Fatty Acid Methyl Ester Chemical Structure 16

2.4 Palm Oil Diesel 17

2.5 Palm Oil A Cost Effective Product 19

2.6 Palm Oil In Malaysia 20

CHAPTER 3 METHODOLOGY

3.1 Introduction 23

3.2 Project Flow Chart 24

3.3 Design Of Project Study 25

3.4 Method In Gathering Information 25

3.5 Project Method 26

3.5.1 Research Methodology 27

3.6 Advantages Of The Research 27

3.7 Measuring Equipment 28

3.8 Injector Tester Equipment 29

3.9 Fuel Injector Tester Flow 32

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction 33

4.2 Spray Pattern For Palm Oil Methyl Ester 34

4.2.1 Spray Pattern At 100 Bar Pressure for POME 34

4.2.2 Spray Pattern At 200 Bar Pressure for POME 36

4.2.3 Spray Pattern At 300 Bar Pressure for POME 37

4.2.4 Spray Pattern At 400 Bar Pressure for POME 38

4.3 Spray Pattern For Diesel 39

4.3.1 Spray Pattern At 100 Bar Pressure for Diesel 39

4.3.2 Spray Pattern At 200 Bar Pressure for Diesel 41

4.3.3 Spray Pattern At 300 Bar Pressure for Diesel 42

4.3.4 Spray Pattern At 400 Bar Pressure for Diesel 43

4.4 Spray Pattern For Cooking Oil 44

		4.4.1 Spray Pattern At 300 Bar Pressure for Cooking Oil	44
		4.4.2 Spray Pattern At 400 Bar Pressure for Cooking Oil	45
	4.5	Comparison POME, Diesel And Cooking Oil	46
	4.6	Biodiesel Properties	46
		4.6.1 Vapour Pressure	46
		4.6.2 Viscosity	48
		4.6.3 Specific Heat Capacity	49
		4.6.4 Surface Tension	50
	4.7	Summary	51
CHAPTER 5	**CONCLUSSION AND RECOMMENDATIONS**		
	5.1	Conclusion	52
	5.2	Recommendations	53
REFERENCES			54
APPENDICES			
A1	Gantt Chart of FYP1		56
A2	Gantt Chart of FYP2		57
B1	Calculation of Vapour Pressure		58
B2	Calculation of Viscosity		59
B3	Calculation of Specific Heat Capacity		60
B4	Calculation of Surface Tension		61

LIST OF TABLES

Table No	Title	Page
2.1	Technical properties of biodiesel	9
2.2	Some fuel properties of six methyl ester biodiesel	15
2.3	Viscosity, density and flash point measurements of nine oil methyl esters	16
2.4	Chemical structure of fatty acid	16
2.5	Standardization of biodiesel	19
2.6	2006 World Oil Palm productions	22
4.1	Fuel comparison	46
4.2	Antoine equation constants of POME	47

LIST OF FIGURES

Figure No.	Title	Page
3.1	Project flow chart	24
3.2	Bomb calorimeter	28
3.3	Pressure gauge for controlling pressure of injector	29
3.4	Cylinder piston of injector tester	30
3.5	Injector of ISUZU 4x4 to produce spray pattern	30
3.6	Injector tester to define the spray pattern	31
3.7	Schematic diagram of fuel injector tester	32
4.1	Spray pattern at given 100 bar pressure of POME	35
4.2	Spray pattern at given 200 bar pressure of POME	36
4.3	Spray pattern at given 300 bar pressure of POME	37
4.4	Spray pattern at given 400 bar pressure of POME	38
4.5	Spray pattern at given 100 bar pressure of diesel	40
4.6	Spray pattern at given 200 bar pressure of diesel	41
4.7	Spray pattern at given 300 bar pressure of diesel	42
4.8	Spray pattern at given 400 bar pressure of diesel	43
4.9	Spray pattern at given 300 bar pressure of cooking oil	44
4.10	Spray pattern at given 400 bar pressure of cooking oil	45
4.11	Vapour pressure of POME	48
4.12	Viscosity of POME	49
4.13	Specific heat capacity of POME	50
4.14	Surface tension of POME	51

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
B80	80% biodiesel and 20% petrodiesel
EC	European Community
FAME	Fatty acid methyl esters
HHVs	Higher heating values
LPG	Liquefied petroleum Gas
MPOB	Malaysia Palm Oil Board
NG	Natural gas
POME	Palm Oil Methyl Ester
PORIM	Palm Oil Research Institute of Malaysia
SMD	Sauter Mean Diameter

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

If the agricultural products market is limited and much of agricultural land is not utilized as is the case in many countries in the world at present, then agriculture should be directed to the production of new alternative products. The land can be used to produce non-food products including biodiesels for the domestic energy market to diminish imports. Much research has been done on biodiesels over the last 20 year after the oil crisis in 1973. At present, concern about environmental regulations has been the major reason to look for alternative fuel. A property of biodiesel has been obtained but there is a lack of full or partial replacement of fossil fuel that needs to be discussed (M.A. Kalam, 2002).

This research is presents the results of the experimental of the characteristic of palm oil methyl ester as an alternative fuel. This biodiesel is defined as the methyl ester of palm oil also known as palm oil diesel. The results of this investigation will be used to find compatible lubricant for biodiesel engine.

Palm oil is one of the most popular fuels in this world. Palm oil can produced the variety of product and is widely use as cooking oil. Palm oil like other vegetable oils can be used to create biodiesel for internal combustion engines. Biodiesel has been promoted as renewable energy source to reduce net emissions of carbon dioxide into atmosphere. Therefore, biodiesel is seen as a way to decrease the impact of the greenhouse effect and as a way of diversifying energy supplies to assist national energy security plans.

Methyl esters derived from vegetable oil (biodiesel) have good potential as an alternative diesel fuel. The cetane number, energy content, viscosity, and phase changes of biodiesel are similar to those of petroleum based diesel fuel (D. Darnoko, 2000). Biodiesel is produced by transesterification of large, branched triglycerides (TG) into smaller, straight chain molecules of methyl esters, using an alkali or acid as catalyst (Munir Cheryan, 2000).

In 1983, the Palm Oil Research Institute of Malaysia (PORIM) successfully converted crude palm oil to palm oil methyl ester (POME) through transesterification. The transesterification shortens the molecular chain from about 57 to about 20, reducing the viscosity and improving the thermal stability. The sulphur content in POME is very low (1.112 wt %), making it less pollutant and more environmentally friendly. However, the cetane number of this POME is relatively low (50-52) compared with ordinary diesel (53) (H.H. Masjuki, 1996).

1.2 PROBLEM STATEMENT

Fuel physical properties and the atomization characteristic of biodiesel are attributes that requires thorough scrutiny in order to be determined. Discreet observation is required to obtain the specific heat profile, specific heat capacity value and liquid property profile in order to define the properties of biodiesel. On the other hand, predicting the physical properties of the vegetables oils and biofuels is crucial in the accurate prediction of the spray atomization.

1.3 SCOPES OF STUDY

The scope of study in this research can be obtained as:

- Collect all characteristics information from the literature.
- Characteristics testing of biodiesel fuel.
- Define and predict the properties of biodiesel.

1.4 OBJECTIVES OF THE PROJECT

The objectives of this research are:

- To determine the spray pattern characteristics of palm oil.
- To prepare a major database of palm oil against other biodiesel sources.
- To investigate fuel spray pattern in order to obtain the cone angle, spray tip penetration and droplet size.

CHAPTER 2

LITREATURE RIVIEW

2.1 BIODIESEL

2.1.1 Introduction to Biodiesel Concept

The scarcity of conventional fossil fuels, growing emissions of combustion generated pollutants and their increasing costs will make biomass sources more attractive (Sensoz, 2000). On the other hand, biomass use in which many people already have an interest has properties of being a biomass source and a carbon-neutral source (Dowaki, 2007). Experts suggest that current oil and gas reserves would suffice to last only a few more decades. To meet the rising energy demand and replace reducing petroleum reserves, fuels such as biodiesel and bioethanol are in the forefront of alternative technologies. Accordingly, the viable alternative for compression-ignition engines is biodiesel.

Biodiesel is briefly defined as the monoalkyl esters of vegetable oils or animal fats. Biodiesel is the best candidate for diesel fuels in diesel engines. Biodiesel burn like petroleum diesel as it involves regulated pollutants. On the other hand, biodiesel probably has better efficiency than gasoline. Biodiesel also exhibits great potential for compression-ignition engines. Diesel fuel can also be replaced by biodiesel made from vegetable oils. Biodiesel is now mainly being produced from soybean, rapeseed and palm oils. The higher heating values (HHVs) of biodiesel are relatively high. The HHVs of biodiesel (39 to 41 MJ/kg) are slightly lower than those of gasoline (46 MJ/kg), petrodiesel (43 MJ/kg), or petroleum (42 MJ/kg), but higher than coal (32 to 37 MJ/kg).

Biodiesel is pure or 100%, biodiesel fuel. It is referred to as B100 or “neat” fuel. A biodiesel blend is pure biodiesel blended with petrodiesel. Biodiesel blends are referred to as BXX. The XX indicates the amount of biodiesel in the blend (*i.e.*, a B80 blend is 80% biodiesel and 20% petrodiesel).

The majority of energy demand is fulfilled by conventional energy sources like coal, petroleum, and natural gas. Petroleum-based fuels are limited reserves concentrated in certain regions of the world. These sources are on the verge of reaching their peak production. The scarcity of known petroleum reserves will make renewable energy sources more attractive (Sheehan, 1998).

World energy demand continues to rise. The most feasible way to meet this growing demand is by using alternative fuels. One such fuels that exhibits great potential is biofuel, in particular biodiesel (Fernando, 2006). The term biofuel can refer to liquid or gaseous fuels for the transport sector that are predominantly produced from biomass (Demirbass, 2006). In developed countries there is a growing trend towards using modern technologies and efficient bioenergy conversion using a range of biofuels, which are becoming cost wise competitive with fossil fuels (Puhan, 2005).

It is well known that transportation is almost totally dependent on fossil, particularly petroleum based fuels such as gasoline, diesel fuel, liquefied petroleum gas (LPG), and natural gas (NG). An alternative fuel to petrodiesel must be technically feasible, economically competitive, environmentally acceptable, and easily available. The current alternative diesel fuel can be termed biodiesel. Biodiesel use may improve emissions levels of some pollutants and deteriorate others. However, for quantifying the effect of biodiesel it is important to take into account several other factors such as raw material, driving cycle and vehicle technology. Use of biodiesel will allow a balance to be sought between agriculture, economic development, and the environment (Meher, 2006).

2.1.2 History of Biodiesel

The process for making fuel from biomass feedstock used in the 1800s is basically the same one used today. The history of biodiesel is more political and economical than technological. The early 20^{th} saw the introduction of gasoline powered automobiles. Oil companies were obliged to refine so much crude oil to supply gasoline that they were left with a surplus of distillate, which is an excellent fuel for diesel engines and much less expensive than vegetable oils. On the other hand, resource depletion has always been a concern with regard to petroleum and farmers have always sought new markets for their products. Consequently, work has continued on the use of vegetable oils as fuel.

Producing biodiesel from vegetable oils is not a new process. The conversion of vegetable oils or animal fats into monoalkyl esters or biodiesel is known as transesterification. Transesterification of triglycerides in oils is not a new process. Duffy and Patrick conducted Transesterification as early as 1853. Life for the diesel engine begins in 1893, when the famous German inventor Dr. Rudolph Diesel published a paper entitled “The theory and construction of a rotational heat engine”. The paper described a revolutionary engine which air would be compressed by a piston to a very high pressure, thereby causing a high temperature. Dr. Diesel designed the original diesel to run on vegetable oil.

Dr. Diesel was educated at the predecessor school to the Technical University of Munich in Germany. In 1878, he was introduced to the work of Sadi Carnot, who theorized that an engine could achieve much higher efficiency than the steam engines of the day. Diesel sought to apply Carnot’s theory to the internal combustion engine. The efficiency of the Carnot cycle increases with the compression ratio-the ratio of gas volume at full expansion to its volume at full compression. Nicklaus Otto invented an internal combustion engine in 1876 that was the predecessor to the modern gasoline engine. Otto’s engine mixed fuel and air before their introduction to the cylinder and a flame or spark was used to ignite the fuel air mixture at the appropriate time. However, air gets hotter as it is compressed and if the compression ratio is too high, the heat of compression will ignite the fuel prematurely. The low compression needed to prevent premature ignition of the fuel air mixture limited the efficiency of the Otto engine. Dr. Diesel wanted to build an engine with the highest possible compression ratio. He introduced fuel only when combustion was desired and allowed the fuel to ignite on its own in the hot compressed air. Diesel’s engine achieved efficiency higher than that of the steam engine. Diesel received a patent in 1893 and demonstrated a workable engine in 1897. Today, diesel engines are classified as “compression-ignition” engines, and Otto engines are classified as “spark-ignition” engines.

Dr. Diesel used peanut oil to fuel one of his engines at the Paris Exposition of 1900 (Nitschkae and Wilson, 1965). Because of the high temperature created, the engine was able to run a variety of vegetable oils including hemp and peanut oil. At the 1911 World’s Fair in Paris, Dr. Diesel ran his engine on peanut oil and declared “the diesel engine can be fed with the vegetable oils and will help considerably in the development of the agriculture of the countries with use it”. One of the first uses of transesterified vegetable oil was powering heavy duty vehicles in South Africa before World War II. The name “biodiesel” has been given to transesterified vegetable oil to describe its use as a diesel fuel (Demirbas, 2002). Vegetable oils were used in diesel engines until the 1920s. During the 1920s, diesel engine manufactures altered their engines to utilize the lower viscosity of petrodiesel, rather than vegetable oil.

The use of vegetable oils as an alternative renewable fuel competing with petroleum was proposed in the early 1980s. The advantages of vegetable oils as diesel fuel are its portability, ready availability, renewability, higher heat content (about 88% of No. 2 petroleum diesel fuel), lower sulphur content, lower aromatic content and biodegradability. The energy supply concerns of the 1970s renewed interest in biodiesel but commercial production did not begin until the late 1990s.

Dr. Diesel believed that the engines running on plant oils had potential and that these oils could one day be as important as petroleum based fuels. Since the 1980s, biodiesel plants have opened in many European countries and some time cities have run buses on biodiesel or blends of petro and biodiesels. Most recently, Renault and Peugeot have approved the use of biodiesel in some of their truck engines. Recent environmental and domestic economic concerns have prompted resurgence in the use of biodiesel throughout the world. In 1991, the European Community (EC) proposed a 90% tax deduction for the use of biofuels, including biodiesel. Biodiesel plants are now being built by several companies in Europe; each of these plants will produce up to 1.5 million gallons of fuel per year. The European Union accounted for nearly 89% of all biodiesel production worldwide in 2005.

2.1.3 Definition of Biodiesel

Biodiesel refers to a diesel-equivalent, processed fuel derived from biological sources. Biodiesel is the name for variety of ester-based oxygenated fuels from renewable biological sources. It can be made from processed organic oils and fats.

Chemically, biodiesel is defined as the monoalkyl esters of long-chain fatty acids derived from renewable biolipids. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol or ethanol in the presence of a catalyst to yield methyl or ethyl esters (biodiesel) and glycerine (Demirbas, 2002). Fatty acid methyl esters or biodiesels are produced from natural oils and fats. Generally, methanol is preferred for transesterification because it is less expensive than ethanol (Graboski and McCormick, 1998).

In general term, biodiesel may be defined as a domestic and renewable fuel for diesel engines derived from vegetable oil which meets the specification of ASTM D 6751 (Fukuda, 2001). Biodiesel consists of alkyl esters, which are produced from the transesterification reaction between triglycerides and alcohol. In experimental studies, the final product is term as fatty acid alkyl esters or fatty acid methyl esters (FAME) instead of biodiesel unless it meets the specification of ASTM D6751 (Lois, 2007). Biodiesel, in application as an extender for combustion in CIEs (diesel), possesses a number of promising characteristics, including reduction of exhaust emissions (Dunn, 2001). Chemically, biodiesel is referred to as the monoalkyl esters, especially methyl ester of long chain fatty acids derived from renewable lipid sources via a transesterification process.

Table 2.1: Technical properties of biodiesel

Technical properties	Description
Common name	Biodiesel (bio-diesel)
Common chemical name	Fatty acid (m)ethyl ester
Chemical formula range	C_{14} – C_{24} methyl ester or C_{15} – C_{25} H_{28-48} O_2
Kinematic viscosity range (mm^2/s, at 313K)	3.3 – 5.2
Density range (kg/m^3, at 288K)	860 – 894
Boiling point range (K)	>475
Flash point range (K)	430 – 455
Distillation range (K)	470 – 600
Vapour pressure (mm Hg, at 295K)	<5
Solubility in water	Insoluble in water
Physical appearance	Light to dark yellow, clear liquid
Odor	Light musty or soapy odor
Biodegradability	More biodegradable than petroleum diesel
Reactivity	Stable but avoid strong oxidation agents

Source: Demirbas (2003)

Biodiesel is mixture of methyl esters of long-chain fatty acids like lauric, palmitic, stearic, oleic, *etc.* Typically examples are rapeseed oil, canola oil, soybean oil, sunflower oil, palm oil and their derivatives from vegetable sources. Beef and sheep tallow and poultry oil from animal sources and cooking oil are also sources of raw materials. The chemistry of conversion into biodiesel is essentially the same. Oil or fat reacts with methanol or ethanol in the presence of sodium hydroxide or potassium hydroxide catalyst to form biodiesel, methyl esters and glycerine.

2.1.4 Biodiesel As An Alternative to Diesel Fuel Engine

Biodiesel is a processed fuel that can be readily use in diesel-engine vehicles, which distinguishes biodiesel from the straight vegetable oils or waste vegetable oils used as fuels in some modified diesel vehicles. In general, the physical and chemical properties and the performance of ethyl esters are comparable to those of the methyl esters. Methyl and ethyl esters have almost the same heat content. The viscosities of ethyl esters are slightly higher and the cloud and pour points are slightly lower than those of the methyl esters. Engine test have demonstrated that methyl esters produce slightly higher power and torque than ethyl esters.

Biodiesel is a clear amber-yellow liquid with a viscosity similar to that of petrodiesel. Biodiesel is non-flammable and in contrast to petrodiesel is non-explosive, with a flash point of 423K for biodiesel as compared to 337K for petrodiesel. Unlike petrodiesel, biodiesel is biodegradable and non-toxic and it significantly reduces toxic and other emissions when burned as a fuel. Currently, biodiesel is more expensive to produce than petrodiesel, which appears to be the primary factor in preventing its more widespread use. Current worldwide production of vegetable oil and animal fat is not enough to replace liquid fossil fuel use (maximum replacement percentage: 20% to 25%) (Bala, 2005).

Methyl esters of vegetable oils (biodiesels) have several outstanding advantages among other new-renewable and clean-engine fuel alternatives. Methanol as a monoalcohol is generally used in the transesterification reaction of triglycerides in the presence of alkali as a catalyst (Clark, 1984). Methanol is a relatively inexpensive alcohol. Several common vegetable oils such as sunflower, palm, rapeseed, soybean, cottonseed and corn oils and their fatty acids can be used as the sample of vegetable oil. Biodiesel is easier to produce and cleaner with equivalent amount of processing when starting with clean vegetable oil. Tallow, lard and yellow grease biodiesels require additional processing at the end of the transesterification process due to the presence of high free fatty acids. Diesel derived from rapeseed oil is the most common biodiesel available in Europe while soybean biodiesel predominates in the United States.

Biodiesel has significant potential for use as an alternative fuel in compression-ignition engines (Demirbas, 2003). Biofuels are non-toxic, biodegrable and free of sulphur and carcinogenic compound (Venkataraman, 2002) as they are obtained from renewable sources. Biodiesel is a plant-derived product and contains oxygen in its molecules, making it a cleaner-burning fuel than petrol and diesel (Sastry, 2006).

Biodiesel is a clean burning alternative fuel produced from domestic, renewable resources that are much more efficient to produce and use than gasoline. The development history of biodiesel is more political than technological. The actual process for making biodiesel was originally developed in the early 1800s and has basically remained unchanged. It was the political and economic influences of industrial leaders during the 1920s and 1930s that caused the fuel trends to favour the use of petroleum-based fuels as opposed to agricultural fuels.

2.1.5 Advantages And Disadvantages of Biodiesel

Biodiesel is a sustainable energy (Hanna, 1999) that is made from renewable sources such as vegetable oils and animal fats. These sources could always be re-planted or grown to ensure its sustainability. Besides that, biodiesel is a non-toxic and clean energy (Omer, 2008). The emissions from vehicles that are using biodiesel contain lower harmful gases such as carbon monoxide, sulfur dioxide (Demirbas, 2007) and aromatic content (Hanna, 1999) compared to that of using petroleum derived diesel. Biodiesel could also reduce the emission of particulate matters (PM).

Biodiesel also acts as a good lubricant to diesel engines. This could therefore prologue the self-life of the engines. Biodiesel also has higher flash point which makes it safer to handle compared diesel (Jamal, 2008). Other advantages of biodiesel as diesel fuel are liquid nature portability, readily available, renewability, higher combustion efficiency (Agarwal, 2008), higher cetane number (Knothe, 2003) and higher biodegradability.

On the other hand, disadvantages of biodiesel include increased emission of NO_x gas, higher cloud and pour points (Hanna, 1999) and also costlier compared to diesel due to high price of vegetable oils especially those of edible type. However, the cost of biodoesel could vary depending on the source of feedstock (Demirbas, 2008). Biodiesel could also dissolve certain parts of the diesel engines, especially those made of elastomers (Flitney, 2007). Nevertheless the advantages of biodiesel superseded the disadvantages generally on the environmental aspects, making it very popular alternative to petroleum derived-diesel oil.

2.1.6 Transesterification Process

Biodiesel is mainly produced from a chemical process known as transesterification. Transesterification, also known as alcoholysis is the displacement of alcohol group from an ester by another alcohol in a process similar to hydrolysis, except that an alcohol is employed instead of water (Fukuda, 2001). The transesterification process consists of three subsequent reversible reactions where the first reaction occurs between triglycerides and alcohol to produce diglycerides and an ester (Sharma, 2008). The second reaction continues with diglycerides (from the first reaction) reacting with alcohol to produce monoglycerides and an ester. The third reaction occurs between the monoglycerides (from the second reaction) and alcohol to produce glycerol and an ester.

From these reactions, one molecule triglycerides requires three molecules alcohol to form three molecules fatty acid alkyl esters and one molecule glycerol. The general equation of the transesterification process is shown in Equation 2.1:

$$\begin{array}{lcccccc}
CH_2\text{-OOC-}R_1 & & & R_1\text{-OOC-}R' & & CH_2\text{-OH} & \\
| & & & & & | & \\
CH_2\text{-OOC-}R_2 & +\ 3\ R'OH & \longleftrightarrow & R_2\text{-OOC-}R' & + & CH_2\text{-OH} & (2.1) \\
| & & & & & | & \\
CH_2\text{-OOC-}R_3 & & & R_3\text{-OOC-}R' & & CH_2\text{-OH} & \\
\text{Triglycerides} & \text{Alcohol} & & \text{Fatty acid alkyl esters} & & \text{Glycerol} &
\end{array}$$

R^1, R^2, R^3 and R' are different type of alkyl group. The elaborate equations of the transesterification process are presented in Equation 2.2 (a-c) (Fukuda, 2001):

$$\text{Triglycerides (TG)} + R'OH \longleftrightarrow \text{Diglycerides (DG)} + R'COOR_1 \qquad (2.2a)$$

$$\text{Diglycerides (DG)} + R'OH \longleftrightarrow \text{Monoglycerides (MG)} + R'COOR_2 \qquad (2.2b)$$

$$\text{Monoglycerides (MG)} + R'OH \longleftrightarrow \text{Glycerol (GL)} + R'COOR_3 \qquad (2.2c)$$

Commonly in biodiesel production, side reaction can occur especially in the homogenous transesterification process when catalyst such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) is used. Instead of producing alkyl esters, soap is formed. This side reaction is called saponification. The saponification process is show in Equation 2.3 (Demirbas, 2003).

$$\text{Vegetable oils or fats} + NaOH \longrightarrow RCOONa + \text{Glycerin} \tag{2.3}$$

2.2 FUEL PROPERTIES OF BIODIESEL

As the use of alternative fuels becomes more widespread, researchers have shown a growing interest in designing and fabricating the fuel injector tester in order to understand the fundamental characteristics of fuels which are renewable, biodegradable and oxygenated such as vegetable oils, their derivative and mixtures. To faithfully predict alternative fuel combustion, accurate prediction of the physical properties of alternative fuels is critical in the representation of spray characteristic of biodiesel.

2.2.1 Critical Properties

The critical properties are used to estimate the properties such as liquid density, viscosity, surface tension, heat capacity, diffusion coefficient, heat of vaporization and thermal conductivity. The critical properties are also used to estimate the fuel boiling point and establish a correlation for vapour pressure. Hence it is particularly important to accurately predict the fuel critical properties, as they will influence the prediction of the other fuel properties.

The Lydersen's method recommended by Reid (1977) was a group contribution method, which employs structural contribution to estimate the critical pressure P_c, the critical temperature T_c and the critical volume V_c of the different groups, which are described as follows:

$$T_c = \frac{T_b}{0.567} + \sum \Delta_T - \left(\sum \Delta_T\right)^2 \quad (2.4)$$

$$P_c = \frac{MW}{(0.34 + \sum \Delta_P)^2} \quad (2.5)$$

$$\mathrm{V_c} = 40 + \sum \Delta_\mathrm{v} \quad (2.6)$$

Δ_T, Δ_V and Δ_P are the contribution constants used for various atoms or groups of atoms. The critical properties of the different fatty acids have been incorporated in the mixing rules using the Lee-Kesler equation:

$$T_{cij} = (T_{ci} T_{cj})^{1/2} \quad (2.7)$$

$$T_{cm} = \frac{1}{V_{cm}^{1/4}} \sum_i \sum_j x_i\, x_j V_{cij}^{1/4} T_{cij} \quad (2.8)$$

$$V_{cij} = \frac{1}{8} \left(V_{ci}^{\frac{1}{3}} + V_{cj}^{\frac{1}{3}}\right)^3 \quad (2.9)$$

$$V_{cm} = \sum_i \sum_j x_i\, x_j V_{cij} \quad (2.10)$$

$$\omega_m = \sum_i x_i\, \omega_i \quad (2.11)$$

$$P_{cm} = \frac{(0.2905 - 0.085\omega_m) R T_{cm}}{V_{cm}} \quad (2.12)$$

Where m refers to the mixture, i and j refer to the pure constituents and x to the mole fraction of the pure constituent i or j. The pure component acentric factor (ω_i) was computed as follows:

$$\omega_i = \frac{\alpha}{\beta} \quad (2.13)$$

Where

$$\alpha = -\ln P_{ci} - 5.97214 + 6.096448\theta^{-1} + 1.28862\ln\theta - 0.163947\theta^{6} \qquad (2.14)$$

$$\beta = 15.2518 - 15.6875\theta^{-1} - 13.4721\ln\theta - 0.43577\theta^{6} \qquad (2.15)$$

With

$$\theta = \frac{T_{br}}{T_{ci}} \qquad (2.16)$$

With T_{bi}: normal boiling point of the pure constituent i (K) and T_{br}: reduced temperature at normal boiling point.

2.2.2 Viscosity, Density And Flash Point of Biodiesel

The properties of biodiesel are similar to those of diesel fuels. Viscosity is the most important property of biodiesels since it affects the operation of fuel injection equipment, particularly at low temperatures when an increase in viscosity affects the fluidity of the fuel. High viscosity leads the poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The lower the viscosity of the biodiesel, the easier it is to pump and atomize and achieve finer droplets (Islam, 2004). The conversion of triglycerides into methyl or ethyl esters through the transesterification process reduces the molecular weight to one third that of the triglyceride and reduces the viscosity by a factor of about eight. Viscosities show the same trends as temperatures with the lard and tallow biodiesels higher than the soybean and rapeseed biodiesels. Biodiesels have a viscosity close to that of diesel fuels. As the oil temperature increase is viscosity will be decrease. Table 2 shows some fuel properties of six methyl ester biodiesels given by different researches.

Table 2.2: Some fuel properties of six methyl ester biodiesel

Source	Viscosity cSt at 313.2K	Density g/mL at 288.7K	Cetane number
Sunflower	4.6	0.880	49
Soybean	4.1	0.884	46
Palm	5.7	0.880	62
Peanut	4.9	0.876	54
Babassu	3.6	-	63
Tallow	4.1	0.877	58

Source: Demirbas (2003)

Table 2.3: Viscosity, density and flash point measurements of nine oil methyl esters

Methyl ester	Viscosity mm^2/s at 313K	Density kg/m^3 at 288K	Flash point K
Cottonseed oil	3.75	870	433
Hazelnut kernel oil	3.59	860	422
Linseed oil	3.40	887	447
Mustard oil	4.10	885	441
Palm oil	3.94	880	431
Rapeseed oil	4.60	894	453
Safflower oil	4.03	880	440
Soybean	4.08	885	441
Sunflower oil	4.16	880	439

Source: Demirbas (2003)

2.3 FATTY ACID METHYL ESTER CHEMICAL STRUCTURE

Table 2.4 lists the chemical structure of fatty acid methyl esters. Biodiesels have a different structure from conventional petroleum-based fuels which contain only carbon and hydrogen atoms, whereas vegetable oil, biodiesels and alcohol are oxygenated hydrocarbons.

Table 2.4: Chemical structure of fatty acid

Number of carbons	Fatty acid methyl ester	Chemical structure
8	Caprylic (carboxylic acid C_8)	$CH_3(CH_2)_6COOCH3$
10	Capric (carboxylic acid C_{10})	$CH_3(CH_2)_8COOCH3$
12	Lauric (carboxylic acid C_{12})	$CH_3(CH_2)_{10}COOCH3$
14	Myristic (carboxylic acid C_{14})	$CH_3(CH_2)_{12}COOCH3$
16	Palmitic (carboxylic acid C_{16})	$CH_3(CH_2)_{14}COOCH3$
16	Palmitoleic (cis-9-Hexadecanoic acid)	$CH_3(CH_2)_5CH=CH(CH_2)_7COOCH3$
17	Heptadecanoic (carboxylic acid C_{17})	$CH_3(CH_2)_{15}COOCH3$
17	Heptadecenoic (cis-9-Heptadecanoic acid)	CH3(CH2)6CH=CH(CH2)7COOCH3
18	Stearic (carboxylic acid C_{18})	CH3(CH2)16COOCH3
18	Oleic (cis-9-Octadecenoic acid)	$CH_3(CH_2)_7CH=CH(CH_2)_7COOCH3$
18	Linoleic (cis, cis-9-12-Octadecadienoic acid)	$CH_3(CH_2)_3(CH_2CH=CH)_2(CH_2)_7$
18	Linolenic (cis, cis, cis-9,12,15-Octadecatrienoic acid)	$CH_3(CH_2CH=CH)_3(CH_2)_7COOCH3$
18	Elaidic (trans-9-Octadecenoic acid)	$CH_3(CH_2)_7CH=CH(CH_2)_7COOCH3$
18	C18:2 (trans, trans- 9,12-Octadecadienoic acid)	$CH_3(CH_2)_3(CH_2CH=CH)_2(CH_2)_7COO$ CH3
18	C18:3 (trans, trans, trans-9,12,15-Octadecadienoic acid)	$CH_3(CH_2CH=CH)_3(CH_2)_7COOCH3$
20	Eicosanoic (carboxylic acid C_{20})	$CH_3(CH_2)_{18}COOCH3$
20	Eicosenoic (cis-10-eisenoic acid)	$CH_3(CH_2)_8CH=CH(CH_2)_8COOCH3$
22	Behenic (carboxylic acid C_{22})	$CH_3(CH_2)_{20}COOCH3$
22	Eruric (cis-13-docosanoic acid)	$CH_3(CH_2)_7CH=CH(CH_2)_{11}COOCH3$
24	Lignoceric (carboxylic acid C_{24})	$CH_3(CH_2)_{22}COOCH3$

Source: Rochaya (2007)

2.4 PALM OIL DIESEL

The methyl ester of palm oil is known as palm oil diesel (POD). The results of POD meet the combustion requirement of diesel engines. The cetane number of 50–52 was slightly lower than that of conventional diesel but within an acceptable range (Ong ASH, 1985). (Ong ASH, 1985) did a field trial and concluded that the consumption of methyl ester of palm oil on the average was 12 km/l compared with 13 km/l for petroleum diesel on 1:8 1 category cars. Moreover, at a speed greater than 80 km/l methyl ester of palm oil gave better fuel economy than conventional diesel.

Another study conducted on the use of palm oil methyl ester in Yammer TF80 and Isuzu 4FB1 diesel engines (H.H. Masjuki, 1991) showed that when fuelled with POD, the output delivered only marginally compared to that of conventional diesel. The fuelling rate and the specific mass fuel consumption for both engines were higher with POD by approximately 15–20% as compared with conventional diesel. The brake specific energy consumption of both engines was found to be similar, with POD having a slightly lower thermal efficiency over conventional diesel. In a study of dynamic combustion events in Ricardo engines (Azhar AA, 1989) at 2.5 bar brake mean effective pressure POD was shown to give ignition delay periods between 1° and 2° (crank) earlier than conventional diesel from low to high speeds, which under high load (5.5 BMEP) palm oil gave an ignition delay 1° shorter than when run on diesel. This indicated its readiness to burn more rapidly after injection than diesel.

Cheah Kien Yoo et al. produced standard fuel specification for palm oil methyl ester (Table 4) and compared them with the German biodiesel standard (rapeseed methyl ester) ‘DIN V51606’ and American biodiesel standard (soybean methyl ester) ‘proposed ASTM’. The standard for biodiesel has also been developed in other European countries. The German standard DIN V51606 is often used as the reference for other nations considering adoption of biodiesel standards although the USA has its own biodiesel standard.

Since the field trial of POD project produced promising results, it is time to look into the establishment of a standard for POD. Prior to proposing a standard for POD, it is appropriate to discuss some fuel properties of POD and compare these properties with the German DIN standards and the proposed American ASTM standards. This comparison will enable identification of the difference between POD and other biodiesels and improve their process to produce palm oil diesel that will meet the DIN and ASTM standards. The German standard is based on rape seed methyl ester whereas the American ASTM standard is based on soybean methyl ester and PORIM standard is based on palm oil methyl ester.

PORIM developed a two-step chemical process to convert crude palm oil and its products into methyl esters to be used as diesel substitutes. This process involved esterification followed by transesterification, which has been successfully evaluated at a 3000 Mt/yr capacity pilot plant. It is a one step procedure possible by the use of lipase enzymes. Aqueous alcoholic media can be used directly without buffers. This method is applicable to all oils regardless of the free fatty acid content. These include palm oil, palm Kernel oil, coconut oil, rapeseed oil, soybean oil, sunflower oil, corn oil and tallow.

Table 2.5: Standardization of biodiesel

Properties	**Units**	**POD[a]**		**DIN V 51606[b]**		**Proposed ASTM[c]**	
		Testing proc.	**Typical value**	**Testing proc.**	**Typical value**	**Testing proc.**	**Typical value**
Density at 15 ^{0}C	g/ml	ASTM D1298	0.870	ISO 3675	0.875-0.900	-	-
Kinematic viscosity at 40 ^{0}C	mm^2/s	ASTM D445	4.44	ISO 3104	3.5–5.0	ASTM D445	1.9-6.0
Flash point	^{0}C	ASTM D93	174	ISO 2719	100min.	ASTM D93	100min.
Sulphur content	wt%	IP242	0.04	ISO 4260	0.01max	ASTM 2622	0.05max.
Carbon residue (10% dist.)	wt%	ASTM D189	0.11	ISO 10370	0.03max	ASTM 4530	0.05max.
Ash	wt%	-	-	ISO 6245	0.01max	ASTM 874	0.02max.
Cetane number		ASTM D613	52	ISO 5165	49max.	ASTM 613	40min.

Source: M.A. Kalam and H.H. Masjuki (2002)

2.5 PALM OIL A COST EFFECTIVE PRODUCT

Palm oil is obtained from the flesh of the palm fruit. Each palm tree produces approximately one fruit bunch, containing as many as 3000 fruitlets, per month. In addition, each palm tree continues producing fruit economically for up 25 years. This ensures a constant stable supply, as compared with other annual crops.

Naturally, palm oil is characterized as stabilized oil due to its chemical composition. As such, it can be used in most food applications without hydrogenation, thus, reducing production cost by as much as 30%. Palm oil also is priced competitively and can represent a saving of up to several cents per ringgit compared to other edible oils.

Palm oil is available in a variety of forms: crude palm oil, palm olein, palm stearin, RBD palm oil, fractionated palm olein and palm mid-fraction. While most of the oil Malaysia exports is RBD palm oil and RBD palm olein, the range of products is available to suit a variety of manufacturing needs and in forms that are ready to use and require no further processing.

2.6 PALM OIL PRODUCTION IN MALAYSIA

Palm oil is the king of biodiesel feedstock in term of yield. Together, Malaysia and Indonesia account for about 87 percent of global palm oil production. Malaysia's first oil palm was set up in 1917's and the country claims to be the world's largest producer and exporter for palm oil products. Malaysia was actually surpassed by Indonesia in crude palm oil in 2007. The total crude palm oil production for Malaysia in 2007 was 15.8 million tons.

It should come as no surprise then that the palm oil industry in Malaysia has experimented with biodiesel for some time. The PORIM has been the prime mover in this initiative and their 10,000 ton capacity biodiesel pilot plant has been the main fuel source for research and field tests. Between 1987 and 1990 PORIM together with Mercedes-Benz conducted palm ester test with city buses in Kuala Lumpur. Additional tests also were run with hundreds of trucks participating. Although palm oil biodiesel does not perform well in cold climates because of its high cloud point there were no problems under the relatively hot local temperatures.

In early 2005, the Malaysian Palm Oil Board announced that it had entered a partnership agreement with Golden Hope Plantations to build a biodiesel plant in Labu, Negeri Sembilan. The 60,000 ton facility was completed in late 2006 and of course used palm oil as its primary feedstock. Plans for a number of additional plants were announced a short time later. In August 2005, the Malaysian government published a new National Biofuel Policy. The primary goal of the policy was to reduce the consumption of imported petroleum. In order to accomplish that, the policy promoted greater production and used B5 palm oil biodiesel, set up palm oil biodiesel standards and provided price support for palm oil at times of low demand. Those supports have not been needed recently, since the demand for palm oil has soared and its price has doubled between 2006 and 2007 causing a lot of problems for many biodiesel producers.

In 2007, two new commercial scale biodiesel refineries were completed. But due to the dramatic increase in the price of palm oil, the new facilities opened at only partial production. The record prices for palm oil have slowed or delayed some other biodiesel projects well. High palm oil prices also have delayed the introduction of biodiesel into the domestic Malaysian market as the government felt that higher biodiesel prices would be a burden on consumers. Nevertheless, in early 2008, the Malaysian government was considering the implementation a B2 blend mandate.

At the end of 2007, 91 biodiesel projects with a total production capacity of 10.1 million tons had been approved by government. Among that number, 4 plans with a combined capacity of 300,000 tons were operating while another 6 with a capacity of 471,000 tons had been completed and were undergoing initial trial runs. But, in response to record high prices for palm oil only 7 plans across the country were actually operating, most well below capacity as of early 2008. The growth of biodiesel capacity in Malaysia recently has been truly remarkable. The growth of environmental concerns surrounding oil palm plantations also has been significant, although the amount of land available for large new plantations in Malaysia is somewhat limited. This has led some Malaysian companies to look at Indonesia as a better place to grow more oil palm, which has raise even more environmental concerns in Indonesia. There also have been some concerns raised about the treatment of indigenous peoples who lands have been appropriated by oil palm plantations, especially Borneo. The growing controversy over palm oil's environmental and social impacts along with its soaring price had caused Malaysian palm oil exports to Europe to drop about 20 percent in 2007.

In partial response to the growing controversy over palm oil, the government announced in November 2007 that is was planning on planting "jarak" (jatropha) trees as possible future feedstock for biodiesel. The Malaysian Palm Oil Board is carrying out the research to try to find suitable climate and land conditions in the country for 300 acre test plantation. If Malaysia hopes to maintain its strong growth in the biodiesel sector it needs to find ways to respond to the growing international concerns surrounding oil palm plantations and rain forest destruction Table 2.6.

Table 2.6: 2006 World Oil Palm productions

Country	**Production (tons)**	**Percentage (%)**
Malaysia	15,881,000	43
Indonesia	15,900,000	44
Thailand	820,000	2
Nigeria	815,000	2
Columbia	711,000	2
Others	2,718,000	7

Source: U.S. Energy Information Administration (2007)

CHAPTER 3

METHODOLOGY

3.1 IINTRODUCTION

Chapter 3 will explain the processes to identify the characteristics of palm oil methyl ester as an alternative fuel. A process model is an abstraction that depicts the process of translation for every phase, project planning, analysis, design and developmental issues. Besides, the methodology also explains how an experiment was setup. In addition, all the information from chapter one to chapter two is related to and had been used to define and analyze for this chapter. At the end of this chapter, user should be able to understand properly on how the data are taken from the experiment and also explain the characteristics of biodiesel used. In this chapter, a clear picture is shown on how the experiment will be conducted from the preliminary stages until the final part.

3.2 FLOW CHART OF PROJECT

The process of this project will be provided in the flow chart in the Figure 3.1.

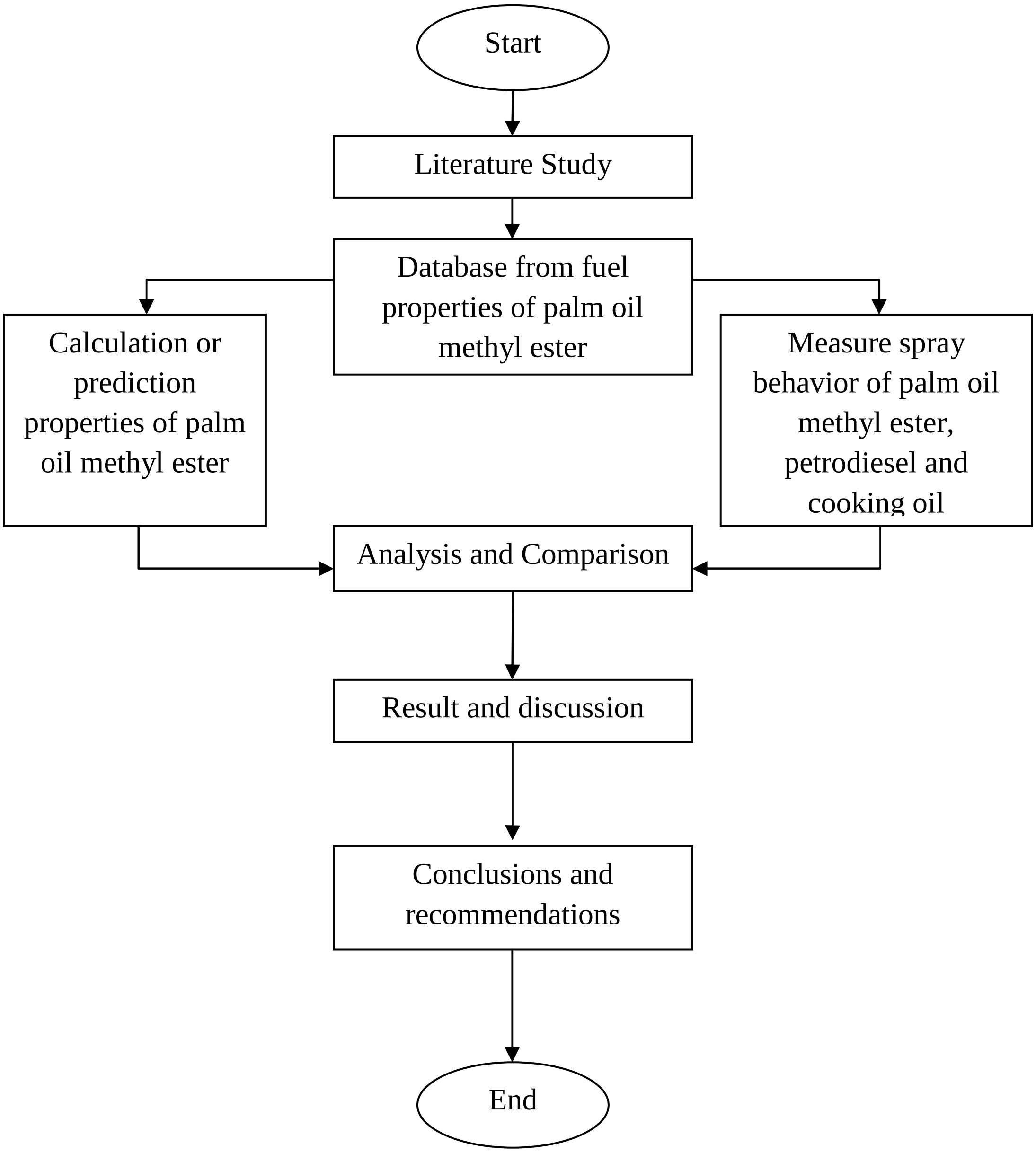

Figure 3.1: Project flow chart

3.3 DESIGN OF PROJECT STUDY

As the starting point of this final year project, after the title and the supervisor of the project is known, the student needs to get a logbook from the faculty. The purpose of the logbook is to be used to write the progress of the report.

After that, there will be one short briefing about the project mainly regarding important information such as the evaluation of the project. Then, the first meeting is arranged with the supervisor to get more details in the progress of the project. In this first meeting, there are several important things to be discussed. The weekly appointment will be set up with the supervisor. Other than that, the title of the project, problem statement of the project, objectives of the project and scope of the project are clarified and understood.

When every weekly appointment is to be attended, the logbook has to be filled before the weekly appointment according to the progress of the project and have to be checked by supervisor and approved by his signature. The supervisor gives important idea or suggestion that had been crucially important for the project in every appointment or meeting with them. After have a meeting with supervisor for the first time, the information regarding the project title are asked to be gathered and referred throughout the project.

Then, after completion of the work needed for the project, preparation for the project presentation is made by discussion with supervisor about the content of the presentation, schedule of the project presentation, panels for the project presentation and other necessary information regarding the project presentation.

3.4 METHOD IN GATHERING INFORMATION

The progress of the project is started with the gathering information regarding the project title. Before that, an appointment with the supervisor has been made and the suggestion by the supervisor is to find suitable journals and reference books about biodiesel properties regarding the project title so that there will be a general idea on how to conduct the project. The journal that is suggested by the supervisor is either from science direct or springerlink because these are established journals and they have more information and more suitable for this project.

3.5 PPROJECT METHODOLOGY

Biofuel is one of the types of renewable energy in the world. The term renewable can be described as it is naturally replenished. Other types of renewable energy are biomass, geothermal, hydropower, solar power, tidal power, wave power and lastly wind power. The growing demand in renewable energy is very exceptionally when in 2007 alone about USD100 billion was invested in new renewable energy capacity, manufacturing plants, and research and development globally as reported in Renewable 2007 Global Status Report (2008).

Malaysia as one of major developing country is not lagging behind to tap this enormous potential of the so called future energy. Using the country's abandon resources of palm oil, Malaysian government via its own research arm at MPOB (Malaysia Palm Oil Board) started doing research to used palm oil as a biofuel in the early 1980s. Their research is primarily on palm biofuel (blends of palm olein and petroleum diesel) and palm biodiesel (Palm Oil Methyl Esters, POME). Consequently, in 2006 MPOB launched the country's first biodiesel called Envodiesel which comes from the blends of fully refined liquid palm oil (RLPO) and 95 percent of petroleum diesel (Yusof Basiron, 2006). On the same year, the government launched National Biofuel Policy which primarily aimed at reducing country's dependence on depleting fossil fuels, promoting the demand for palm oil as well as stabilizing its prices at a remunerative level (Michael Dosim Lunjew, 2006).

It is known that the biofuel that consists of palm oil will have different properties from petroleum fuel as in this case diesel. Properties such as viscosity and density of palm oil are larger than diesel (Yusof Basiron and Choo Yuen May, 2007). Thus, a complete database of biofuel physical properties is needed as a reference.

Due to the difference of the biofuel in term of physical properties compared to petroleum diesel, it is important to study these effects on the atomization and combustion. The physical properties are very critical in the atomization process whether in internal combustion engine or gas turbine engine. This is because viscosity affects the quality of atomization of fuel injection into the combustion chamber, droplet size distribution and the uniformity of mixture while the surface tension have a effect on disintegration of a liquid jet into droplets (Lefebvre, A.H., 1983).

Moreover, atomization characteristics of palm biofuel such as Sauter Mean Diameter (SMD) distribution, spray pattern, cone angle, spray tip penetration and mean droplet size play an important role in the engine performance and the emission characteristics. Therefore, the relationship between the fuel physical properties and the atomization characteristics of biodiesels needs to be properly investigated.

Furthermore, the Sauter Mean Diameter (SMD) distribution cannot be investigate properly due to the lack of tools and requires a high cost to buy it. Cone angle, spray tip penetration and mean droplet size can be investigated by our prediction.

3.5.1 Research methodology

From this research, database of palm biofuel blends physical properties is developed using experimental test and compare with analytical approach that is available on literature. Besides that, the spray characteristics of palm biofuel blends is evaluated by comparing it to the petroleum diesel. This is done using fuel injector tester.

3.6 ADVANTAGES OF THE RESEARCH

This research will promote more understanding about palm biofuel and its spray characteristic, both to the palm oil industry and academic world, as very few publications on palm oil as biofuel sources are available in literature. Apart from that, we can also understand the limitations in terms of quantity of palm olein that can be blended together with petroleum diesel so that it can be used in any internal combustion engine without major modifications.

An extensive research on palm biofuel also will further strengthen Malaysian palm oil industry thus keeps Malaysia as a major powerhouse on palm oil industry. Furthermore, the availability of publications towards palm biofuel also enhances Malaysia’s positions as research and developments (R&D) centre in the south East Asia region.

3.7 MEASURING EQUIPMENT

From this part, many measuring devices are used to define the properties of biodiesel such as bomb calorimeter and pressure gauge. Unfortunately, the bomb calorimeter that is available at the laboratory is not in good condition. The bomb calorimeter is damaged and cannot measure data accurately. Due to this problem, some of the data from calculation cannot be compared. Figure 3.7 shows the bomb calorimeter that is to be used for this experiment method. This bomb calorimeter is used to measure the heat capacity of biodiesel.

Figure 3.7: Bomb calorimeter to measure specific heat capacity

Besides that, from this experiment, pressure gauge is the most important device to control the pressure flow from the injector tester. Figure 3.8 shows the pressure gauge that is to be used for this experiment.

Figure 3.8: Pressure gauge for controlling pressure of injector

3.8 INJECTOR TESTER EQUIPMENT

From this subtopic, the purpose of this injector tester that being used for this experiment is to define the spray characteristics of palm oil and diesel. This injector tester needs to be properly installed due to the high cost of maintenance and high sensitivity. From the end of this experiment, the spray characteristic can be investigated by their properties of fuel such as viscosity, spray atomization and surface tension. Figure 3.9 shows the piston in the tester.

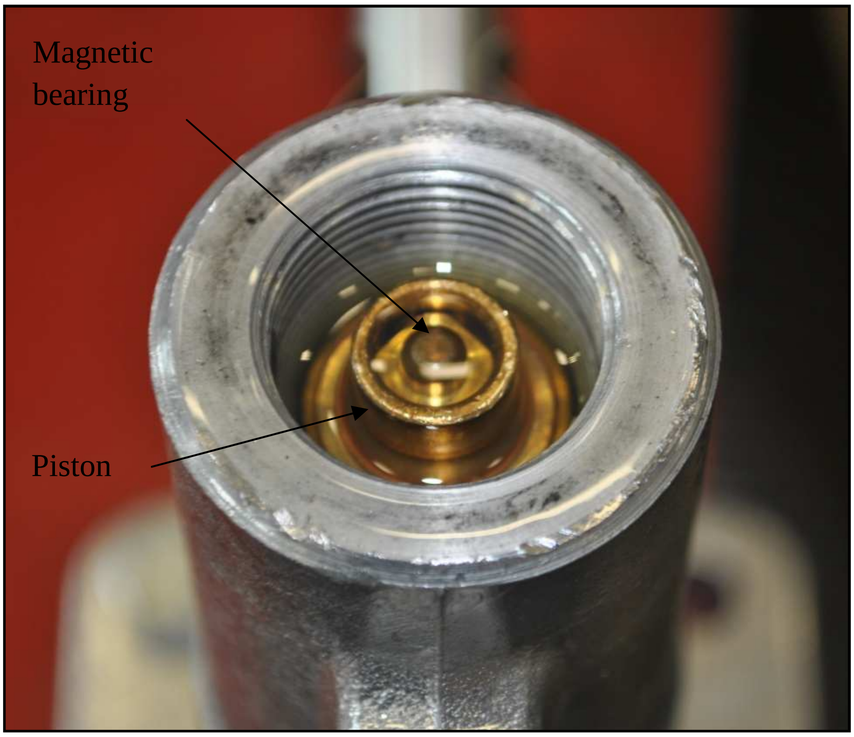

Figure 3.9: Cylinder piston of injector tester

This piston is to make sure that the pressure that will be applied moves up and compresses the injector. This is a sensitive part with very high cost of material. Other equipment that needs to be used for this experiment is injector as shown in Figure 3.10 for diesel vehicle. For this experiment, the injector that will be used is from ISUZU 4x4 (Diesel engine).

Figure 3.10: Injector of ISUZU 4x4 to produce spray pattern

Figure 3.11: Injector tester to define the spray pattern

This injector tester Figure 3.11 has a range of pressure that will be used. The range is about 0-600 bar. Besides that, this is injector tester need to be properly and firmly placed at a suitable place. For this experiment, this injector tester has been fastened at the table in order to cope with the high force given to push the holder of the tester.

3.9 FUEL INJECTOR TESTER FLOW

The characteristics of palm oil and diesel are defined by this flow of schematic diagram as shown in Figure 3.12.

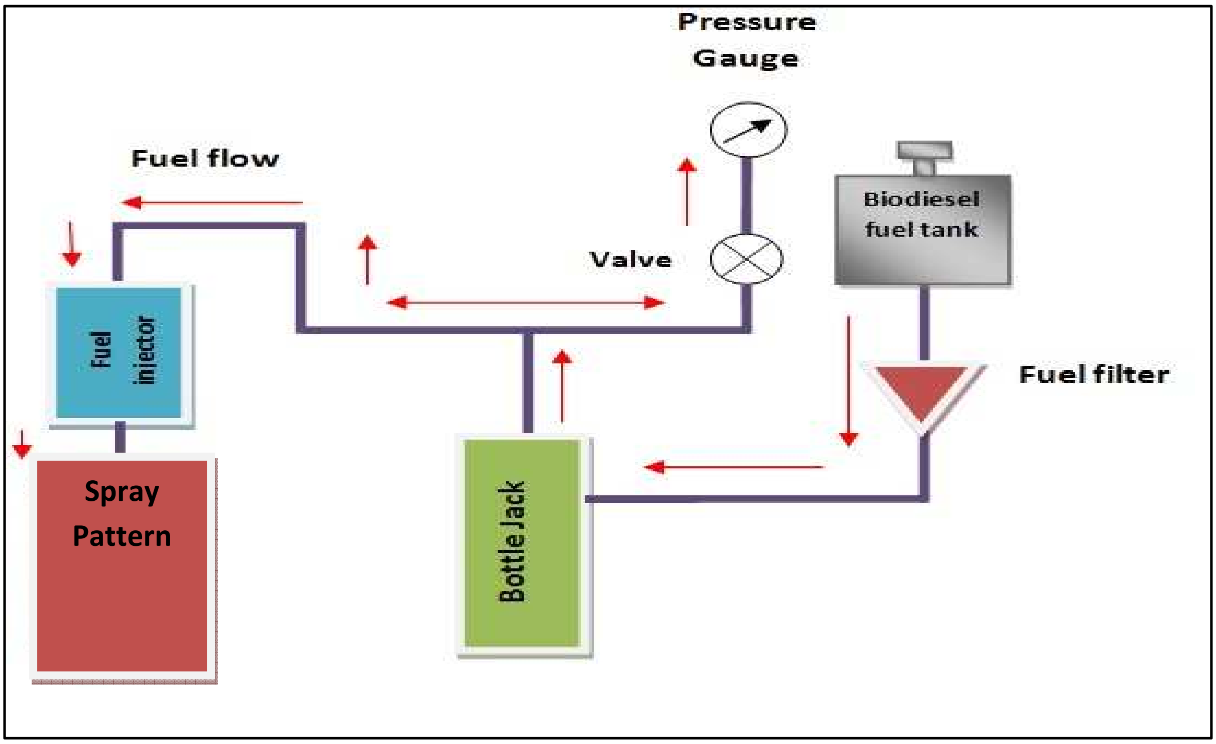

Figure 3.12: Schematic diagram of fuel injector tester

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

This experiment was carried out by the author with the help of assistant instructor, Mr. Mohd Idzwanrosli bin Mohd Ramli. A lot of things must be observed before the start of the experiment, especially in terms of safety aspects of the experiment. Safety goggles and gloves are among the necessary safety equipments that are being used during this experiment. The main objective in this section is to determine the spray characteristics of palm oil methyl esters and biodiesel. Then, the results of this experiment will be used as a comparison between experiments and later, calculations will be explained in a detailed manner. In the experiments involved, great sacrifices were made so that a data that is precise and accurate could be obtained as well pictures of each spray penetration. Other than that, this section also has a goal to obtain a detailed understanding of the structure of the spray and its physics as well as being able to assess how the spray interacts with the different pressure from the injector tester and how it affects the combustion process.

Experimental data are required to get a better understanding of the different physical processes involved, such as evaporation, mixing, and momentum exchange. Measurements have been made at atmospheric pressure which is at a standard value of 101.325 kPa. The pressure inside the injector starts at 0 bar and progressively increases within a range up to 600 bar. The measurement techniques chosen have been discussed and uncertainty analyses are described in later section.

This experiment was carried out for the diesel, palm oil and cooking oil. In principle, the results of this experiment show the difference between the various particle sizes produced by applying a pressure difference on the injector. Therefore, this experiment will show how the real characteristics of diesel, palm oil and cooking oil are produced.

4.2 SPRAY PATTERN FOR PALM OIL METHYL ESTER

This section described about the spray pattern of palm oil methyl ester (POME). The pattern of this POME is being defined by using the injector tester and injector of biodiesel vehicle that has been discussed at the previous chapter. This spray pattern is defined in different pressure that applies for the injector tester. Pressure that applied for the injector is 100 bar, 200 bar, 300 bar and 400 bar.

4.2.1 Spray Pattern at 100 bar Pressure

In the experiments that were conducted, the data includes an image taken for each pressure. From Figure 4.1, the pattern has 18^o spray cone angle. The spray tip penetration is 0.580m. This spray pattern is smaller compared to the pattern for the 200 bar. Different pressure plays an important role for droplet size. This spray pattern result the small droplet size because the pressure is lower. So theoretically, the pressure is lower thus creating larger droplet size. With larger droplet size, it results in incomplete combustion in combustion chamber. The viscosity of the resulting spray pattern is lower due to the increasing of supply pressure. Figure 4.1 shows that the spray pattern of POME at 100 bar.

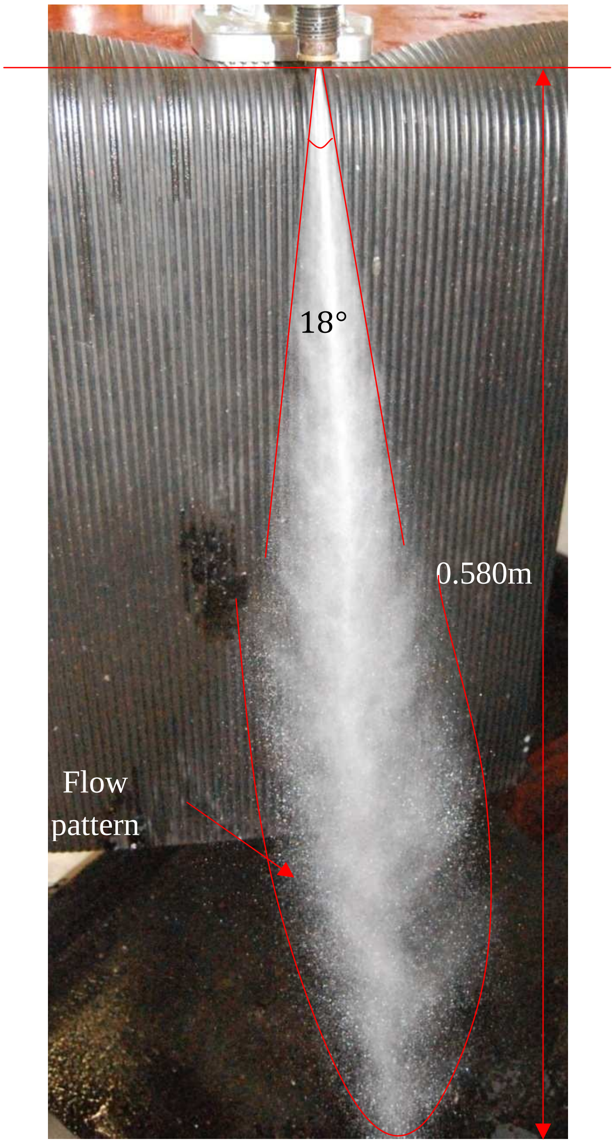

Figure 4.1: Spray pattern at given 100 bar pressure of POME

4.2.2 Spray Pattern at 200 bar Pressure

From the Figure 4.2 below, the cone angle size is 18.5^{o}, greater than the pressure supply at 100 bar. This will affect the spray tip penetration of the spray pattern. The increasing pressure supply also will generate a complete combustion at the end of the spray pattern. The viscosity of the particle is also higher due to the pressure differences that are given in this injector. The variation of supply pressure slightly affected the flow pattern as shown in figure 4.2. Thus, this flow pattern results in a large amount of area in combustion chamber and it will give a complete combustion and a high power of the engine.

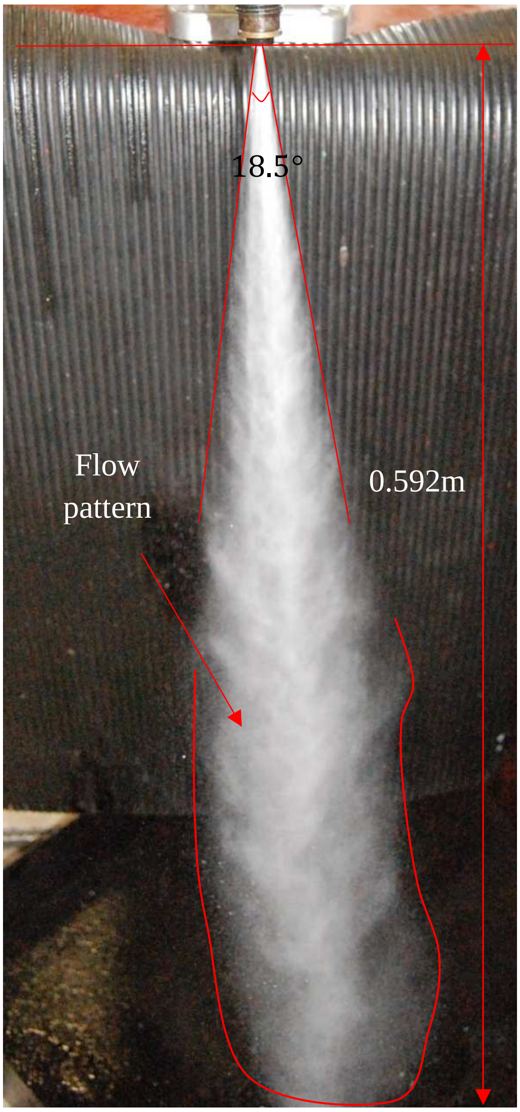

Figure 4.2: Spray pattern at given 200 bar pressure of POME

4.2.3 Spray Pattern at 300 bar Pressure

The increasing of injection pressure caused an increase of the initial spray momentum. For the presence of the spray pattern in Figure 4.3, the cone angle of this spray pattern becomes larger than the Figure 4.2 which is 23°. The spray tip penetration increases with the increase of the injection pressure which is now 0.595m as shown in Figure 4.3. This pattern also describes a large area of the tip pattern. The droplet size for this pattern is smaller than the previous pattern thus it will cause a complete combustion at the combustion chamber.

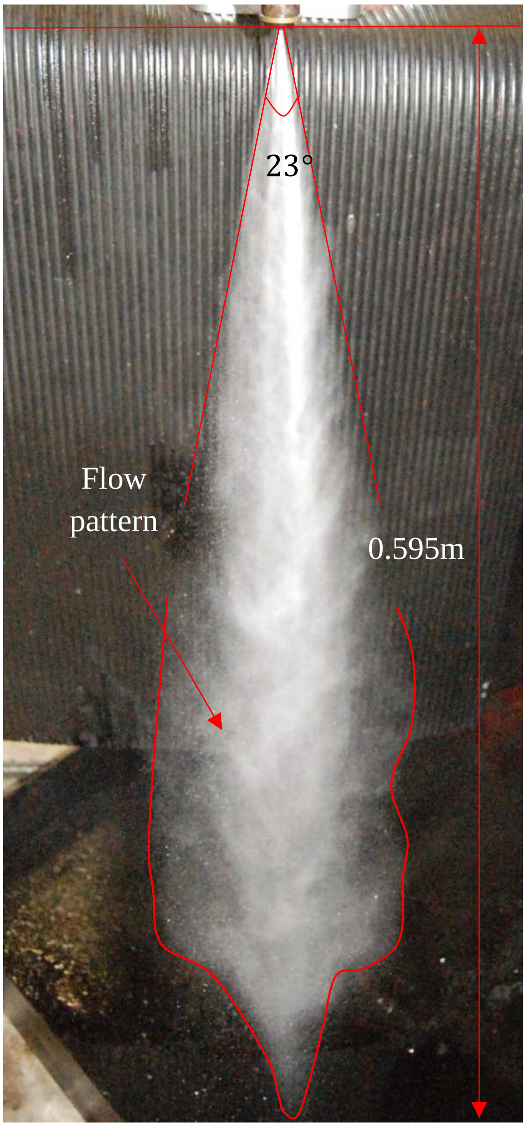

Figure 4.3: Spray pattern at given 300 bar pressure of POME

4.2.4 Spray Pattern at 400 bar Pressure

Spray tip penetration was only slightly affected by the variation in the pressure supply, as shown in the experimental analysis. Therefore, it can be said that the spray tip penetration was not remarkably affected by a change in the fuel properties caused by the variation of pressure supply. From the Figure 4.4 below, the cone angle size is 19^{o} which is less than the Figure 4.3, while the droplet size will become smaller than the previous. For complete combustion chamber, the higher pressure supply is need of having a small droplet size and also to have a larger area of spray tip penetration. The spray tip penetration of this spray pattern is 0.595m which is higher than the previous.

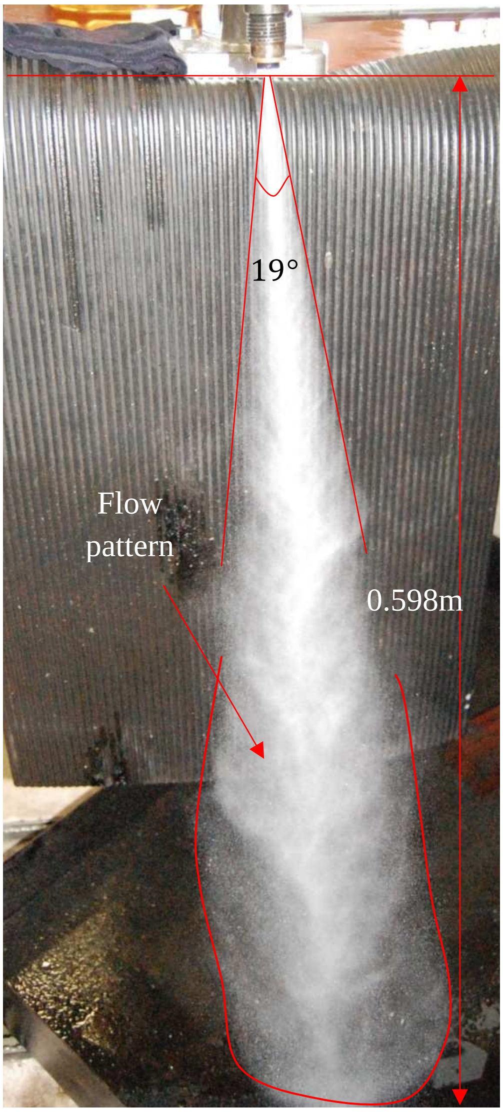

Figure 4.4: Spray pattern at given 400 bar pressure of POME

4.3 SPRAY PATTERN FOR DIESEL

This section has described about the spray pattern of diesel. The pattern of this diesel is being defined by using the same injector tester and also same injector which is from ISUZU 4x4 vehicles that has been discussed at the previous chapter. This spray pattern is defined in different pressures that apply for the injector tester. Diesel is a fast and volatile fluid, thus this will cause some difficulty to collect data from the particle produced. Therefore a camera that has a higher resolution is required to take a picture of the resulting particle with a maximum speed. The camera that was used in this experiment was Nikon D40.

4.3.1 Spray Pattern at 100 bar Pressure

In the experiments that were conducted, the data includes an image taken for each pressure. This type of pattern has 25^o spray angle. Thus the resulting cone angle size is bigger compared to Figure 4.6 which is 23^o. The variation of pressure supply affects this cone angle size thus influences the spray tip penetration which is 0.540m as shown in figure below. The resulting colour is a bright particle. This is caused from the density of this diesel. The droplet sizes of this spray pattern are almost the same as shown in Figure 4.6 thus proving that this variation of pressure supply does not greatly affect the droplet size.

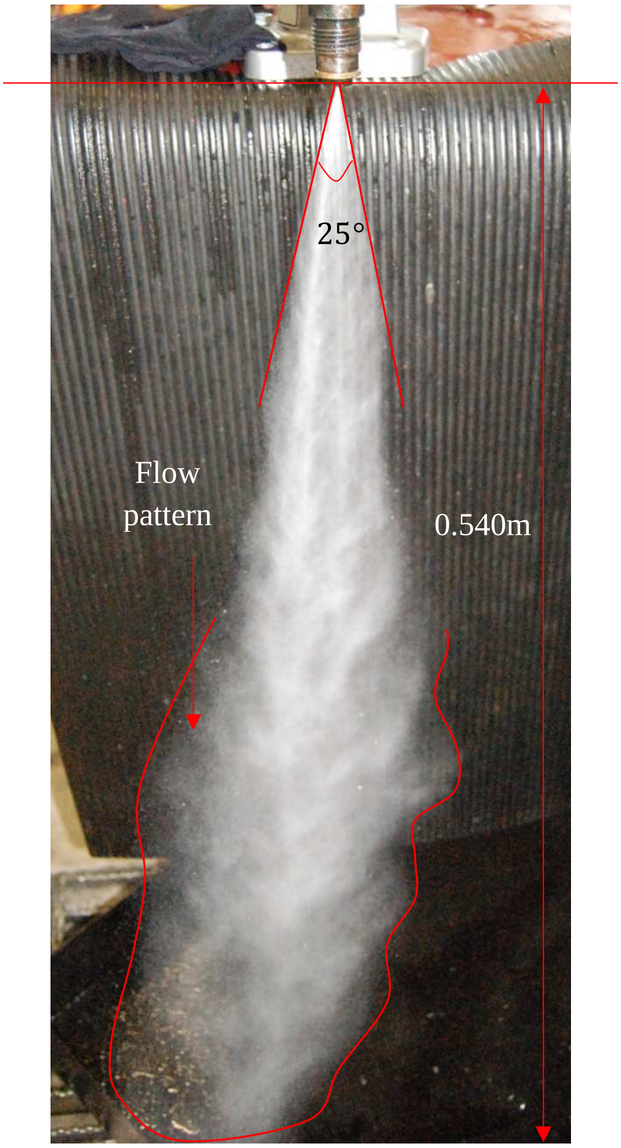

Figure 4.5: Spray pattern at given 100 bar pressure of diesel

4.3.2 Spray Pattern at 200 bar Pressure

From this result of spray pattern, the increasing spray tip penetration will influence the characteristics of the spray pattern. This result is affected by the increasing of the pressure supply. Besides, the increasing of pressure supply will also affect the cone angle which would become smaller than the previous figure. As seen in Figure 4.6, the shape of this spray pattern is bigger than Figure 4.5 which affects the combustion process in the combustion chamber. As a result, better combustion occurs thus providing more power to the engine. Hence, high acceleration will occur for this situation.

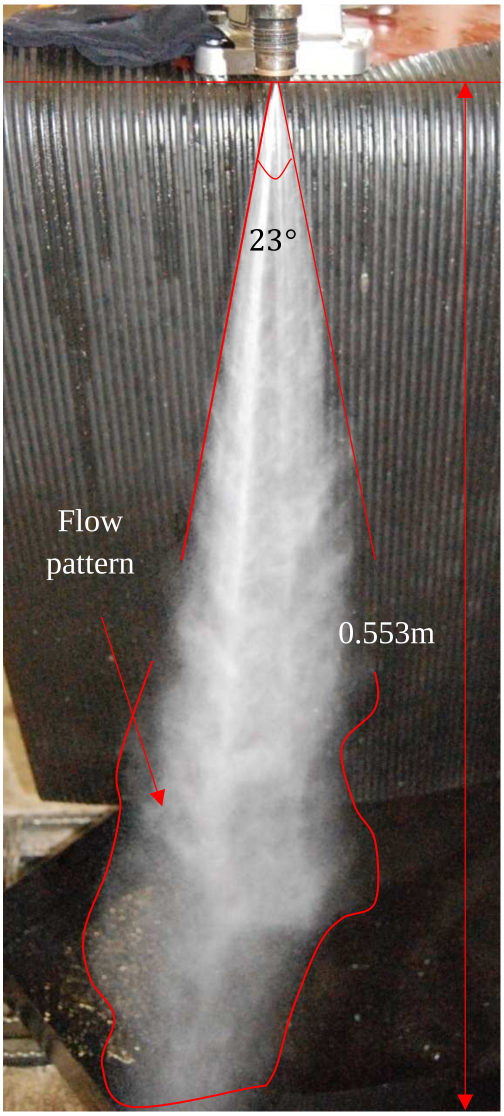

Figure 4.6: Spray pattern at given 200 bar pressure of diesel

4.3.3 Spray Pattern at 300 bar Pressure

For the presence of the spray pattern in Figure 4.7, the cone angle of this spray pattern becomes smaller than the Figure 4.6 which is 20^{o}. This pattern also describes the increase of spray tip penetration. This spray pattern will result a 0.557m spray tip penetration which is higher than Figure 4.5. The increased value of spray tip penetration happens due to the increase of pressure supply. A large amount of flow pattern area will be generated at the combustion chamber.

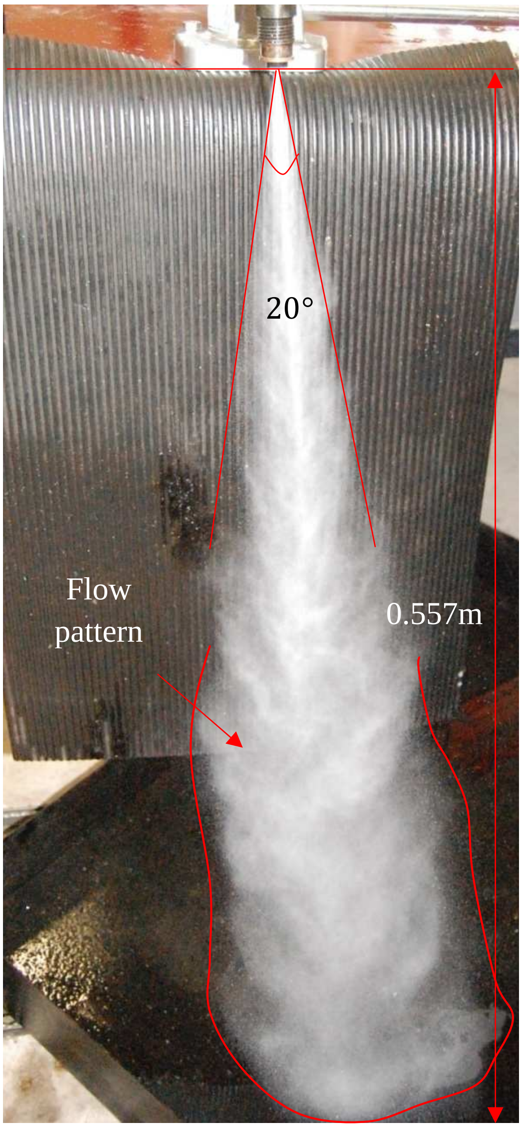

Figure 4.7: Spray pattern at given 300 bar pressure of diesel

4.3.4 Spray Pattern at 400 bar Pressure

The spray tip penetration length increases with the supply pressure as shown in Figure 4.8. From this result, the flow pattern is bigger compared to the Figure 4.7. This flow pattern is affected by the variation of pressure supply and will cause complete combustion. Hence, it will cause the engine to produce high power. The cone angle of the spray decreases which is now 18.5^{o} compared to the previous figure. The droplet size also becomes smaller and will influence the area of the combustion chamber. The viscosity of this diesel decreases due to different pressure supplies. At the end of the result, the specific heat capacity of diesel also increases due to the high pressure on the pressure supply.

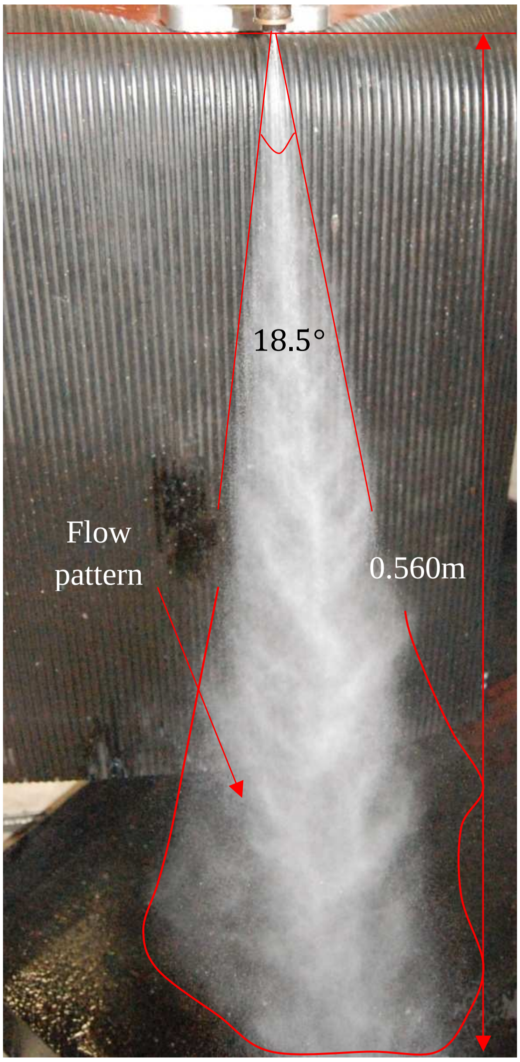

Figure 4.8: Spray pattern at given 400 bar pressure of diesel

4.4 SPRAY PATTERN FOR COOKING OIL

In the experiment for cooking oil, the pressures that are to be imposed are only 300 bar and 400 bar. This is because, at low pressures of 100 and 200 bar, the injector cannot produce the pattern and this is closely related to fuel properties such as its viscosity and density.

4.4.1 Spray Pattern at 300 bar Pressure

For the presence of the spray pattern in Figure 4.9, the result of spray tip penetration is 0.370m which is higher than Figure 4.10. As the pressure supply increases, it will affect the cone angle of the spray. As a result, the 18^o of cone angle is found to be bigger compared to the Figure 4.10. On the other hand, this will result in the increasing of flow pattern. When the flow pattern is increased, complete combustion will occur at combustion chamber thus high power will be produced.

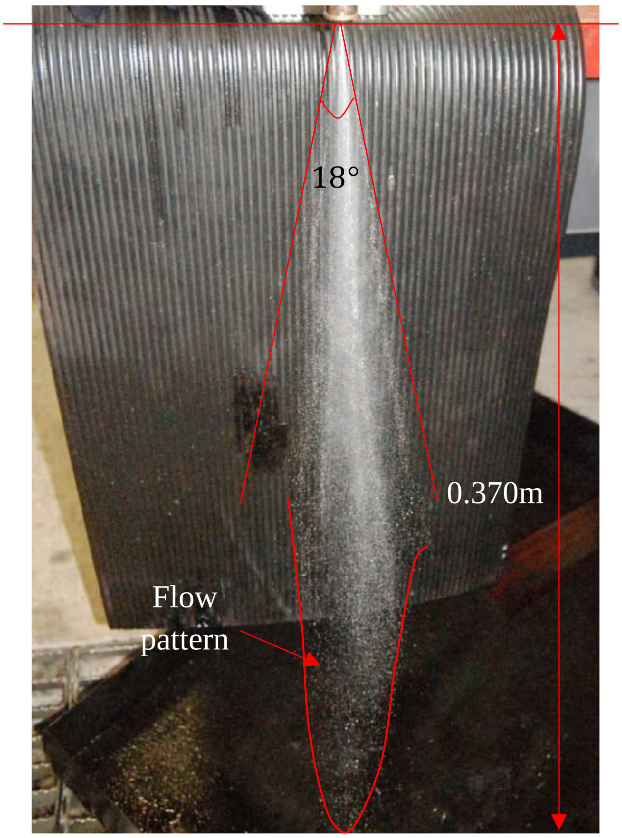

Figure 4.9: Spray pattern at given 300 bar pressure of cooking oil

4.4.2 Spray Pattern at 400 bar Pressure

The increasing pressure supply will cause the decreasing of cone angle size. For the cooking oil, the viscosity of this fluid is higher than diesel. Hence, the small spray tip penetration will occur which is 0.242m as shown in Figure 4.10. The droplet size of this spray pattern is also bigger compared to the previous figure. Due to that, incomplete combustion will occur at combustion chamber. Thus the lack of power and torque will influence the low acceleration of the vehicle.

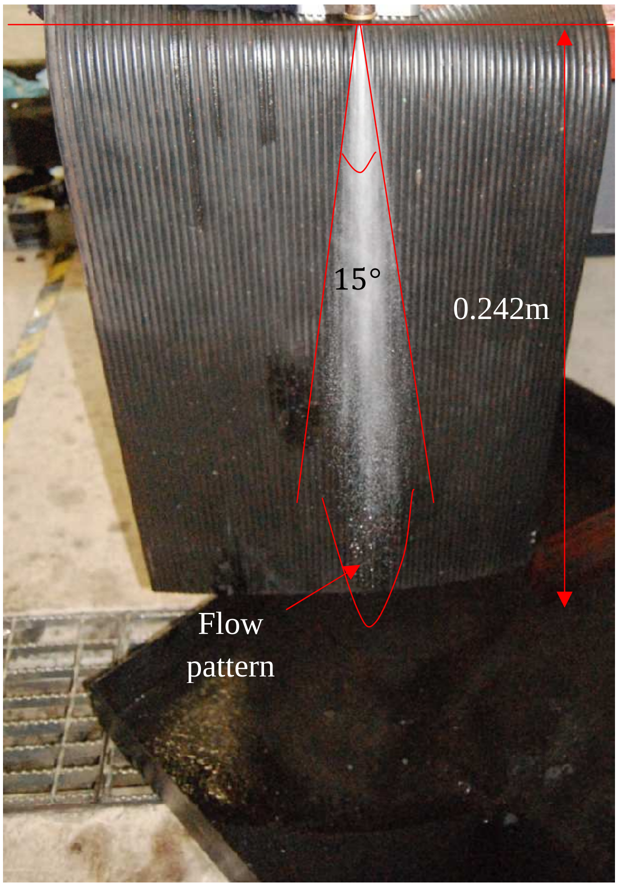

Figure 4.10: Spray pattern at given 400 bar pressure of cooking oil

4.5 COMPARISON POME, DIESEL AND COOKING OIL

Table 4.1: Fuel comparison

Pressure (bar)	Characteristic	POME	Diesel	Cooking oil
100	Cone angle	Very small	Very large	-
	Spray tip penetration	Low	Low	-
	Spray atomization	Small	Small	-
	Droplet size	Large	Medium	-
200	Cone angle	Small	Large	-
	Spray tip penetration	Medium	Medium	-
	Spray atomization	Medium	Medium	-
	Droplet size	Medium	Medium	-
300	Cone angle	Large	Medium	Medium
	Spray tip penetration	High	Large	High
	Spray atomization	Large	Large	Small
	Droplet size	Small	Small	Small
400	Cone angle	Medium	Small	Small
	Spray tip penetration	High	High	Low
	Spray atomization	Large	Large	Small
	Droplet size	Very small	Small	Large

4.6 BIODIESEL PROPERTIES

4.6.1 Vapour Pressure

Volatility is a fuel tendency to vaporize and the vapour pressure curve helps to determine the level of volatility. Palm oil methyl ester (POME) can be regarded as a near ideal solution (Goodrum, 2002). Therefore, the total vapour pressure is based on the mixture of the vapour pressure of the different fatty acids composing the biodiesel and can be calculated based on the Antoine equation:

$$\log Pv = A - \frac{B}{T+C} \tag{4.1}$$

Pv = Vapour pressure, A, B, and C = Constant

Table 4.2: Antoine equation constants of POME

	Palm	A	B	C
C8:0	0.1	9.466	1765	-70.61
C10:0	0.1	10.0582	2261.99	-53.91
C12:0	0.9	9.4297	1958.77	-96.99
C14:0	1.3	9.6258	2194.36	-95.5
C16:0	43.9	9.5714	2229.94	-111.01
C18:0	4.9	9.3746	2174.39	-131.23
C18:1	39	9.9155	2583.52	-96.15
C18:2	9.5	8.2175	1450.62	-188.03
C18:3	0.3	8.1397	1387.93	-196.16

Source: Rochaya, (2007)

Table 4.2 shows an Antoine equation constant of POME. Based on Equation 4.1 by using the Table 4.2, the vapour pressure for biodiesel can be plotted as Figure 4.11. The graph shows the increasing of vapour pressure due to the increasing of temperature. The prediction has been defined as when the pressure of spray pattern of POME is increased, the vapour pressure of the POME will also increase. This graph will also affect the cone angle of the POME spray pattern and the droplet size. Tip pattern for POME will also be affected due to the increasing of vapour pressure.

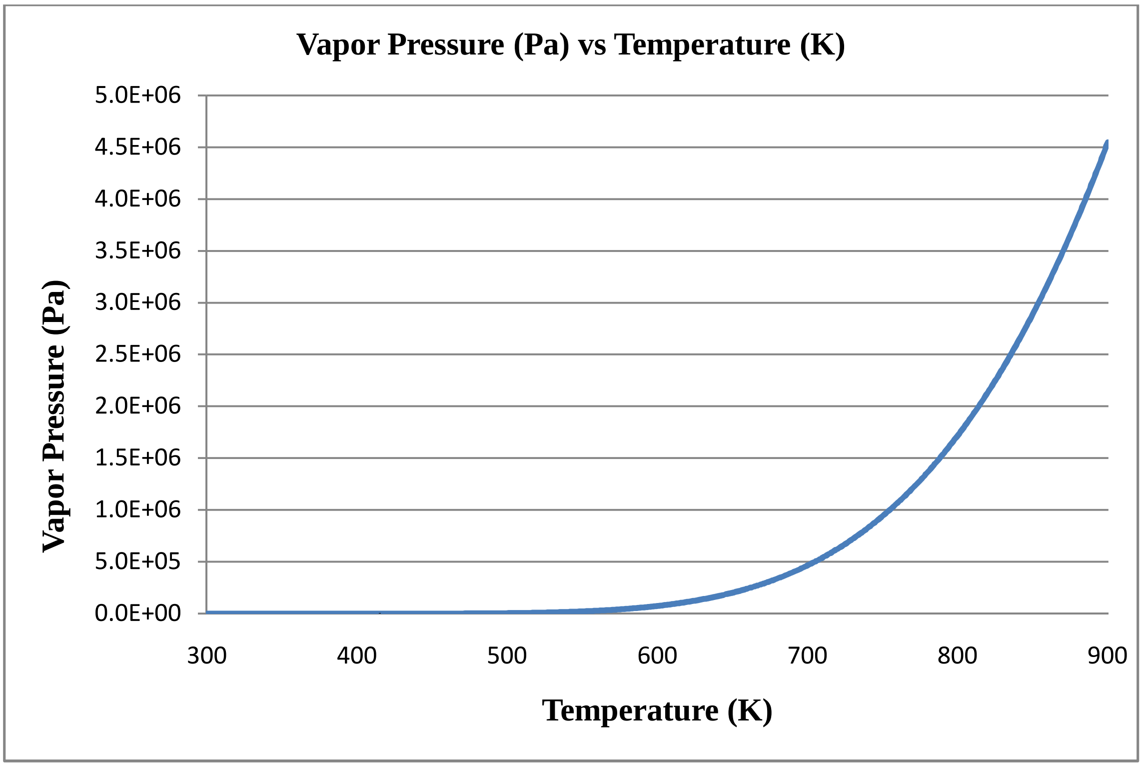

Figure 4.11: Vapour pressure of POME

4.6.2 Viscosity

From the Equation 4.2, the graph viscosity versus temperature has been plotted. The graph shows the decreasing value of viscosity when the temperature is increased. This phenomenon can be defined as POME has a higher viscosity than diesel. In the other hand, the viscosity of POME will decrease due to the increasing temperature because the viscosity would affect the combustion. If the fuel has the lower viscosity, complete combustion occurs in combustion chamber.

$$\ln \mu = -0.87 \ln T + 4.68 \quad (4.2)$$

μ = Viscosity, T = Temperature, 0.87 = Constant, 4.68 = Constant

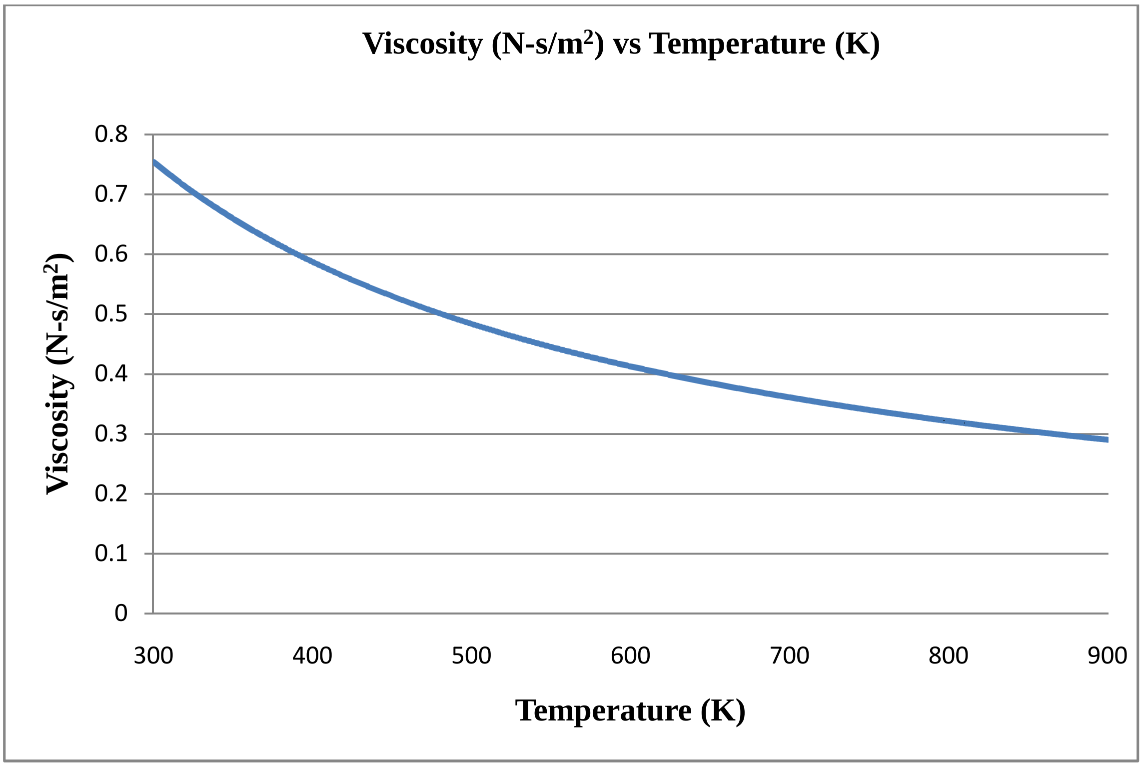

Figure 4.12: Viscosity of POME

4.6.3 Specific Heat Capacity

Based on Equation 4.3, the specific heat capacity for biodiesel can be plotted as Figure 4.13. The graph shows the increasing of specific heat capacity due to the increasing of temperature. The prediction can be defined when the pressure of spray pattern of POME is increase, the specific heat capacity of the POME will also be increased. Besides that, the temperature when the combustion occurred is higher so that, the specific heat capacity for POME also increases. The tip penetrations of the spray pattern of POME also increase due to the increasing of specific heat capacity.

$$Cp = 0.0050\,T + 0.987 \tag{4.3}$$

Cp = Specific heat capacity, T = Temperature, 0.0050 = Constant, 0.987 = Constant

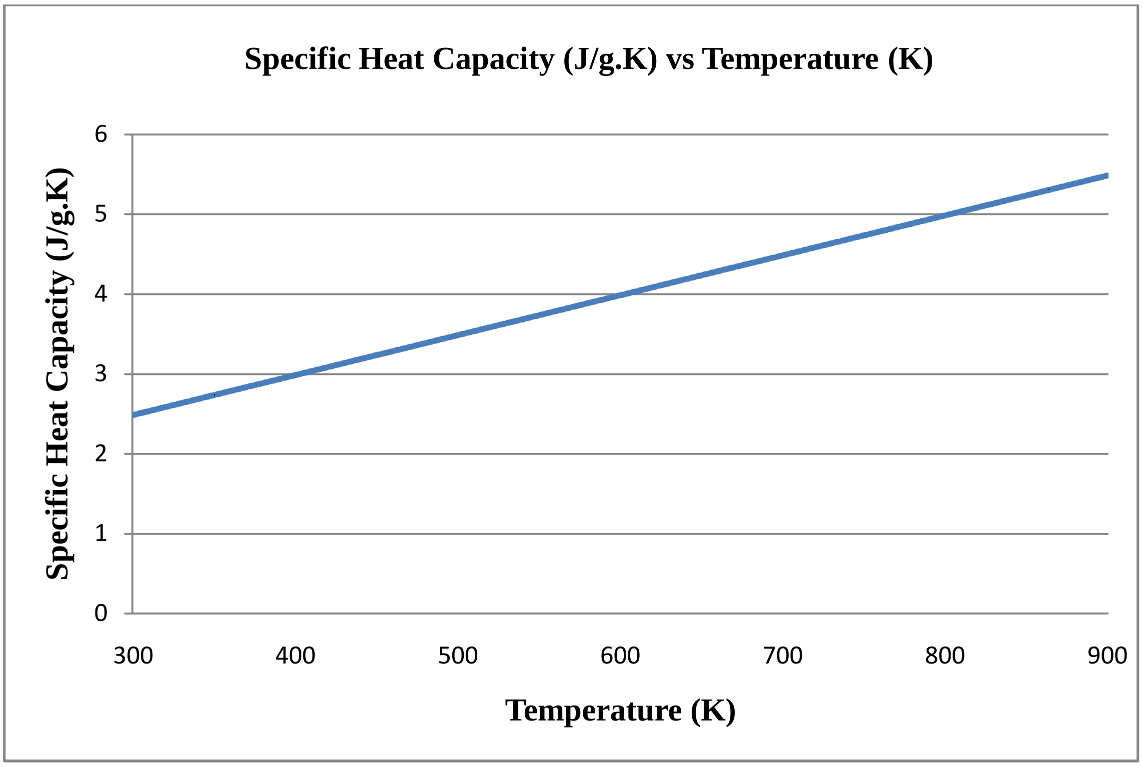

Figure 4.13: Specific heat capacity of POME

4.6.4 Surface Tension

From the Equation 4.4, the graph surface tension versus temperature has been plotted. The graph shows the decreasing value of surface tension when the temperature is increased. This graph also shows that can POME has a higher surface tension than diesel. In the other hand, the surface tension of POME must be decreased due to the increasing temperature because the surface tension would affect the combustion. During the decrement of surface tension, the larger cone angle and the larger tip penetration of spray pattern occur. This can cause complete combustion and more power can also be achieved.

$$\mathrm{ST} = 52.46 - 0.0658\,T \tag{4.4}$$

ST = Surface tension, T = Temperature, 52.46 = Constant, 0.00658 = Constant

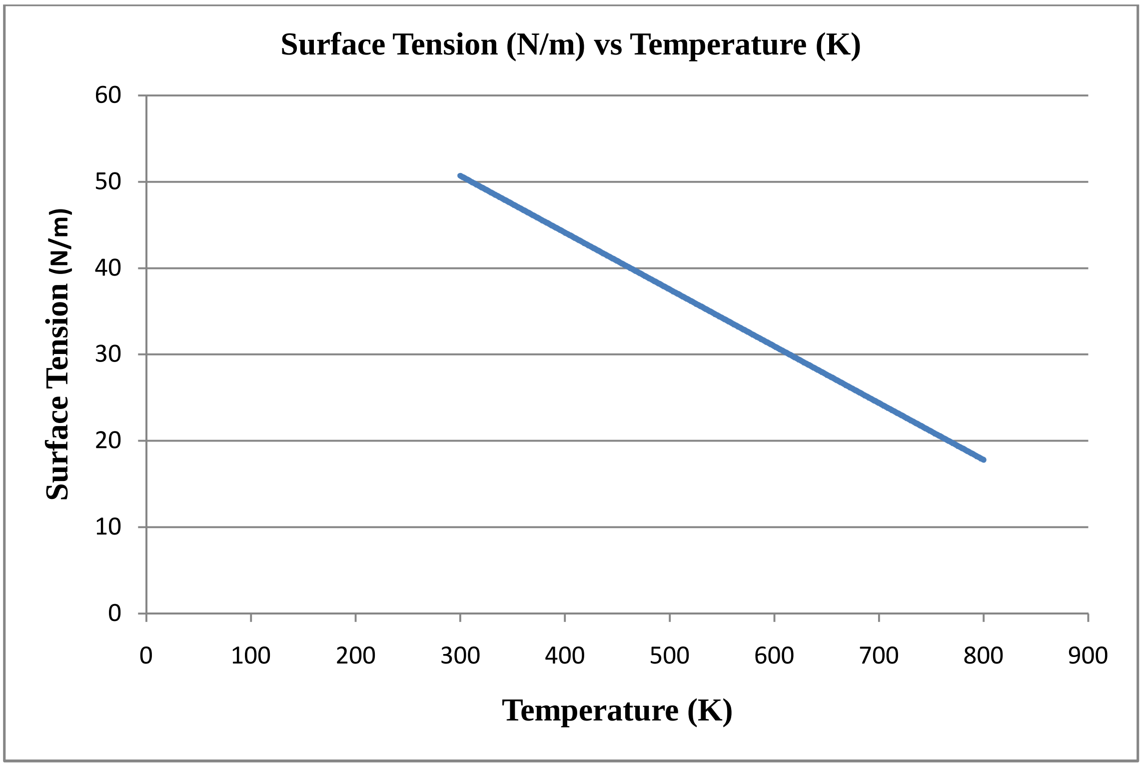

Figure 4.14: Surface tension of POME

4.7 SUMMARY

The fluid properties such as, specific heat, vapour pressure, surface tension and viscosity have been determined over a wide range of temperatures. Palm oil methyl ester possesses a high boiling point compared to petrodiesel (diesel) and this study has showed that the fuel chemical structure and critical properties significantly influences the fuel properties. This section has shown that the fuels differ significantly in their physical and chemical characteristics significantly modifying the evaporation and combustion process and therefore the properties need to be accurately determined.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

As a conclusion, characteristics of palm oil methyl ester as alternative fuel were successfully developed. This is because it managed to achieve the objective which is to determine the characteristics of palm oil and to prepare a database of palm oil against other biodiesel sources.

This project started from the finding and analyzing of journals or books, defining the spray characteristics and lastly, making a prediction of the database and calculations. Every single thing needed to be done systematically and properly in order to ensure the database of palm oil will be prepared and the characteristic palm oil methyl ester will be determined.

From this project, it is observed that as the pressure supply increases, the spray tip penetration of the spray pattern also increases, thus affecting the combustion in the combustion chamber. As a result, complete combustion will occur due to the effect of spray pattern. Hence, more power will be provided and acceleration of the vehicle will be increased.

Palm oil methyl ester (POME) possesses a high boiling point compared to diesel and this study has shown that the fuel chemical structure and critical properties significantly influences the fuel properties.

Every single result, advantages, disadvantages and constraint of this project has been discussed. So that further researches could be done and applied for this project. Finally, this database can be used to make palm oil methyl ester as a fuel alternative in the future.

5.2 RECOMMENDATIONS

Throughout the development of this project, there are several things that can be done for further research and enhancement. By using the Phase Doppler Particle Analyzer (PDPA), very detailed information on the different spray characteristics, is being capable of directly measuring simultaneously the droplet size and velocity as well as calculating the particle number density and volume flux throughout the spray. This PDPA is one of the most popular techniques for spray characterization in combusting sprays even though the cost of this equipment is high.

Besides that, in order to limit the cost of this project, we need to develop our own fuel which is in the form of palm oil methyl ester. This is possible since we already have the Chemical Laboratory at the Gambang campus, and therefore the opportunities to develop this fuel are high.

REFERENCES

Bala, B.K. 2005. *Studies on biodiesels from transformation of vegetable oils for diesel engines.* Edu Sci Technol.

Basiron, Y. and May, C.Y. 2007, Crude palm oil as a source of biofuel - Its impact on price stabilization and environment MPOB, Malaysia.

Clark, S.J., Wagner, L., Schrock, M.D., Pinnaar, P.G. 1984. Methyl and ethyl esters as renewable fuels for diesel engines. *JAOCS*. **61**: 1632-1638.

Demirbas, A. 2002. Biodiesel from vegetable oils via transesterification in supercritical methanol. *Convers Mgmt.* **43**: 2349-56.

Demirbas, A. 2003. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: a survey. *Energy Convers.* **44**: 2093-2109.

Demirbas, A. 2003, A realistic fuel alternative for diesel engine, Professor of Energy Technology, Turkey.

Demirbas, A. 2006. *Global biofuel strategies*. Energy Edu Sci Technol.

Dowaki, K., Ohta, T., Kasahara, Y., Kameyama, M., Sakawaki, K., Mori, S. 2007. An economic and energy analysis on bio-hydrogen fuel using a gasification process. *Renewable Energy*. **32**: 80-94.

Fernando, S., Hall, C., Jha, S., 2006. NO, reduction from biodiesel fuels. *Energy Fuels*. **20**: 376-382

Graboski, M.S., McCormick, R.L. 1998. Combustion of fat and vegetable oil derived fuels in diesel engines. *Prog Energy Combust Sci*. **24**: 125-164.

Islam, M.N., Islam, M.N., Beg, M.R.A. 2004. The fuel properties of pyrolysis liquid derived from urban solid wastes in Bangladesh. *Bioresour Technol*. **92**: 181-186.

Kalam, M.A. and Masjuki, H.H. 2002. Biodiesel from palm oil – An analysis of it properties and potential. *Department of Mechanical Engineering, University of Malaya,* Kuala Lumpur, Malaysia.

Lunjew, M.D. 2007, Fourth biomass-asia workshop: Policy and legislation on biofuel utilisation, Malaysia.

Lefebvre, A. H. 1985, Fuel Effects on Gas Turbine Combustion - Ignition, stability, and combustion efficiency. *Journal of Engineering for gas turbine and power*.

Ma, F., Hana, M.A. 1999. Biodiesel production: a review. Bioresour Technol **70**: l-15.

Masjuki, H. H., Kam, M. A., Maleque, M. A., Kubo, A. and Nonaka, T. 2001, Performance, Emissions and Wear Characteristics of an I.D.I. Diesel Engine using Coconut Blended Oil.

Masjuki, H.H. and Maleque, M.A. 1996, The effect of palm oil diesel fuel contaminated lubricant on sliding wear of cast iron against mild steel. *WEAR 198.*

Meher, L.C., Vidya Sagar, D., Naik, S.N. 2006. Technical aspects of biodiesel production by transesterification-a review. Renew Sustain Energy. **10**: 248-268.

Nitschke, W.R., Wilson, C.M. 1965. Rudolph Diesel, Pioneer of the Age of Power. University of Oklahoma Press, Norman, OK.

Puhan, S., Vedaraman, N., Rambrahaman, B.V., Nagarajan, G. 2005. Mahua (Madhuca indica) seed oil: a source of renewable energy in India. *J Sci Ind Res*. **64**: 890-896.

Reijnders, L. 2006. Conditions for the sustainability of biomass based fuel use. *Energy Policy*. **34**: 863-876.

Rochaya, D. 2007, *Numerical Simulation of Spray Combustion using Bio-mass Derived Liquids Fuels,* Phd’s Thesis, Cranfield University.

Sastry, G.S.R., Krishna Murthy, A.S.R., Ravi Prasad, P., Bhuvaneswari, K., Ravi, P.V. 2006. Identification and determination of biodiesel in Diesel. *Energy Sources Part A.* **28**: 1337-1342.

Sensoz, S., Angin, D., Yorgun, S.2000. Influence of particle size on the pyrolysis of rapeseed (Brassica napus L.): fuel properties of bio-oil. *Biomass Bioenergy*. **19**: 271-279.

Sheehan, J., Dunahay, T., Benemann, J., Roessler, P. 1998. A Look Back at the U.S. Department of Energy’s Aquatic Species Program-Biodiesel from Algae. National Renewable Energy Laboratory (NREL) Report: NREmP-580-24190. Golden, CO.

Venkataraman, N.S (ed.) 2002. Focus on bio-diesel. Nandini Chem J 1X (IO): 19-21.

APPENDIX A1

GANTT CHART OF FYP 1

No	Activities	week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Project progress																
1	Chapter : Introduction	Planning															
		Actual															
2	Chapter 2: Literature review	Planning															
		Actual															
3	Chapter 3: Methodology	Planning															
		Actual															
4	Finalizing thesis writing as draft 1	Planning															
		Actual															
5	Presentation	Planning															
		Actual															

Planning to complete work

Actual complete work

APPENDIX A2

GANTT CHART OF FYP 2

No	Activities	week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Project progress																
1	Prepared equipment for experimental	Planning															
		Actual															
2	Experimental	Planning															
		Actual															
3	Result	Planning															
		Actual															
4	Documentation	Planning															
		Actual															
5	Finishing of final draft and Prepare full report	Planning															
		Actual															
6	Submission of final draft with logbook and prepare for presentation	Planning															
		Actual															

Planning to complete work

Actual complete work

APPENDIX B1

CALCULATION OF VAPOUR PRESSURE

$$\log(Pv) = A - \frac{B}{T+C}$$

	Palm	X	Y	Z
C8:0	0.1	9.466	1765	-70.61
C10:0	0.1	10.0582	2261.99	-53.91
C12:0	0.9	9.4297	1958.77	-96.99
C14:0	1.3	9.6258	2194.36	-95.5
C16:0	43.9	9.5714	2229.94	-111.01
C18:0	4.9	9.3746	2174.39	-131.23
C18:1	39	9.9155	2583.52	-96.15
C18:2	9.5	8.2175	1450.62	-188.03
C18:3	0.3	8.1397	1387.93	-196.16

A	B	C
0.009466	1.765	-0.07061
0.010058	2.26199	-0.05391
0.084867	17.62893	-0.87291
0.125135	28.52668	-1.2415
4.201845	978.9437	-48.7334
0.459355	106.5451	-6.43027
3.867045	1007.573	-37.4985
0.780663	137.8089	-17.8629
0.024419	4.16379	-0.58848
9.562854	**2285.217**	**-113.352**

Temperature (K)	T+C	B/(T+C)	A-B/(T+C)	Pv
300	186.648	12.24346	-2.6806	0.002086
400	286.648	7.972206	1.590648	38.96258
500	386.648	5.910329	3.652525	4492.879
600	486.648	4.695831	4.867023	73624.53
700	586.648	3.89538	5.667474	465022.3
800	686.648	3.328076	6.234778	1717029
900	786.648	2.905006	6.657848	4548291

APPENDIX B2

CALCULATION OF VISCOSITY

$$Ln\mu_{FAME} = -0.87 LnT + 4.68$$

	Palm	**X**	**Y**	**Z**
C8:0	0.1	9.466	1765	-70.61
C10:0	0.1	10.0582	2261.99	-53.91
C12:0	0.9	9.4297	1958.77	-96.99
C14:0	1.3	9.6258	2194.36	-95.5
C16:0	43.9	9.5714	2229.94	-111.01
C18:0	4.9	9.3746	2174.39	-131.23
C18:1	39	9.9155	2583.52	-96.15
C18:2	9.5	8.2175	1450.62	-188.03
C18:3	0.3	8.1397	1387.93	-196.16

A	**B**	**C**
0.009466	1.765	-0.07061
0.010058	2.26199	-0.05391
0.084867	17.62893	-0.87291
0.125135	28.52668	-1.2415
4.201845	978.9437	-48.7334
0.459355	106.5451	-6.43027
3.867045	1007.573	-37.4985
0.780663	137.8089	-17.8629
0.024419	4.16379	-0.58848
9.562854	**2285.217**	**-113.352**

Temperature (K)	**Ln T**	**A(Ln T)**	**A(Ln T)+B**	**Viscosity (μ)**
300	5.703782475	-4.962290753	-0.282290753	0.754054409
400	5.991464547	-5.212574156	-0.532574156	0.587091757
500	6.214608098	-5.406709046	-0.726709046	0.483497543
600	6.396929655	-5.5653288	-0.8853288	0.412578495
700	6.551080335	-5.699439891	-1.019439891	0.360796969
800	6.684611728	-5.815612203	-1.135612203	0.321225406
900	6.802394763	-5.918083444	-1.238083444	0.289939371

APPENDIX B3

CALCULATION OF SPECIFIC HEAT CAPACITY

$$c_{pFAME} = 0.0050\ T + 0.987$$

	Palm	X	Y	Z
C8:0	0.1	9.466	1765	-70.61
C10:0	0.1	10.0582	2261.99	-53.91
C12:0	0.9	9.4297	1958.77	-96.99
C14:0	1.3	9.6258	2194.36	-95.5
C16:0	43.9	9.5714	2229.94	-111.01
C18:0	4.9	9.3746	2174.39	-131.23
C18:1	39	9.9155	2583.52	-96.15
C18:2	9.5	8.2175	1450.62	-188.03
C18:3	0.3	8.1397	1387.93	-196.16

A	B	C
0.009466	1.765	-0.07061
0.010058	2.26199	-0.05391
0.084867	17.62893	-0.87291
0.125135	28.52668	-1.2415
4.201845	978.9437	-48.7334
0.459355	106.5451	-6.43027
3.867045	1007.573	-37.4985
0.780663	137.8089	-17.8629
0.024419	4.16379	-0.58848
9.562854	**2285.217**	**-113.352**

Temperature (K)	A(T)	Cp = A(T)+B
300	1.5	2.487
400	2	2.987
500	2.5	3.487
600	3	3.987
700	3.5	4.487
800	4	4.987
900	4.5	5.487

APPENDIX B4

CALCULATION OF SURFACE TENSION

$$ST = 52.46 - 0.0658\,t$$

	Palm	X	Y	Z
C8:0	0.1	9.466	1765	-70.61
C10:0	0.1	10.0582	2261.99	-53.91
C12:0	0.9	9.4297	1958.77	-96.99
C14:0	1.3	9.6258	2194.36	-95.5
C16:0	43.9	9.5714	2229.94	-111.01
C18:0	4.9	9.3746	2174.39	-131.23
C18:1	39	9.9155	2583.52	-96.15
C18:2	9.5	8.2175	1450.62	-188.03
C18:3	0.3	8.1397	1387.93	-196.16

A	B	C
0.009466	1.765	-0.07061
0.010058	2.26199	-0.05391
0.084867	17.62893	-0.87291
0.125135	28.52668	-1.2415
4.201845	978.9437	-48.7334
0.459355	106.5451	-6.43027
3.867045	1007.573	-37.4985
0.780663	137.8089	-17.8629
0.024419	4.16379	-0.58848
9.562854	**2285.217**	**-113.352**

Temperature (K)	A(t)	ST = B - A(t)
300	19.74	32.72
400	26.32	26.14
500	32.9	19.56
600	39.48	12.98
700	46.06	6.4
750	49.35	3.11