TOOL KITS FOR TESTING BIODIESEL QUALITY

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ABSTRACT

Nowadays, the alternative ways to conventional fossil-based diesel is the used of biodiesel instead of fossil diesel fuel. In Thailand, there are many productions of biodiesel in small and medium enterprises to use with their engine, while the production in these scales did not have the quality testing. The objective of this research is to make the inexpensive tool kits and easy way for testing the impurity of biodiesel and to make a model tool kits for convenient use. The design of tool kits was created by Rhinoceros program. The raw materials were investigated base on price and convenient. The assembly line of tool kits was created follow the design. And the completed tool kit was built along the assembly line. The total cost of tool kits is 3,795 Baht. The conditions for testing the quality utilization of tool kits with biodiesel are at 60 °C, 30 minutes reaction time and 24 hours precipitation time. The result from tool kits utilization with biodiesel was testified by the volume of precipitate the percent of methyl ester compared with the ASTM standard. The methyl ester of two biodiesel samples was 97.44 % and 98.06 %. It was indicated that both are these biodiesel were pure enough to apply with the diesel engine. However, this tool kits can test the purity just only the approximately level, it can not test in the component of impurities.

Keywords: tool kits, testing, biodiesel, quality

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Abbreviation and Symbol

Abbreviation	**Meaning**
WCO	Waste Cooking Oil
WFG	Waste Fryer Grease
ASTM	American Society for Testing and Materials
KOH	Potassium Hydroxide
H_2SO_4	Sulfuric Acid
GC	Gas Chromatography
GCMS	Gas Chromatography Mass Spectroscopy
TLC	Thin Layer Chromatography
HPLC	High Performance Liquid Chromatography
TGA	Thermogravimetric Analyzer
App.	Appendix
°C	Degree Celcius
No.	Number
atm	Atmospheric Temperature and Pressure
ml	Milliliter
g	Gram
hr	Hour
cm	Centimeter

Chapter 1

INTRODUCTION

1.1 Motivation

Nowadays, the main source of energy demand which is petroleum is increasing rapidly owing to the excessive use of the fossil fuel. Beside, world is presently faced with the crisis of depletion. So the increment of oil price has been expedited. The increasing demand of petroleum in developing country has also increase the oil price [1]. The combustion of petroleum, which threatens wild and human life, impacted on the environment and human health. There is an increasing aspect in developing alternative energy resources such as hydrogen cells, solar energy and wind power. However, these technologies have very high cost. One of the alternative ways to conventional fossil-based diesel is the used of biodiesel instead of fossil diesel fuel.

Biodiesel is an alternative fuel for diesel engines that is monoalkyl ester of long chain fatty acids made from renewable biological sources such as vegetable oil or animal fats. The biodiesel is as effective as petroleum diesel in powering unmodified diesel engines. It is biodegradable and non-toxic which lowering emission of particulate matter, sulphur compound, carbon monoxide, carbon dioxide, and unburned hydrocarbon except NO_x [2-4]. It has low undesirable tailpipe emission profiles and therefore is environmentally benign [5].

The most common way to produce biodiesel is by transesterification reaction. In this reaction, triglyceride as the main component of vegetable oils reacts with an alcohol to form fatty acid and glycerol. This is justified by the rapidly of the transesterification reaction in presence of alcohol soluble bases and by the low cost material. Although 100% of excess methanol is generally used to obtain a higher conversion of oil, biodiesel is not 100% monoalkyl ester after the typical refinement process, including unreacted methanol separation, catalyst removal by water washing and subsequent water elimination. It also contains small quantities of monoglycerides (MG), diglycerides (DG), triglycerides (TG) and glycerine, etc. because of the irreversible reaction.

Since, free and bonded glycerin content can reflects the quality of biodiesel. High total glycerin content can cause injection fouling. It may also contribute to the formation of deposits at injection nozzle, piston, which can clog the fuel system and valve, and severity of engine durability problem. It can also build up in the bottom of storage and fuel tank [6].

Nowadays in Thailand, there are many productions of biodiesel in small and medium enterprises to use with their engine, while the production in these scales did not have the quality testing. In the presence, general methods for testing biodiesel are very high cost and waste times. From these reasons, the development of easy testing biodiesel is invented by the determining the amount of glycerine left in biodiesel oil by taking it into the transresterification again [8]. For the convenience testing biodiesel at the biodiesel process area, tool kit is should be used. Therefore, this tool kit for testing amount of glycerine in biodiesel is invented.

1.2 Objectives

1. To make the inexpensive tool kits and easy way for testing the impurity of biodiesel.
2. To make a model tool kits for convenient use.

1.3 Scopes of study

1. Sketch and design tool kits model.
2. To search heater used for tool kits model; which can generate heat for transesterificstion process.
3. To investigate raw material used for making tool kits and biodiesel testing.
4. To assembly a tool kit which composes of 2 sides, one side is used for fit with heater and another side is used for storing the apparatus and chemicals.
5. Testing tool kits for quality utilization with biodiesel.

6. Modification tool kits for biodiesel testing application.

1.4 Expected Results

1. To get an inexpensive tool kits for testing impurities (glycerol) in biodiesel.
2. To get an easy way for testing quality of biodiesel.

Chapter 2

THEORY AND LITERATURE REVIEW

2.1 Glycerol

Glycerol is a chemical compound also commonly called glycerin or 1,2,3-propanetriol.The simplest trihydric alcohol, with the formula $CH_2OHCHOHCH_2OH$. The name glycerol is preferred for the pure chemical, but the commercial product is usually called glycerin. It is widely distributed in nature in the form of its esters, called glycerides. The glycerides are the principal constituents of the class of natural products known as fats and oils.

Glycerol has three hydrophilic hydroxyl groups as shown in figure 2.1 that are responsible for its solubility in water and its hygroscopic nature. It is a very weak base. Glycerol substructure is a central component of many lipids.

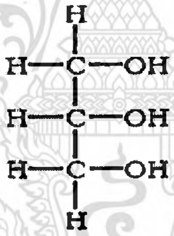


Figure 2.1 Structure of Glycerol [9]

Pure glycerin is a colorless, odorless, viscous liquid with a sweet taste. It is completely soluble in water and alcohol but is only slightly soluble in many common solvents, such as ether, ethyl acetate, and dioxane. Glycerol is a trihydric alcohol. It melts at 17.8°C, boils with decomposition at 290°C, and is miscible with water and ethanol. It is hygroscopic; i.e., it absorbs water from the air; this property makes it valuable as a moistener in cosmetics.

Glycerin is used in nearly every industry. With dibasic acids, such as phthalic acid, it reacts to make the important class of products known as alkyd resins, which are widely used as coating and in paints. It is used in innumerable pharmaceutical and cosmetic preparations; it is an ingredient of many tinctures, elixirs, cough medicines, and anesthetics; and it is a basic medium for toothpaste. In foods, it is an important moistening agent for baked goods and is added to candies and icings to prevent crystallization. It is used as a solvent and carrier for extracts and flavoring agents and as a solvent for food colors. Many specialized lubrication problems have been solved by using glycerin or glycerin mixtures. Many millions of pounds are used each year to plasticize various materials. In foods and beverages, glycerol serves as a humectant, solvent and sweetener, and may help preserve foods. It is also used as filler in commercially prepared low-fat foods (e.g., cookies), and as a thickening agent in liqueurs. Glycerol also serves as a way, along with water, to preserve certain types of leaves. Glycerol is also used as a sugar substitute. In this regard, it has approximately 27 calories per teaspoon and is 60% as sweet as sucrose. Although it has about the same food energy as table sugar, it does not raise blood sugar levels, nor does it feed the bacteria that form plaques and cause dental cavities. As a food additive [10], glycerol is also known as E number E422.

In organic synthesis, glycerol is used as a readily available prochiral building block. Even if glycerol with no substitutions is symmetrical, and carbon atoms 1 and 3 are exchangeable, once one of them forms an ester or ether bond, the two are no longer exchangeable. Further bond formation and hydrolysis may lead to products substituted solely at the third carbon; due to such circumstances, to maintain both full description and conformance to the chemistry naming rules (which require carbon counting to minimize ordinal numbers of substituents), the carbons are named *sn*-1, *sn*-2, and *sn*-3, with "sn" standing for "sterospecifical numbering".

Glycerin can also serve as a substitute for petroleum based products. Glycerin derived epichlorohydrin and propylene glycol are substitutes for petroleum-based Polypropylene.

2.1.1 Categorization

Glycerol is currently categorized by the American Dietetic Association as a carbohydrate. The FDA [11] carbohydrate designation includes all caloric macronutrients excluding protein and fat. This group includes indigestible fibers, but not ash. Glycerin has a caloric density similar to table sugar, but a lower glycemic index and different metabolic pathway within the body, so some dietary advocates accept glycerin as a sweetener compatible with low carbohydrate diets.

2.1.2 Feedstock

It is one of the major raw materials for the manufacture of polyols for flexible foams, and to a lesser extent rigid polyurethane foam.

Glycerol is used to produce nitroglycerin, or glycerol-trinitrate (GTN) [12], which is an essential ingredient of smokeless gunpowder and various explosives such as dynamite, gelignite and munitions like cordite. Reliance on soap-making to supply co-product glycerine made it difficult to increase production to meet wartime demand. Hence, synthetic glycerin processes were national defense priorities in the days leading up to World War II. GTN is commonly used to relieve *angina pectoris*, taken in the form of sub-lingual tablets, or as an aerosol spray.

Glycerol is also used to manufacture mono- and di-glycerides for use as emulsifiers, as well as polyglycerol esters going into shortenings and margarine.

2.1.3 Research laboratory usage

Glycerol is a common component of solvents for enzymatic reagents stored at temperatures below zero degrees Celsius due to the depression of the freezing temperature of solutions with high concentrations of glycerol. It is also dissolved in water to reduce damage by ice crystals to laboratory organisms that are stored in frozen solutions, such as bacteria, nematodes, and fruit flies. Samples are loaded into a arose gel electrophoresis mixed in loading buffers that mainly consist of glycerol; when the sample is injected into wells, the glycerol causes the solution to sink through the running buffer to the bottom of the well.

2.2 Biodiesel [13]

Biodiesel is commonly produced by the transesterification of the vegetable oil or animal fat of feedstock. There are several methods for carrying out this transesterification reaction including the common batch process, supercritical processes, ultrasonic methods, and even microwave methods.

Chemically, transesterified biodiesel comprises a mix of mono-alkyl esters of long chain fatty acids. The most common form uses methanol (converted to sodium methoxide) to produce methyl esters (commonly referred to as Fatty Acid Methyl Ester - FAME) as it is the cheapest alcohol available, though ethanol can be used to produce an ethyl ester (commonly referred to as Fatty Acid Ethyl Ester - FAEE) biodiesel and higher alcohols such as isopropanol and butanol have also been used. Using alcohols of higher molecular weights improves the cold flow properties of the resulting ester, at the cost of a less efficient transesterification reaction. A lipid transesterification production process is used to convert the base oil to the desired esters. Any free fatty acids (FFAs) in the base oil are either converted to soap or removed from the process, or they are esterified (yielding more biodiesel) using an acidic catalyst. After this processing, unlike straight vegetable oil, biodiesel has combustion properties very similar to those of petroleum diesel, and can replace it in most current uses.

A by-product of the transesterification process is the production of glycerol. For every 1-tonne of biodiesel that is manufactured, 100 kg of glycerol are produced. Originally, there was a valuable market for the glycerol, which assisted the economics of the process as a whole. However, with the increase in global biodiesel production, the market price for this crude glycerol (containing 20% water and catalyst residues) has crashed. Research is being conducted globally to use this glycerol as a chemical building block. One initiative in the UK is The Glycerol Challenge.

2.2.1 Properties

Kinematic viscosity

Biodiesel is much less viscous than the oil from which it is made. In diesel engines viscosity affects injector lubrication and fuel atomization. In the present study kinematic viscosity was determined using a COMECTA Cannon-Fenske viscometer.

Density

Density is an important parameter for diesel fuel injection systems. Many performance characteristics, such as cetane number and heating value, are related to density. This property influences the effciency of fuel atomization.

Flash point

The flash point temperature of diesel fuel is the minimum temperature at which the fuel will flash upon application of an ignition source. One of the most important advantages of biodiesel is that its flash point is greater than that of diesel fuel, which is reflected in the specifications in the standards. The flash point of biodiesel must be a minimum 120 °C and 130°C.

Copper strip corrosion

Corrosion is a chemical action that destroys the surface of a metal by oxidation alone or in combination with a chemical process. It should be tested in fuels, especially for transportation and storage conditions. Free fatty acids and some sulphur compounds that exist in biodiesel may cause corrosion.

Total and free glycerol

Glycerin is a by-product of the transesterification reaction. The stoichiometry of the transesterification reaction requires a 3:1 molar ratio to yield 3 mol of ester and 1 mol of glycerol. Total and free glycerol is used to determine the level of glycerin in the fuel and includes the free glycerin portion of any unreacted or partially reacted oil or fat. High levels of free glycerin can cause injector deposits as well as clogged fuelling systems, and can result in the build up of free glycerin at the bottom of storage and fuelling systems.

Acid value

The acid value measures the amount of unreacted acids remaining in the finished fuel, and is also an indicator of oxidized fuel. The acid value defines the number of milligrams of potassium hydroxide necessary to neutralize. The free acids in 1 g of sample. A high acid value will damage fuel pumps and fuel filter.

Distillation temperatures

Distillation is an indicator of the purity of finished fuel. Distillation includes determination of the range of boiling points for the fuel and is used to characterize the fuel in terms of the boiling temperatures of its components.

Cetane index

The cetane index is measured of the ignition quality of a fuel and influences white smoke and combustion roughness. The cetane index is based on specific gravity and the 10%, 50%, and 90% distillation temperatures of the fuel.

Pour point and freezing point

Liquids have a characteristic temperature at which they turn into solids, known as their freezing point. On the other hand, pour points define the lowest temperature at which the fuel can still be moved, before it has gelled. The pour point and freezing point are used to characterize the cold flow operability of fuel, because the pour point and the freezing point of fuel affect the utility of a fuel, especially in cold climate conditions.

Table 2.1 Specification from the department of energy business for biodiesel [13].

Item	Description	Standard requested by Department of energy Business	Unit	Test
1	Density @ 15°C	not less than 860 and not more than 900	kg/m^3	ASTMD1298
2	Kinematics viscosity @ 40°C	not less than 3.5 and not more than 5.0	cSt	ASTMD445
3	Flash point	not less than 120	°C	ASTMD93
4	Sulfur	not more than 10	mg/kg	ASTMD2622
5	Sulfated ash content	not more than 0.30	%wt	ASTMD874
6	Water content	not more than 0.05	%wt	EN ISO12937
7	Total contaminate	not more than 0.0024	%wt	EN12662
8	Copper strip corrosion (3 hrs @ 50°C)	not more than “Standard No. 1”	Ratting	ATSMD130
9	Oxidation stability @ 110°C	not less than 6	Hours	EN14112
10	Cetane number	not less than 51	-	ASTMD613
11	Carbon residue (10% distillation residue)	not more than 0.30	%wt	ASTMD4530
12	Acid value	not more than 0.50	mgKOH/g	ASTMD664
13	Iodine value	not more than 120	g 1/100 g	EN1411
14	Methyl ester	not less than 96.5	%wt	EN14103

15	Linolenic acid Methyl ester	not more than 12.0	%wt	EN14103
16	Methanol	not more than 0.20	%wt	EN14110
17	Monoglycerides	not more than 0.80	%wt	EN14105
18	Diglycerides	not more than 0.20	%wt	EN14105
19	Triglycerides	not more than 0.20	%wt	EN14105
20	Free glycerin	not more than 0.02	%wt	EN14105
21	Total glycerin	not more than 0.25	%wt	EN14105
22	Phosphorous	not more than 0.0010	mg/kg	ASTMD4951
23	Group I metals (Na+K)	not more than 5.0	mg/kg	EN14108 and EN14109
24	Group II metal (Ca+Mg)	not more than 5.0	mg/kg	EN14538

Biodiesel has better lubricating properties and much higher cetane ratings than today's lower sulfur diesel fuels. Biodiesel addition reduces fuel system wear, and in low levels in high pressure systems increases the life of the fuel injection equipment that relies on the fuel for its lubrication. Depending on the engine, this might include high pressure injection pumps, pump injectors (also called *unit injectors*) and fuel injectors.

The calorific value of biodiesel is about 37.27 MJ/L. This is 9% lower than regular Number 2 petroleum diesel. Variations in biodiesel energy density are more dependent on the feedstock used than the production process. Still these variations are less than for petroleum diesel. It has been claimed biodiesel gives better lubricity and more complete combustion thus increasing the engine energy output and partially compensating for the higher energy density of petroleum diesel.

Biodiesel is a liquid which varies in color (between golden and dark brown) depending on the production feedstock. It is immiscible with water, has a high boiling point and low vapor pressure. *The flash point of biodiesel (>130 °C, >266 °F) is significantly higher than that of petroleum diesel (64 °C, 147 °F) or gasoline (-45 °C, -52 °F). Biodiesel has a density of ~ 0.88

g/cm³, less than that of water. Biodiesel has virtually no sulfur content, and it is often used as an additive to Ultra-Low Sulfur Diesel (ULSD) fuel.

Table 2.2 Comparison of biodiesel and petroleum-based diesel properties [13].

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTMD975	ASTMD6751
Lower Heating Value , Btu/gal	~129,050	~118,170
Kinematic Viscosity.@ 40° C	1.3-1.4	4.0-6.0
Specific Gravity kg/l @ 60° F	0.85	0.88
Density, lb/gal @ 15° C	7.079	7.328
Water and Sediment, vol %	0.05 max	0.05max
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, by dif.Wt%	0	11
Sulfur, wt%	0.05 max	0.0-0.0024
Boiling Point, ° C	180-340	315-350
Flash Point, ° C	60-80	100-170
Cetane Number	40-55	48-65
Lubricity SLBOCLE, grams	2,000-5,000	>7,000
Lubricity HFRR, micron	300-600	<300
Acid number, mg KOH/g	N/A	<0.8

2.2.2 Biodiesel categories [14].

1. (Straight Vegetable Oil) Vegetable oil is an alternative fuel for diesel engines and for heating oil burners. For engines designed to burn #2 diesel fuel, the viscosity of vegetable oil must be lowered to allow for proper atomization of fuel; otherwise incomplete combustion and carbon build up will ultimately damage the engine. Many enthusiasts refer to vegetable oil used as fuel as waste vegetable oil (WVO) if it is oil that was discarded from a restaurant or straight vegetable oil (SVO) or pure plant oil (PPO) to distinguish it from biodiesel.

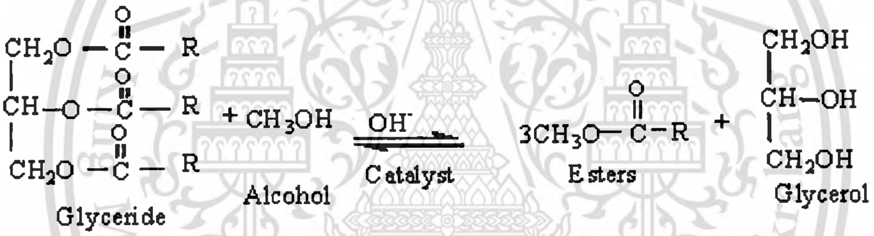
2. Veggie / Kero Mix are the mixing of vegetable fats or oils and kerosene or diesel to reduce the viscosity. The suitable mixed ratio is 20%kerozeze: 80% Vegetable fats and oils.

3. Ester Biodiesel Blends of biodiesel and conventional hydrocarbon-based diesel are products most commonly distributed for use in the retail diesel fuel marketplace. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix: fuel containing 20% biodiesel is labeled B20, while pure biodiesel is referred to as B100. It is common in the USA to see B99.9 because a federal tax credit is awarded to the first entity which blends petroleum diesel with pure biodiesel. Blends of 20 percent biodiesel with 80 percent petroleum diesel (B20) can generally be used in unmodified diesel engines. Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems.

2.3 Transesterification Process [15-17] .

The Transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol. A triglyceride has a glycerine molecule as its base with three long chain fatty acids attached. The characteristics of the fat are determined by the nature of the fatty acids attached to the glycerine. The nature of the fatty acids can in turn affect the characteristics of the biodiesel. During the esterification process, the triglyceride is reacted with alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide. The alcohol reacts with the fatty acids to form the mono-alkyl ester, or biodiesel and crude glycerol. In most production methanol or ethanol is the alcohol used (methanol produces methyl esters, ethanol produces ethyl esters) and is base catalysed by either potassium or sodium hydroxide. Potassium hydroxide has been found to be more suitable for the ethyl ester biodiesel production; either base can be used for the methyl ester. A common product of the transesterification process is Rape Methyl Ester (RME) produced from raw rapeseed oil reacted with methanol.

The figure below shows the chemical process for methyl ester biodiesel. The reaction between the fat or oil and the alcohol is a reversible reaction and so the alcohol must be added in excess to drive the reaction towards the right and ensure complete conversion. Products of the reaction are the biodiesel itself and glycerol as shown in equation (2.1).



$$\begin{matrix} CH_2O-\overset{O}{\overset{\|}{C}}-R \\ | \\ CH-O-\overset{O}{\overset{\|}{C}}-R \\ | \\ CH_2O-\overset{O}{\overset{\|}{C}}-R \end{matrix} + CH_3OH \underset{\text{Catalyst}}{\overset{OH^-}{\rightleftharpoons}} 3CH_3O-\overset{O}{\overset{\|}{C}}-R + \begin{matrix} CH_2OH \\ | \\ CH-OH \\ | \\ CH_2OH \end{matrix} \quad (2.1)$$

A successful transesterification reaction is signified by the separation of the ester and glycerol layers after the reaction time. The heavier, co-product, glycerol settles out and may be sold as it is or it may be purified for use in other industries, e.g. the pharmaceutical, cosmetics etc.

Straight vegetable oil (SVO) can be used directly as a fossil diesel substitute however using this fuel can lead to some fairly serious engine problems. Due to its relatively high viscosity SVO leads to poor atomization of the fuel, incomplete combustion, coking of the fuel injectors, ring carbonization, and accumulation of fuel in the lubricating oil. The best method for solving these problems is the transesterification of the oil.

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The factors affecting the transesterification process are

1. Free fatty acid act as content of the oil is above 1%, difficulties arise due to the formation of soap, which promotes emulsification during the water washing stage. If the FFA content is above 2%, the process becomes unworkable.

2. Quantity of NaOH catalyst should between 0.4-2 % w/w of oil for produce biodiesel.

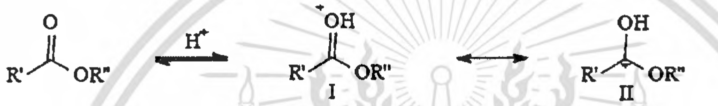
3. Ratio of alcohol to oil. From the reaction in equation (2.1) the ratio is 3: 1, but this reaction is reversible, the ratio should be 6:1 to 9:1 for compulsion the reaction to produce high amount of biodiesel.

4. Reaction time, reaction rate oil convert to biodiesel oil will increase depend on reaction time.

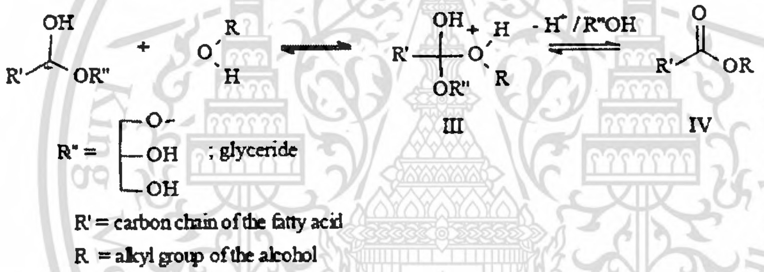
5. Rate oil convert to biodiesel oil will increase depend on temperature reaction, normally use temperature about 60 oC that below boiling point of methanol.

2.3.1 Acid-Catalyzed Processes [17]

The transesterification process is catalyzed by Bronsted acids, preferably by sulfonic and sulfuric acids. These catalysts give very high yields in alkyl esters, but the reactions are slow, requiring, typically, temperatures above 100 °C and more than 3 h to reach complete conversion. Pryde *et al.* showed that the methanolysis of soybean oil, in the presence of 1 mol% of H_2SO_4, with an alcohol/oil molar ratio of 30:1 at 65 °C, takes 50 h to reach complete conversion of the vegetable oil (> 99%), while the butanolysis (at 117 °C) and ethanolysis (at 78 °C), using the same quantities of catalyst and alcohol, take 3 and 18 h, respectively. The alcohol/ vegetable oil molar ratio is one of the main factors that influence the transesterification. An excess of the alcohol favors the formation of the products. On the other hand, an excessive amount of alcohol makes the recovery of the glycerol difficult, so that the ideal alcohol/oil ratio has to be established empirically, considering each individual process. The mechanism of the acid-catalyzed transesterification of vegetable oils is shown in equation (2.3), for a monoglyceride. However, it can be extended to di- and triglycerides 31. The protonation of the carbonyl group of the ester leads to the carbocation II which, after a nucleophilic attack of the alcohol, produces the tetrahedral intermediate III, which eliminates glycerol to form the new ester IV, and to regenerate the catalyst H+. According to this mechanism, carboxylic acids can be formed by reaction of the carbocation II with water present in the reaction mixture. This suggests that an acid-catalyzed transesterification should be carried out in the absence of water, in order to avoid the competitive formation of carboxylic acids which reduce the yields of alkyl esters. Mechanism of the acid-catalyzed trans-esterification of vegetable oils as shown in equation (2.2) and (2.3).



(2.2)



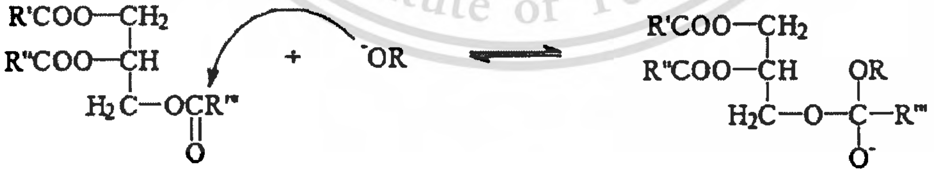
(2.3)

2.3.2 Base-Catalyzed Processes

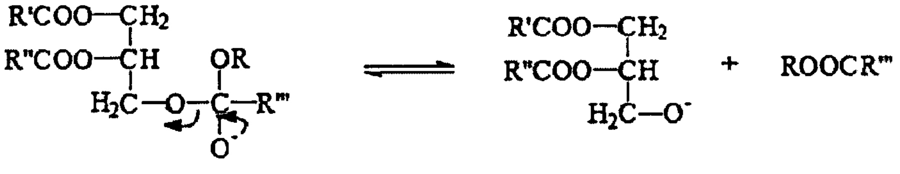
The base-catalyzed transesterification of vegetable oils proceeds faster than the acid-catalyzed reaction. Due to this reason, together with the fact that the alkaline catalysts are less corrosive than acidic compounds, industrial processes usually favor base catalysts, such as alkaline metal alkoxides and hydroxides as well as sodium or potassium carbonates. The mechanism of the base-catalyzed transesterification of vegetable oils is shown in equation (2.4)-(2.7). The first step (equation (2.4)) is the reaction of the base with the alcohol, producing an alkoxide and the protonated catalyst. The nucleophilic attack of the alkoxide at the carbonyl group of the triglyceride generates a tetrahedral intermediate (equation (2.5)), from which the alkyl ester and the corresponding anion of the diglyceride are formed (equation (2.6)). The latter deprotonates the catalyst, thus regenerating the active species (equation (2.7)), which is now able to react with a second molecule of the alcohol, starting another catalytic cycle. Diglycerides and monoglycerides are converted by the same mechanism to a mixture of alkyl esters and glycerol. Alkaline metal alkoxides (as CH_3ONa for the methanolysis) are the most active catalysts, since they give very high yields (> 98%) in short reaction times (30 minutes) even if they are applied at low molar concentrations (0.5 mol%). However, they require the absence of water which makes them inappropriate for typical industrial processes. Alkaline metal hydroxides (KOH and NaOH) are cheaper than metal alkoxides, but less active. Nevertheless, they are a good alternative since they can give the same high conversions of vegetable oils just by increasing the catalyst concentration to 1 or 2 mol%.

However, even if a water-free alcohol/oil mixture is used, some water is produced in the system by the reaction of the hydroxide with the alcohol. The presence of water gives rise to hydrolysis of some of the produced ester, with consequent soap formation. This undesirable saponification reaction reduces the ester yields and considerably difficult the recovery of the glycerol due to the formation of emulsions. Potassium carbonate, used in a concentration of 2 or 3 mol% gives high yields of fatty acid alkyl esters and reduces the soap formation. This can be explained by the formation of bicarbonate instead of water, which does not hydrolyze the esters.

$$ROH + B \rightleftharpoons RO^- + BH^+ \qquad (2.4)$$



(2.5)



(2.6)

(2.7)

2.3.3 Lipase-Catalyzed Processes

Due to their ready availability and the ease with which they can be handled, hydrolytic enzymes have been widely applied in organic synthesis. They do not require any coenzymes, are reasonably stable, and often tolerate organic solvents. Their potential for regioselective and especially for enantioselective synthesis makes them valuable tools. Although the enzyme-catalyzed transesterification processes are not yet commercially developed, new results have been reported in recent articles and patents. The common aspects of these studies consist in optimizing the reaction conditions (solvent, temperature, pH, type of microorganism which generates the enzyme, etc) in order to establish suitable characteristics for an industrial application. However, the reaction yields as well as the reaction times are still unfavorable compared to the base-catalyzed reaction systems.

2.3.4 Non-Catalyzed Processes

In order to obtain the reaction by critical conditions of methanol and used high temperature to break the hydrogen bond of methanol and also decreased the polarity. They will mix together and produced high purification and the reaction time is 2-4 minutes.

2.3.5 Heterogeneously Catalyzed Processes

The advantage of using guanidine in the transesterification of vegetable oils is the possibility to heterogenize them on organic polymers. Schuchardt *et al.* tested principally cellulose and poly (styrene/divinylbenzene), but also polyuretanes and other organic polymers allow the suitable incorporation of guanidine. The heterogenization of guanidine on organic polymers and their use in the transesterification of vegetable oils were described in a patent. The heterogenization of unsubstituted guanidine can be achieved by their reaction with microcrystalline cellulose activated by cyanuric chloride at the C-6 position.

2.4 Vegetable Oils and Biodiesel

Now we can start to deal with biodiesel. As you know, biodiesel is derived from vegetable oils. The major components of vegetable oils are *triglycerides. The term triacylglycerols* is being used more and more, but we will use the classical term in this discussion. *Triglycerides* are *esters of* glycerol (see above; an alcohol with a hydroxy group on each of its three carbon atoms) withlong-chain acids, commonly called *fatty acids*. Tables list the most common fatty acids and their corresponding methyl esters.

Note from the comparison of the rational names of the fatty acids with their structural formulas how the position of the double bonds is defined by numbers. The number of carbon atoms is counted by beginning with the first carbon having the functional group defining the fatty compound as acid or ester. As you can see from the former example (for example, 1-propanol and 2-propanol), this way of counting holds for other functional groups as well. The trivial names of fatty acids and their esters are far more commonly used than their rational names.

Table 2.3 The melting point and Iodine values in vegetable oil [17].

Oils and their melting points and Iodine Values		
Oil	**Approx. melting point (°C)**	**Iodine Value**
Coconut oil	25	10
Palm kernel oil	24	37
Mutton tallow	42	40
Palm oil	35	54
Olive oil	-6	81
Castor oil	-18	85
Peanut oil	3	93
Rapeseed oil	-10	98
Cotton seed oil	-1	105
Sunflower oil	-17	125
Soybean oil	-16	130
Tung oil	-2.5	168
Linseed oil	-24	178

Table 2.4 Structure and properties of fatty acid [17].

Name	Number of Carbon	Structure
Luaric acid	12	$CH_3(CH_2)_{10}COOH$
Myristic acid	14	$CH_3(CH_2)_{12}COOH$
Palmitic acid	16	$CH_3(CH_2)_{14}COOH$
Stearic acid	18	$CH_3(CH_2)_{16}COOH$
Arachidic acid	20	$CH_3(CH_2)_{18}COOH$
Palmitoleic acid	16	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$
Oleic acid	18	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
Linoleic acid	18	$CH_3(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOH$*(cis)*
Linoleic acid	18	$CH_3(CH_2CH=CH)_3(CH_2)_7COOH$*(cis , cis)*
Arachidonic acid	20	$CH_3(CH_2CH=CHCH_2)_4(CH_2)_2COOH$*(all cis)*

2.4.1. Palm oil

Palm oil and palm kernel oil are composed of fatty acids, esterified with glycerol just like any ordinary fat. Both are high in saturated fatty acids, about 50% and 80%, respectively. The oil palm gives its name to the 16-carbon saturated fatty acid palmitic acid found in palm oil; monounsaturated oleic acid is also a constituent of palm oil while palm kernel oil contains mainly lauric acid. Palm oil is the largest natural source of tocotrienol, part of the vitamin E family. Palm oil is also high in vitamin K and dietary magnesium.

Table 2.5 The approximate concentration of fatty acids (FAs) in palm oil [17].

Fatty acid content of palm oil		
Type of fatty acid	**Saturated**	**pct**
Palmitic C16	Saturated	44.3%
Stearic C18	Saturated	4.6%
Myristic C14	Saturated	1.0%
Oleic C18	Mono unsaturated	38.7%
Linoleic C18	Poly unsaturated	10.5%
Other/Unknown	Poly unsaturated	0.9%

Table 2.6 The approximate concentration of fatty acids (FAs) in palm kernel oil [17].

Fatty acid content of palm kernel oil		
Type of fatty acid	**Saturated**	**pct**
Lauric C12	Saturated	48.2%
Myristic C14	Saturated	16.2%
Palmitic C16	Saturated	8.4%
Capric C10	Saturated	3.4%
Caprylic C8	Saturated	3.3%
Stearic C18	Saturated	2.5%
Oleic C18	Mono unsaturated	15.3%
Linoleic C18	Poly unsaturated	2.3%
Other/Unknown	Poly unsaturated	0.4%

Fatty acids are saturated and unsaturated aliphatic carboxylic acids with carbon chain in the range of C_3 up to C_{28}. An example of a fatty acid is palmitic acid, $CH_3–(CH_2)_{14}–COOH$.

Splitting of oils and fats by hydrolysis, or under basic conditions saponification, yields fatty acids, with glycerin (glycerol) as a byproduct. The split-off fatty acids are a mixture of fatty acids ranging from C_4 to C_{18} depending on the type of oil/fat.

Palm oil products are made using milling and refining processes: first using fractionation, with crystallization and separation processes to obtain solid (stearin), and liquid (olein) fractions. By melting and degumming, impurities can be removed and then the oil filtered and bleached. Next, physical refining removes smells and coloration, to produce refined bleached deodorized palm oil, or RBDPO, and free sheer fatty acids, used as an important raw material in the manufacture of soaps, washing powder and other hygiene and personal care products. RBDPO is the basic oil product which can be sold on the world's commodity markets; although many companies fractionate it out further into palm olein, for cooking oil, or other products.

Palm is also used in biodiesel production, as either a simply-processed palm oil mixed with petrodiesel, or processed through transesterification to create a palm oil methyl ester blend which meets the international EN 14214 specification, with glycerin as a byproduct. The actual process used varies between countries and the requirements of different export markets. Next-generation biofuel production processes are also being trailed in relatively small quantities.

2.5 Methanol

Methanol, also known as **methyl alcohol, wood alcohol, wood naphtha** or **wood spirits**, is a chemical with formula CH_3OH (often abbreviated MeOH). It is the simplest alcohol, and is a light, volatile, colorless, flammable, liquid with a distinctive odor that is very similar to but slightly sweeter than ethanol (drinking alcohol) [18]. At room temperature it is a polar liquid and is used as an antifreeze, solvent, fuel, and as a denaturant for ethanol. It is also used for producing biodiesel via transesterification reaction.

Methanol is produced naturally in the anaerobic metabolism of many varieties of bacteria, and is ubiquitous in the environment. As a result, there is a small fraction of methanol vapor in the atmosphere. Over the course of several days, atmospheric methanol is oxidized with the help of sunlight to carbon dioxide and water.

Methanol burns in air forming carbon dioxide and water:

$$2\,CH_3OH + 3\,O_2 \longrightarrow 2\,CO_2 + 4\,H_2O \qquad \textbf{(2.8)}$$

A methanol flame is almost colorless in bright sunlight.

Because of its toxic properties, methanol is frequently used as a denaturant additive for ethanol manufactured for industrial uses — this addition of methanol exempts industrial ethanol from liquor excise taxation. Methanol is often called wood alcohol because it was once produced chiefly as a byproduct of the destructive distillation of wood.

2.5.1 Production

Today synthesis gas is most commonly produced from the methane component in natural gas rather than from coal. Three processes are commercially practiced. At moderate pressures of 4 MPa (40 atm) and high temperatures (around 850 °C), methane reacts with steam on a nickel catalyst to produce syngas according to the chemical equation:

$$CH_4 + H_2O \rightarrow CO + 3\ H_2 \qquad \textbf{(2.9)}$$

This reaction, commonly called steam-methane reforming or SMR is endothermic and the heat transfer limitations place limits on the size of and pressure in the catalytic reactors used. Methane can also undergo partial oxidation with molecular oxygen to produce syngas, as the following equation shows:

$$2\ CH_4 + O_2 \longrightarrow 2\ CO + 4\ H_2 \qquad \textbf{(2.10)}$$

This reaction is exothermic and the heat given off can be used *in-situ* to drive the steam-methane reforming reaction. When the two processes are combined, it is referred to as autothermal reforming. The ratio of CO and H_2 can be adjusted to some extent by the water-gas shift reaction, to provide the appropriate stoichiometry for methanol synthesis.

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \textbf{(2.11)}$$

The carbon monoxide and hydrogen then react on a second catalyst to produce methanol. Today, the most widely used catalyst is a mixture of copper, zinc oxide, and alumina first used by ICI in 1966. At 5–10 MPa (50–100 atm) and 250 °C, it can catalyze the production of methanol from carbon monoxide and hydrogen with high selectivity:

$$CO + 2\ H_2 \longrightarrow CH_3OH \qquad \textbf{(2.12)}$$

It is worth noting that the production of synthesis gas from methane produces 3 moles of hydrogen gas for every mole of carbon monoxide, while the methanol synthesis consumes only 2 moles of hydrogen gas for every mole of carbon monoxide. One way of dealing with the excess hydrogen is to inject carbon dioxide into the methanol synthesis reactor, where it, too, reacts to form methanol according to the equation:

$$CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O \qquad \textbf{(2.13)}$$

Although natural gas is the most economical and widely used feedstock for methanol production, many other feedstocks can be used to produce syngas via steam reforming. Coal is increasingly being used as a feedstock for methanol production, particularly in China. In addition, mature technologies available for biomass gasification are being utilized for methanol production. For instance, woody biomass can be gasified to water gas (a hydrogen-rich syngas), by introducing a blast of steam in a blast furnace. The water-gas / syngas can then be synthesized to methanol using standard methods. The net process is carbon neutral since the CO_2 byproduct is required to produce biomass via photosynthesis.

$$2\ C_{16}H_{23}O_{11} + 19\ H_2O + O_2 \longrightarrow 42\ H_2 + 21\ CO + 11\ CO_2 \longrightarrow 21\ CH_3OH + 11\ CO_2 \qquad \textbf{(2.14)}$$

2.5.2 Applications

Methanol is a common laboratory solvent. It is especially useful for HPLC, UV/VIS spectroscopy, and LCMS due to its low UV cutoff.

Feedstock

The largest use of methanol by far is in making other chemicals. About 40% of methanol is converted to formaldehyde, and from there into products as diverse as plastics, plywood, paints, explosives, and permanent press textiles.

Also in the early 1970s, a methanol to gasoline process was developed by Mobil for producing gasoline ready for use in vehicles. One such industrial facility was built at Motunui in New Zealand in the 1980s. In the 1990s, large amounts of methanol were used in the United States to produce the gasoline additive methyl tert-butyl ether (MTBE). While MTBE is no longer marketed in the U.S., it is still widely used in other parts of the world. In addition to direct use as a fuel, methanol (or less commonly, ethanol) is used as a component in the transesterification of triglycerides to yield a form of biodiesel.

Other chemical derivatives of methanol include dimethyl ether, which has replaced chlorofluorocarbons as an aerosol spray propellant, and acetic acid. Dimethyl ether, or "DME" also can be blended with liquified petroleum gas (LPG) for home heating and cooking, and can be used as a diesel replacement transportation fuel.

Fuel for vehicles

Methanol is used on a limited basis to fuel internal combustion engines. Pure methanol is required by rule to be used in Champcars, Monster Trucks, USAC sprint cars (as well as midgets, modifieds, etc.), and other dirt track series such as World of Outlaws, and Motorcycle Speedway.

Methanol is also used, as the primary fuel ingredient since the late 1940s, in the powerplants for radio control, control line and free flight airplanes (as methanol is required in the "glow-plug" engines that primarily power them), cars and trucks, from such an engine's use of a platinum filament glow plug being able to ignite the methanol vapor through a catalytic reaction. Drag racers and mud racers also use methanol as their primary fuel source. Methanol is required with a supercharged engine in a Top Alcohol Dragster and, until the end of the 2006 season, all vehicles in the Indianapolis 500 had to run methanol. Mud racers have mixed methanol with gasoline and nitrous oxide to produce more power than gasoline and nitrous oxide alone.

One of the drawbacks of methanol as a fuel is its corrosivity to some metals, including aluminium. Methanol, although a weak acid, attacks the oxide coating that normally protects the aluminium from corrosion:

$$6\ CH_3OH + Al_2O_3 \rightarrow 2\ Al(OCH_3)_3 + 3\ H_2O \qquad \textbf{(2.15)}$$

The resulting methoxide salts are soluble in methanol, resulting in clean aluminium surface, which is readily oxidized by some dissolved oxygen. Also the methanol can act as an oxidizer:

$$6\ CH_3OH + 2\ Al \rightarrow 2\ Al(OCH_3)_3 + 3\ H_2 \qquad \textbf{(2.16)}$$

This reciprocal process effectively fuels corrosion until either the metal is eaten away or the concentration of CH_3OH is negligible. Concerns with methanol's corrosivity have been addressed by using methanol compatible materials, and fuel additives that serve as corrosion inhibitors.

When produced from wood or other organic materials, the resulting organic methanol (bioalcohol) has been suggested as renewable alternative to petroleum-based hydrocarbons. Low levels of methanol can be used in existing vehicles, with the use of proper cosolvents and corrosion inhibitors. The European Fuel Quality Directive allows up to 3% methanol with an equal amount of cosolvent to be blending in gasoline sold in Europe. Today, China uses more than one billion gallons of methanol per year as a transportation fuel in both low level blends used in existing vehicles, and as high level blends in vehicles designed to accommodate the use of methanol fuels.

Other applications

Methanol is a traditional denaturant for ethanol, thus giving the term *methylated spirit* [19]. Methanol is also used as a solvent, and as an antifreeze in pipelines and windshield washer fluid. In some wastewater treatment plants, a small amount of methanol is added to wastewater to provide a food source of carbon for the denitrifying bacteria, which convert nitrates to nitrogen to reduce the denitrification of sensitive aquifers.

During World War II, methanol was used as a fuel in several German military rocket designs, under name M-Stoff, and in a mixture as C-Stoff.

Methanol was used as an automobile coolant antifreeze in the early 1900s. [20] Methanol is used as a denaturing agent in polyacrylamide gel electrophoresis. Direct-methanol fuel cells are unique in their low temperature, atmospheric pressure operation, allowing them to be miniaturized to an unprecedented degree. This, combined with the relatively easy and safe storage and handling of methanol may open the possibility of fuel cell-powered consumer electronics, such as for laptop computers and mobile phones [21].

Methanol is also a widely used fuel in camping and boating stoves. Methanol burns well in an unpressurized burner, so alcohol stoves are often very simple, sometimes little more than a cup to hold fuel. This lack of complexity makes them a favorite of hikers who spend extended time in the wilderness.

Methanol is mixed with water and injected into high performance diesel engines for an increase of power and a decrease in exhaust gas temperature. This is called water methanol injection.

Health and safety

Toxicity

Methanol has a high toxicity in humans. If ingested, as little as 10 mL can cause permanent blindness by destruction of the optic nerve and 30 mL is potentially fatal, [22] although a fatal dose is typically 100–125 mL (4 fl oz). Toxic effects take hours to start and effective antidotes can often prevent permanent damage. Because of its similarities to ethanol (the alcohol in beverages), it is difficult to differentiate between the two (such is the case with denatured alcohol).

Methanol is toxic by two mechanisms. Firstly, methanol (whether it enters the body by ingestion, inhalation, or absorption through the skin) can be fatal due to its CNS depressant properties in the same manner as ethanol poisoning. Secondly, in a process of toxication, it is metabolised to formic acid (which is present as the formate ion) via formaldehyde in a process initiated by the enzyme alcohol dehydrogenase in the liver. The reaction to formate proceeds completely, with no detectable formaldehyde remaining [23] . Formate is toxic because it inhibits mitochondrial cytochrome c oxidase, causing the symptoms of hypoxia at the cellular level, and also causing metabolic acidosis among a variety of other metabolic disturbances. [24] Fetal tissue will not tolerate methanol.

Methanol poisoning can be treated with the antidotes ethanol or fomepizole. [25] Both of these drugs act to reduce the action of alcohol dehydrogenase on methanol by means of competitive inhibition, so that it is excreted by the kidneys rather than being transformed into toxic metabolites. Further treatment may include giving sodium bicarbonate for metabolic acidosis and haemodialysis or haemodiafiltration can be used to remove methanol and formate from the blood. Folinic acid or folic acid is also administered to enhance the metabolism of formate.

The initial symptoms of methanol intoxication include central nervous system depression, headache, dizziness, nausea, lack of coordination, confusion, and with sufficiently large doses, unconsciousness and death. The initial symptoms of methanol exposure are usually less severe than the symptoms resulting from the ingestion of a similar quantity of ethanol. Once the initial symptoms have passed, a second set of symptoms arises, 10 to as many as 30 hours after the initial exposure to methanol, including blurring or complete loss of vision and acidosis.[9] These symptoms result from the accumulation of toxic levels of formate in the bloodstream, and may progress to death by respiratory failure. The ester derivatives of methanol do not share this toxicity.

Ethanol is sometimes denatured (adulterated), and thus made undrinkable, by the addition of methanol. The result is known as methylated spirit, "meths" (UK use) or "metho" (Australian slang). The latter should not be confused with *meth*, a common U.S. abbreviation for methamphetamine.

Safety in automotive fuels

Pure methanol has been used in open wheel auto racing since the mid-1960s. Unlike petroleum fires, methanol fires can be extinguished with plain water. A methanol-based fire burns invisibly, unlike gasoline, which burns with a visible flame. If a fire occurs on the track, there is no flame or smoke to obstruct the view of fast approaching drivers, but this can also delay visual detection of the fire and the initiation of fire suppression. The decision to permanently switch to methanol in American IndyCar racing was a result of the devastating crash and explosion at the 1964 Indianapolis 500 which killed drivers Eddie Sachs and Dave MacDonald. In 2007 IndyCars switched back to ethanol.

Methanol is readily biodegradable in both aerobic (oxygen present) and anaerobic (oxygen absent) environments. Methanol will not persist in the environment. The "half-life" for methanol in groundwater is just one to seven days, while many common gasoline components have half-lives in the hundreds of days (such as benzene at 10–730 days). Since methanol is miscible with water and biodegradable, methanol is unlikely to accumulate in groundwater, surface water, air or soil. [26]

2.6 Potassium Hydroxide

Figure 2.2 Potassium hydroxide [27].

Potassium hydroxide as shown in figure 2.2 is an inorganic compound with the formula KOH. Its common name is **caustic potash**. Along with sodium hydroxide (NaOH), this colourless solid is a prototypical strong base. It has many industrial and niche applications. Most applications exploit its reactivity toward acids and its corrosive nature. In 2005, an estimated 700,000 to 800,000 tons were produced. Approximately 100 times more NaOH than KOH is produced annually [27]. KOH is noteworthy as the precursor to most soft and liquid soaps as well as numerous potassium-containing chemicals.

2.6.1 Properties and structure

Potassium hydroxide can be found in pure form by reacting sodium hydroxide with impure potassium. Potassium hydroxide is usually sold as translucent pellets, which will become tacky in air because KOH is hygroscopic. Consequently, KOH typically contains varying amounts of water (as well as carbonates, see below). Its dissolution in water is strongly exothermic, meaning the process gives off significant heat. Concentrated aqueous solutions are sometimes called potassium lyes. Even at high temperatures, solid KOH does not dehydrate readily.

2.6.2 Structure

At higher temperatures, solid KOH crystallizes in the NaCl motif. The OH group is either rapidly or randomly disordered so that the OH^- group is effectively a spherical anion of radius 1.53 Å (between Cl^- and F^- in size). At room temperature, the OH^- groups are ordered and the environment about the K^+ centers is distorted, with K^+—OH^- distances ranging from 2.69 to 3.15 Å, depending on the orientation of the OH group. KOH forms a series of crystalline hydrates, namely the monohydrate $KOH{\cdot}H_2O$, the dihydrate $KOH{\cdot}2H_2O$, and the tetrahydrate $KOH{\cdot}4H_2O$. [28].

2.6.3 Solubility and desiccating properties

Approximately 121 g of KOH will dissolve in 100 ml of water at room temperature (compared with 100 g of NaOH in the same volume). Lower alcohols such as methanol, ethanol, and propanols are also excellent solvents. The solubility in ethanol is about 40 g KOH/100 ml.

Because of its high affinity for water, KOH serves as a desiccant in the laboratory. It is often used to dry basic solvents, especially amines and pyridines: distillation of these basic liquids from a slurry of KOH yields the anhydrous reagent.

2.6.4 Reactions

As a base

KOH is highly basic, forming strongly alkaline solutions in water and other polar solvents. These solutions are capable of deprotonating many acids, even weak ones. In analytical chemistry, titrations using solutions of KOH are used to assay acids.

As a nucleophile in organic chemistry

KOH, like NaOH, serves as a source of OH^-, a highly nucleophilic anion that attacks polar bonds in both inorganic and organic materials. In perhaps its most well-known reaction, aqueous KOH saponifies esters:

$$KOH + RCO_2R' \rightarrow RCO_2K + R'OH \qquad \textbf{(2.17)}$$

When R is a long chain, the product is called potassium soap. This reaction is manifested by the "greasy" feel that KOH gives when touched — fats on the skin are rapidly converted to soap and glycerol. Molten KOH is used to displace halides and other leaving groups. The reaction is especially useful for aromatic reagents to give the corresponding phenols. [29].

Reaction with inorganic compounds

Complementary to its reactivity toward acids, KOH attacks oxides. Thus, SiO_2 is attacked by KOH to give soluble potassium silicates. KOH reacts with carbon dioxide to give bicarbonate:

$$KOH + CO_2 \rightarrow KHCO_3 \qquad \textbf{(2.18)}$$

2.7 Water - Thermal Properties

Thermal properties of water - density, freezing temperature, boiling temperature, latent heat of melting, latent heat of evaporation, critical temperature and more.

Some common used thermal properties for water:

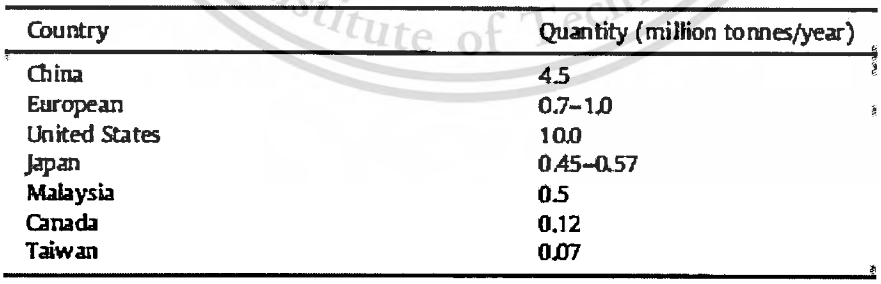
- Maximum density at *4 °C - 1,000 kg/m³, 1.940 slugs/ft³*
- Specific Weight at *4 °C - 9.807 kN/m³, 62.43 Lbs./Cu.Ft, 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.*
- Freezing temperature - *0 °C (Official Ice at 0 °C)*
- Boiling temperature - *100 °C*
- Latent heat of melting - *334 kJ/kg*
- Latent heat of evaporation - *2,270 kJ/kg*
- Critical temperature - *380 °C - 386 °C*
- Critical pressure - *221.2 bar, 22.1 MPa (MN/m²)*
- Specific heat capacity water - *4.187 kJ/kgK*
- Specific heat capacity ice - *2.108 kJ/kgK*

- Specific heat capacity water vapor - *1.996 kJ/kgK*
- Thermal expansion from *4* ^{o}C *to 100* ^{o}C *-* $4.2x10^{-2}$
- Bulk modulus elasticity - *2.15 x* 10^{9} *(Pa,* N/m^{2}*)*

2.8 Waste Cooking Oil [35].

Currently, world oil and fats production is about 154 million tons (MPOC, 2008). This figure refer to the production of 17 major oils and fats, comprising from vegetable oils (i.e. soybean, cottonseed, groundnut, sunflower, rapeseed, sesame, corn, olive, palm, palm kernel, coconut, linseed, and castor) and animal fats/oils (i.e. butter, lard, tallow, grease and fish oil). Most of this oil is used for deep-frying processes, after which could cause disposal problem. Serious water contamination may occur if no proper disposal method is implemented. Such scenario does not only contribute to pollution problems but is also harmful to human beings. In fact, EU has enforced a ban on the utilization of all waste oils as domestic animal feed because during frying process, many harmful compounds are formed. Eventually, these harmful compounds will enter the human food chain during meat consumption (Kulkarni and Dalai, 2006).

Table 2.7 Quantity of waste cooking oil produced in selected countries [35].



Country	Quantity (million tonnes/year)
China	4.5
European	0.7–1.0
United States	10.0
Japan	0.45–0.57
Malaysia	0.5
Canada	0.12
Taiwan	0.07

Since frying improves the taste of food, it has become a common method in food preparation. During frying, oil is heated under atmospheric condition at temperature of 160–190 °C (Gazmuri and Bouchon, 2009) for relative long period of time. In addition, the same oil or fat is used several times, mainly because of economical reasons. However, continuously using the same oil or fat for frying will causes various physical and chemical changes in the oil, depending on the type of oil and oil composition. Some physical changes observed in vegetable oil after frying are (i) an increase in viscosity, (ii) an increase in specific heat, (iii) a change in surface tension, and (iv) a change in color (Cvengros and Cvengrosova, 2004).

Apart from that, oils are also subjected to three types of reactions during frying, mainly thermolytic, oxidative and hydrolytic (Mittelbach and Enzelsberger, 1999; Nawar, 1984). These three reactions will continuously cause the formation of many undesired and harmful compounds if the oil is used repeatedly. The toxicological effects of these compounds upon human consumption are still not completely known. However, if waste cooking oil is to be made feedstock for biodiesel production, the amount of polar compound in the waste cooking oil, especially free fatty acid (FFA) must be taken into consideration as it will greatly affect the transesterification reaction. Refined oil usually contains less than 0.5 wt.% FFA whereas for waste cooking oil, FFA contents range between 0.5 and 15 wt.% (Gerhard Knothe and Krahl, 2004).

2.8.1 Thermolytic reaction

A thermolytic reaction occurs in the absence of oxygen at high temperatures. A series of alkanes, alkenes, lower fatty acids, symmetric ketones, oxopropyl esters, CO, and CO2 are produced from the saturated fatty acids in the oil. For unsaturated fatty acids, basically diametric compounds including dehydrodimers, saturated dimers and polycyclic compounds are formed. In addition, dimers and trimers may be formed when unsaturated fatty acids react with other unsaturated fatty acids through Diels–Alder reaction (Kulkarni and Dalai, 2006).

2.8.2 Oxidative reaction

Oxidative reaction occurs when oxygen in air dissolved in the oil or fat and reacts mainly with unsaturated acyglycerols (AG) resulting in the formation of various oxidation products. The main reactions involved in the oxidation reactions are summarized in Figure 2.3 (Velasco and

Dobarganes, 2002). RH represents triacylglycerol undergoing oxidation in one of its unsaturated fatty acyl groups. Initially, radicals — alkyl radicals (R·) are formed. By the addition of oxygen, eventually alkylperoxyl radicals (ROO·) are produced. Finally, alkoxyl radicals (RO·) are formed due to the decomposition of hydroperoxides (ROOH) which produce various saturated and unsaturated aldehydes, ketones, hydrocarbons, lactones, alcohols, acids and esters. Most of these compounds will remain within the oil or fat, e.g. dimeric and polymeric acid, dimeric AG and polyglycerols as products of the radical reactions and increase the viscosity of the cooking oil. Others might be further decomposed through alkoxyradicals to volatile polar compounds, e.g. hydroxyl- and epoxyacids that escape from the oil (Cvengros and Cvengrosova, 2004).

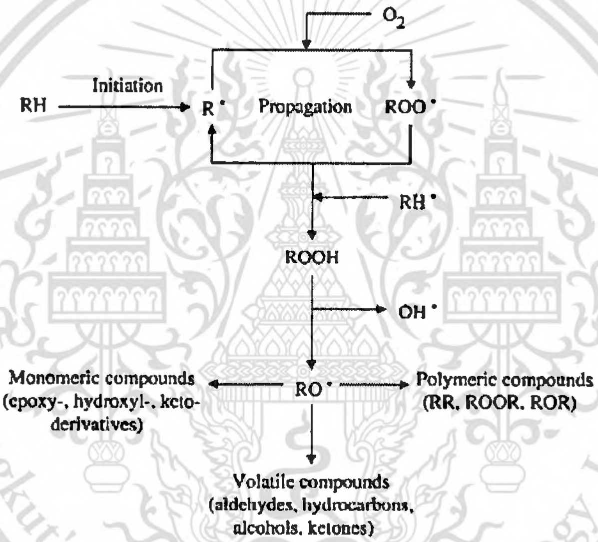


Figure 2.3 Simplified mechanisms for oil oxidation reaction during frying [35].

2.8.3 Hydrolytic reaction

The hydrolysis of triglycerides occurs when steam produced during the preparation of food. Part of the water quickly evaporates, but a certain part dissolved in the oil or fat and induces its cleavage to give higher fatty acids, glycerol, monoglycerides and diglycerides concentration (Kulkarni and Dalai, 2006).

2.9 Approximate test quality of biodiesel by using microwave [36]

This experimental is the analysis of quality of biodiesel by take the biodiesel react the transesterification again in microwave. Based on principle of biodiesel if biodiesel has glyceride (Tri-, Di-, Mono-) left in the reaction of transesterification with methanol and KOH in the proper proportion would occur glycerol. So amount of glycerol occur will indicate the quality of biodiesel. After test biodiesel sample was used to measure GCMS for calculate methylester and then compare with the standard of biodiesel.

Calculate % methylester :

Y = Observed glycerol

G =%retain of glycerol = Y + (0.0144÷0.0611) **(2.19)**

E= % of methyl ester after the reaction = 100 – G **(2.20)**

2.10 Literature Review

Yusuke Asakuma, Kouji Maeda, Hidetoshi Kuramochib and Keisuke Fukuia. [37] had studied the transesterification of various triglycerides was considered. Transesterfication reaction is completed via a transition state, in which ring formation consisting of the carbon of the carboxyl and alkoxy groups appears. An ideal reaction pathway, in which the ester bond at the center of the triglyceride is transesterified before peripheral ester bonds was shown by an activation energy analysis and electrostatic potential (ESP) distribution.

A.W.Schwab, M.O.Bagby and B.Freedman. [38] had described how to preparation and properties of diesel fuels from vegetable oils. Solution to the viscosity problem has been approached in at least four ways: (1) dilution, (2) microemulsification, (3) pyrolysis and

(4) transesterification. Transesterification with methanol, ethanol or butanol produces alternative fuels which could be used in times of emergency.

V. Lertsathapornsuk, R. Pairintra, K. Aryusuk and K. Krisnangkura. [39] had analyzed microwave assisted in continuous biodiesel production from waste frying palm oil and its performance in a 100 kW diesel generator. A household microwave (800W) was modified as a biodiesel reactor for continuous transethylation of waste frying palm oil. The high free fatty acid oil was simultaneously neutralized and transesterified with sodium hydroxide. With the ethanol to oil molar ratio of 12:1, 3.0% NaOH (in ethanol) and 30s residence time, the continuous conversion of waste frying palm oil to ethyl ester was over 97%. The waste palm oil biodiesel was then tested in a 100 kW diesel generator as a neat fuel (B100) and 50% blend with diesel No. 2 fuel (B50). The engine performance and emission are recorded. At the engine loads varied from 0 kW to 75 kW (at 25 kW intervals) of the maximum electrical rating, the performance of the neat and B50 are slightly lower than diesel No. 2 fuel. Emissions of NO_x, CO and HC from B100 and B50 are lower than those of diesel No. 2 fuel, except that at the 75 kW engine load, where the B100 emits higher levels of NO_x than the diesel No. 2 fuel.

Anh N. Phan and Tan Phan. [40] had criticized biodiesel production from waste cooking oils. Alkali-catalyzed transesterification of waste cooking oils with methanol was carried out in a laboratory scale reactor. The effects of methanol/waste cooking oils ratio, potassium hydroxide concentration and temperature on the biodiesel conversion were investigated. Biodiesel yield of 88–90% was obtained at the methanol/oil ratios of 7:1–8:1, temperatures of 30–50 C and 0.75 wt% KOH. The results showed that the biodiesel experienced a higher but much narrower boiling range than conventional diesel. Carbon residue content was up to 4 wt%. Blends with a percentage of the biodiesel below 30 vol% had their physical properties within EN14214 standard, which indicated that these could be used in engines without a major modification.

Martin Mittelbach. [41] had discussed the rising importance of biodiesel as alternative fuel in many countries, it is absolutely necessary to establish standards for the description of the quality of the product. The parameters and the corresponding threshold values defining the quality of rapeseed-oil methyl esters (RME) used as biodiesel according to the latest Austrian standardization (O-NORM) are presented and discussed. The difference is distinguished between general fuel parameters, which already exist for mineral diesel fuel, and vegetable-oil-specific parameters, which have to be additionally defined. Correlations between parameters like Conradson carbon residue, sulfate ash and phosphorus content are outlined. Problems concerning the inclusion of parameters, which have not yet been taken up in the Austrian standards, like iodine number and water content, are discussed. In the second part, analytical aspects for the determination of free and bonded glycerol, as well as mono-, di- and triglycerides are described. Well tested methods for the analysis of glycerol and glycerides are presented, including the desctiption of the advantages and disadvantages of each method.

Nezihe Azcan and Aysegul Danisman. [42] had studied rapeseed is one of the important vegetable oil sources for biodiesel production due to its high oil content (around 40%). In this study rapeseed oil was converted to biodiesel by transesterification using microwave heating. Experiments were carried out in the presence of two different alkali catalysts which are sodium hydroxide and potassium hydroxide. Effects of various reaction parameters such as catalyst ratio, reaction temperature and time were investigated. Mono-, di- and triglyceride content of biodiesel were determined by gas chromatography analysis. Yield and purity (ester content) percentages of biodiesel were specified in weight, which are 88.3–93.7% and 87.1–99.4%, respectively. The results indicated that microwave heating has effectively increased the biodiesel yield and decreased the reaction time.

Shaoyang Liu, Timothy McDonald and Yifen Wang. [43] had described efficient biodiesel conversion from waste cooking oil with high free fatty acids (FFAs) was achieved via a two-stage procedure (an acid-catalyzed esterification followed by an alkali-catalyzed transesterification) assisted by radio frequency (RF) heating. In the first stage, with only 8-min RF heating the acid number of the waste cooking oil was reduced from 68.2 to 1.64 mg KOH/g by reacting with 3.0% H_2SO_4 (w/w, based on oil) and 0.8:1 methanol (weight ratio to waste oil). Then, in the second stage, the esterification product (primarily consisting of triglycerides and fatty acid methyl esters) reacted with 0.91% NaOH (w/w, based on triglycerides) and 14.2:1 methanol (molar ratio to triglycerides) under RF heating for 5 min, and an overall conversion rate of 98.8 : 0.1% was achieved. Response surface methodology was employed to evaluate the effects of RF heating time, H2SO4 dose and methanol/oil weight ratio on the acid-catalyzed esterification. A significant positive interaction between RF heating time and H_2SO_4 concentration on the esterification was observed.

Shakinaz A. Sherbiny, Ahmed A. Refaat and Shakinaz T. Sheltawy. [44] had analyzed biodiesel production is worthy of continued study and optimization of production procedures because of its environmentally beneficial attributes and its renewable nature. Non-edible vegetable oils such as Jatropha oil, produced by seed-bearing shrubs, can provide an alternative and do not have competing food uses. However, these oils are characterized by their high free fatty acid contents. Using the conventional transesterification technique for the production of biodiesel is well established. In this study an alternative energy stimulant, ''microwave irradiation'', was used for the production of the alternative energy source, biodiesel. The optimum parametric conditions obtained from the conventional technique were applied using microwave irradiation in order to compare the systems. The study showed that the application of radio frequency microwave energy offers a fast, easy route to this valuable biofuel with the advantages of enhancing the reaction rate (2 min instead of 150 min) and of improving the separation process. The methodology allows for the use of high free fatty acid content feedstock, including Jatropha oil. However, this emerging technology needs to be further investigated for possible scale-up for industrial application.

M. Berrios, M.A.Martin, A.F.Chica and A. Martin. [45] had criticized used frying oils are a good alternative for biodiesel production but their treatment is more complex than fresh vegetable oils. Used frying oils contain a large amount of free fatty acids, so an esterification step is necessary before transesterification. This reaction is usually carried out in batch reactors with pressure and temperature conditions (ambient pressure and 60 °C) where the esterification reaction acts as the limiting step of the production. The aim of this work was to investigate the acidity removal and the subsequent transesterification at different temperatures and mole ratios in a batch reactor in order to improve the biodiesel production from used frying oils. The influence of temperature was studied in order to know the kinetics of esterification. The reaction rate increased when the temperature was increased. The experimental results were found to fit a firstorder kinetic law for the forward reaction and a second-order for the reverse reaction. The influence of temperature was found to be insignificant on the transesterification reaction. Nevertheless, methanol/oil mole ratio influenced up to 6.0:1. The influence of upper mole ratios was insignificant on the FAME content evolution. Based on the experimental results, biodiesel from used frying oil did not fulfil all the specifications from EN 14214 Standard due to the chemical modifications in the oil during cooking (presence of polar compounds). Therefore, biodiesel was proposed for use in combustion processes or in blends with biodiesel from other vegetable oils or even animal fats, which had not undergone chemical modifications.

Xiangmei Meng, Guanyi Chen and Yonghong Wang. [46] had discussed waste cooking oils (WCO), which contain large amounts of free fatty acids produced in restaurants, are collected by the environmental protection agency in the main cities of China and should be disposed in a suitable way. Biodiesel production from WCO was studied in this paper through experimental investigation of reaction conditions such as methanol/oil molar ratio, alkaline catalyst amount, reaction time and reaction temperature which are deemed to have main impact on reaction conversion efficiency. Experiments have been performed to determine the optimum conditions for this transesterification process by orthogonal analysis of parameters in a four-factor and three-level test. The optimum experimental conditions, which were obtained from the orthogonal test, were methanol/oil molar ratio 9:1, with 1.0 wt.% sodium hydroxide, temperature of 50 °C and 90 min. Verified experiments showed methanol/oil molar ratio 6:1 was more suitable in the process, and under that condition WCO conversion efficiency led to 89.8% and the physical and chemical

properties of biodiesel sample satisfied the requirement of relevant international standards. After the analysis main characteristics of biodiese sample, the impact of biodiesel/diesel blend fuels on an YC6M220G turbo-charge diesel engine exhaust emissions was evaluated compared with diesel. The testing results show without any modification to diesel engine, under all conditions dynamical performance kept normal, and the B20, B50 blend fuels (include 20%, 50% crude biodiesel respectively) led to unsatisfactory emissions whilst the B20 blend fuel (include 20% refined biodiesel) reduced significantly particles, HC and CO etc. emissions. For example CO, HC and particles were reduced by 18.6%, 26.7% and 20.58%, respectively.

Ayhan Demirbas. [47] had studied vegetable oil fuels have not been acceptable because they were more expensive than petroleum fuels. With recent increases in petroleum prices and uncertainties concerning petroleum availability, there is renewed interest in vegetable oil fuels for Diesel engines. Dilution of oils with solvents and microemulsions of vegetable oils lowers the viscosity, but some engine performance problems still exist. The purpose of the transesterification process is to lower the viscosity of the oil. Pyrolysis produces more biogasoline than biodiesel fuel. Soap pyrolysis products of vegetable oils can be used as alternative Diesel engine fuel. Methyl and ethyl esters of vegetable oils have several outstanding advantages among other new renewable and clean engine fuel alternatives. The main factors affecting transesterification are the molar ratio of glycerides to alcohol, catalyst, reaction temperature and pressure, reaction time and the contents of free fatty acids and water in oils. The commonly accepted molar ratios of alcohol to glycerides are 6:1–30:1.

Maria Jesus Ramos, Carmen Maria Fernandez, Abraham Casas, Lourdes Rodriguez and Angel Perez. [48] had described the aim of this work was the study of the influence of the raw material composition on biodiesel quality, using a transesterification reaction. Thus, ten refined vegetable oils were transesterificated using potassium methoxide as catalyst and standard reaction conditions (reaction time, 1 h; weight of catalyst, 1 wt.% of initial oil weight; molar ratio methanol/oil, 6/1; reaction temperature, 60 °C). Biodiesel quality was tested according to the standard [UNE-EN 14214, 2003. Automotive fuels. Fatty acid methyl esters (FAME) for diesel engines. Requirements and test methods]. Some critical parameters like oxidation stability, cetane number, iodine value and cold filter plugging point were correlated with the methyl ester composition of each biodiesel, according to two parameters: degree of unsaturation and long chain saturated factor. Finally, a triangular graph based on the composition in monounsaturated, polyunsaturated and saturated methyl esters was built in order to predict the critical parameters of European standard for whatever biodiesel, known its composition.

Titipong Issariyakul, Mangesh G. Kulkarni, Ajay K. Dalai and Narendra N. Bakhshi. [49] had analyzed transesterification of waste fryer grease (WFG) containing 5–6 wt.% free fatty acid (FFA) was carried out with methanol, ethanol, and mixtures of methanol/ethanol maintaining the oil to alcohol molar ratio of 1:6, and initially with KOH as a catalyst. Mixtures of methanol and ethanol were used for transesterification in order to use the better solvent property of ethanol and rapid equilibrium using methanol. Formation of soap by reaction of FFA present in WFG with KOH instigated difficulty in the separation of glycerol from biodiesel ester. To untangle this problem, two-stage (acid and alkali catalyzed) method was used for biodiesel synthesis. More than 90% ester was obtained when two-stage method was used compared to ~50% ester in single stage alkaline catalyst. In the case of mixed alcohol, a relatively smaller amount of ethyl esters was formed along with methyl esters. Acid value, viscosity, and cetane number of all the esters prepared from WFG were within the range of the ASTM standard. Esters obtained from WFG showed good performance as a lubricity additive.

C.C. Enweremadu and M.M. Mbarawa. [50] had discussed the increasing awareness of the depletion of fossil fuel resources and the environmental benefits of biodiesel fuel has made it more attractive in recent times. The cost of biodiesel, however, is the major hurdle to its commercialization in comparison to petroleum-based diesel fuel. The high cost is primarily due to the raw material, mostly neat vegetable oil. Used cooking oil is one of the economical sources for biodiesel production. However, the products formed during frying, can affect the transesterification reaction and the biodiesel properties. This paper attempts to review various technological methods of biodiesel production from used cooking oil. The analytical methods for high quality biodiesel fuel from used cooking oil like GC, TLC, HPLC, GPC and TGA have also been summarized in this paper. In addition, the specifications provided by different countries are presented. The fuel properties of biodiesel fuel from used cooking oil were also reviewed and compared with those of conventional diesel fuel.

Chapter 3

EXPERIMENTAL DETAILS

3.1 Machine design

Tool kits of testing impurities of biodiesel was designed base on convenient usage and its price as shown in Figure 3.1, this design was created by Rhinoceros program [50]. This tool kit was made of foam box which has the dimension of width is 33.8 cm, length of 48.4 cm. and height of 32.5 cm.

Figure 3.1 Box design

The box composed of 3 compartments as follows:

Compartment 1: It is the part for install heater for boiling water to generate heat for transesterification process as shown in Figure 3.2. The size of inside heater is 17.9 cm of height and 15.8 cm of diameter. The electric power of this heater is 600 watt. The power is 2.75 ampere and the voltage is 220 volt. [App.C-5] This compartment is in the bottom side of the tool kit box and it was set at the center of this area.

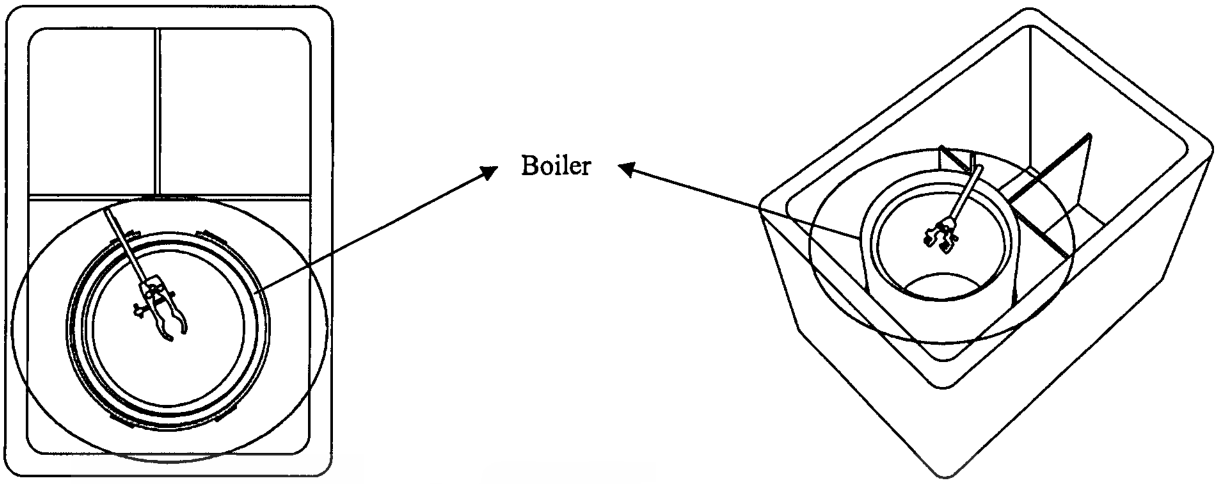


Figure 3.2 Heater for generate heat for transesterification process

Compartment 2: It is the part for install thermocouple and temperature controller as shown in figure 3.3. The power of temperature controller [App.C-3] is 100~250 watt. Volt of alternating current of this temperature controller is 50/60 Hz. The range of temperature is -50°C ~ 1,200°C. Thermocouple and temperature controller were set in the little box which has dimension of width is 8.5 cm, length of 14.8 cm and height of 14.5 cm. The position of thermocouple and temperature controller is in the top side of the tool kit box at the right-top corner.

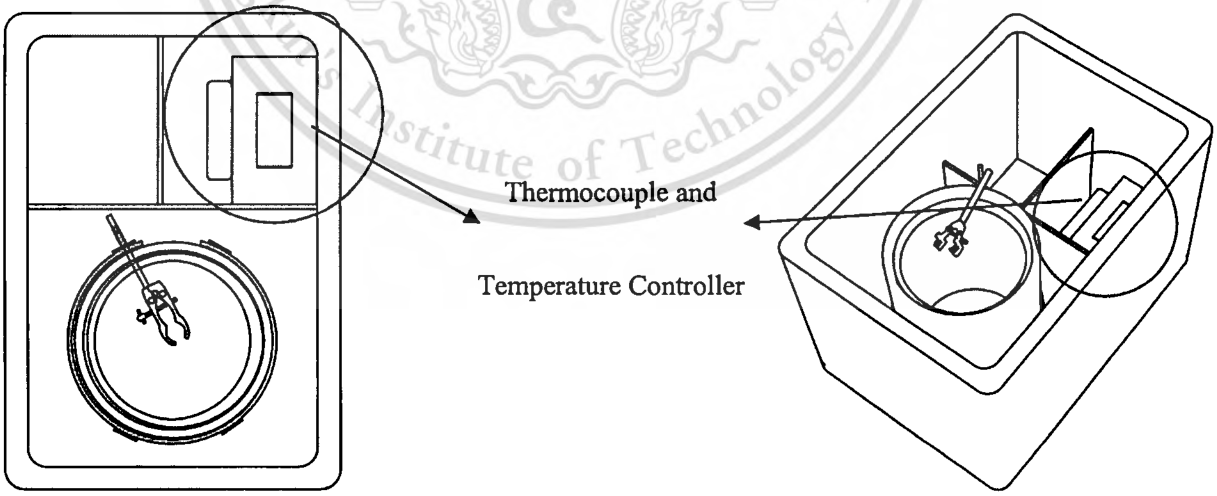


Figure 3.3 Thermocouple and temperature controller

Compartment 3: It is the part for storage chemicals and equipments such as beaker, a bottle of methanol, and a container of potassium hydroxide. This part is also in the top side of the tool kit box at the right-top corner. This part is made from recycled paper which has dimension of width is 11.8 cm, length of 16 cm and height of 10 cm. There is another part for storage the centrifuge tube; it is in the bottom side of the box. Volume of this centrifuge tube is 100 ml. Size of centrifuge tube height is 20 cm. and dimension of 3.9 cm. Material that is used to wrap up this centrifuge tube is plastic sponge which has dimension of width is 6.5 cm, length of 7.3 cm and height of 20.3 cm. The position of the centrifuge tube is at the right-top corner of this side or it is next to the heater as shown in Figure 3.4.

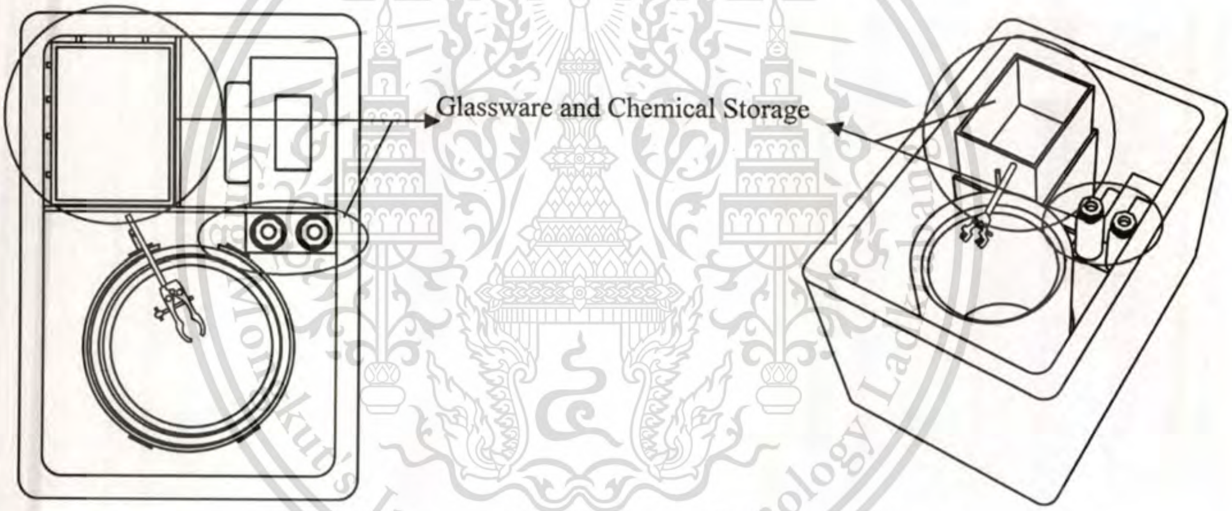


Figure 3.4 Box for glass wares and chemicals

3.2 Tools of machine

3.2.1 Foam box

Foam box was used as a container to carry all the equipment. Its length is 48.4 cm, width of 33.8 cm. and height of 32.5 cm. The foam box was used as a carrier because of it is an insulator, it has a light weight and it is not expensive. This foam box is the general foam box that can be found in any retail shop as shown in Figure 3.5.

Figure 3.5 Foam box

3.2.2 Boiler

Boiler was used to serve the function of heater provider. It boils the water to generate heat for tranesterification process. This boiler is the product of Toshiba Company as shown in Figure 3.6. Its version and volume are PKL-G26E and 2.6 liters, respectively. It has electric power 600 watts, power 2.75 amperes and voltage 220 volts. [App.C-5]

Figure 3.6 Boiler

3.2.3 Thermocouple and Temperature controller

Thermocouple type K [App.C-3] was used for measurement of hot water temperature in boiler. Thermocouple connects with temperature controller to control temperature in boiler. This temperature controller has power of 100~250 watts, volt of alternating current is 50/60 Hz. and the range of the temperature is -50°C~1,200°C. This temperature controller has a monitor for display the current temperature and it has the "set" and "arrow" buttons for set the desire temperature as shown in Figure 3.7. [App.C-3]

Figure 3.7 Thermocouple and Temperature controller

3.2.4 Boiling locker

Boiling locker used for locking a boiler and for standing a clamp. It made from steel. And its dimension is 7.5 cm. on height and 21 cm. diameter. It also has a bar for standing clamp which is 20.5 cm. heights as shown in Figure 3.8.

Figure 3.8 Boiling locker

3.2.5 Foam slab

Foam slab was used for dividing a tool kit box into 2 sections. Its dimension is 17.8 cm. width and 31.7 cm. length. An aperture beside the foam slap edge was created to enclose the wire plug which connects the boiler with AC power as shown in Figure 3.9.

Figure 3.9 Foam slab

3.2.6 Glue and Double sided glue tapes

UHU glue [App.C-6] and 3M double sided glue tape [App.C-1] as shown in Figure 3.10 were used for connected all of foam slap and all equipments to the foam box.

Figure 3.10 Glue and Double side glue tape

3.2.7 Socket outlet and AC power plug

The socket which contains three slots was used to receive the wire plug from the boiler and 220 volts AC power outlet plug was used to connect with the temperature controller as shown in Figure 3.11.

Figure 3.11 Socket outlet and AC power plug

3.2.8 Glassware box

Glassware box was made from recycle corrugated paper. Its width is 11.8 cm, length of 16 cm. and height of 10 cm. It was created by drawing on the recycle corrugated paper and then connects it with glue as shown in Figure 3.12.

Figure 3.12 Box for glassware and chemicals

3.2.9 Centrifuge tube

Centrifuge tube was used as a container for transesterification process as shown in Figure 3.13. The volume of this centrifuge tube is 100 ml. and its height is 3.9 cm. It is the centrifuge of Kimax USA from THAI PURE SCIENCE Co.,LTD. This centrifuge tube has scale of 0.05 ml. (0-3 ml.), 0.20 ml. (3-6 ml.), 0.50 ml. (6-10 ml.) and 1.00 ml (10-100 ml.) because the volume around 0-5 ml. must be read to measure the volume of precipitate.

Figure 3.13 Centrifuge tube 100 ml.

3.2.10 Stirring rod, Beaker, Spoon, Bottle of KOH and Bottle of Methanol

The stirring rod; length is 21 cm; was used for stir the potassium hydroxide to dissolve with methanol in beaker 50 ml. The spoon volume with 1.57 cm^3 was used to measure potassium hydroxide. A bottle of potassium hydroxide which has height 5.1 cm. and diameter 6 cm. and the bottle of methanol as shown in Figure 3.14.

Figure 3.14 Stirring rod, Beaker, Spoon, Bottle of KOH and Bottle of Methanol

3.3 Procedure for testing biodiesel by using tool kits

3.3.1 Process conditions and Chemicals

Temperature of reaction	60 °C
Reaction time	30 minutes
Precipitation time	24 hrs
Sample volume (biodiesel)	60 ml.
Reactant volume (methanol)	25 ml.
Catalyst weight (KOH)	0.75 g. or 1 full spoon

3.3.2 Experimental

1. Fill the boiler with tap water and place the boiler at the same position as shown in Figure 3.15.

Figure 3.15 Boiler with tap water

2. Connect the boiler with AC power and then plug the AC power into socket outlet.
3. Plug another socket from temperature controller into the other socket outlet. Wait until the water boiled.

4. Set the clamp with the standing clamp and sets the position of clamp at the center of boiler for holding the centrifuge tube which is used as a container in the transesterification process as shown in Figure 3.16.

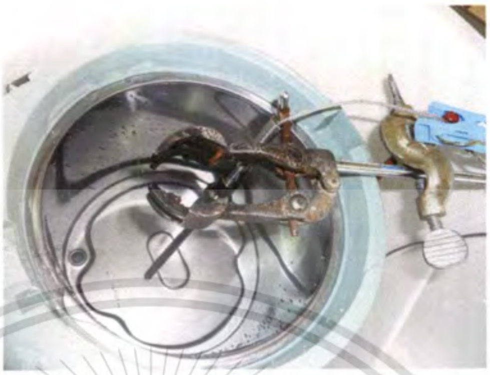


Figure 3.16 Standing clamp at center of boiler

5. Set the temperature controller at 60 °C. (Press set bottom and then adjust the temperature and press set when it is done) Put the thermocouple into boiler and wait until the temperature reach 60 °C. (See at the monitor of temperature controller.) as shown in Figure 3.17.

Figure 3.17 Temperature controller

6. Prepare the sample by adding 60 ml. of biodiesel sample into centrifuge tube as shown in Figure 3.18.

Figure 3.18 Biodiesel sample

7. Mix 25ml. of methanol with 0.75 g. or 1.57 cm^3 of potassium hydroxide. Swirl these until all of the potassium hydroxide dissolved as shown as Figure 3.19.

Figure 3.19 Mixture of methanol and potassium hydroxide

8. Then pour 10 ml. of these solutions into centrifuge tube mix it together as shown in Figure 3.20.

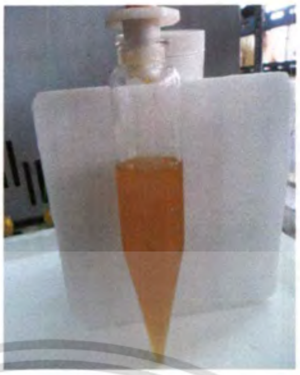


Figure 3.20 Centrifuge tube

9. Then put the sample tube into 60°C of water boiler. Wait for 30 minutes for the transestrification process as shown in Figure 3.21.

Figure 3.21 Centrifuge tube in water boiler

10. After 30 minutes, take the sample tube out and let it precipitates for 24 hours as shown in Figure 3.22.

Figure 3.22 Precipitation of sample

11. Then calculate the percent of methyl ester by using the volume of precipitate calculated with the equation below and compare percent of methyl ester with standard.[13]

$G = (Y + 0.0136)/0.0611$

$E = 100 - G$

Where; Y is the volume of observed glycerol

G is the percent of glyceride left

E is the percent of methyl ester after reaction

Chapter 4

RESULTS AND DISCUSSIONS

4.1 The overall design and assembly line of machine

Tool kit was made on foam box from the reason of weight and price. Foam box has light weight and cheap price. This tool kit is composed of 3 compartments which are in 2 parts, the first part is in the right side of tool kit box and another part is in the left side. At the right side, it is the area for install the boiling locker, standing clamp and boiler which can be used to generate heat for transesterification process. And at the left side, it is the area for install thermocouple, temperature controller and box for storage glassware. There is another part for storage the centrifuge tube; it is in the right side of the tool kit box beside the boiler. These were design to fit the equipment with the box area for the convenient use as shown in Figure 4.1 and Figure 4.2.

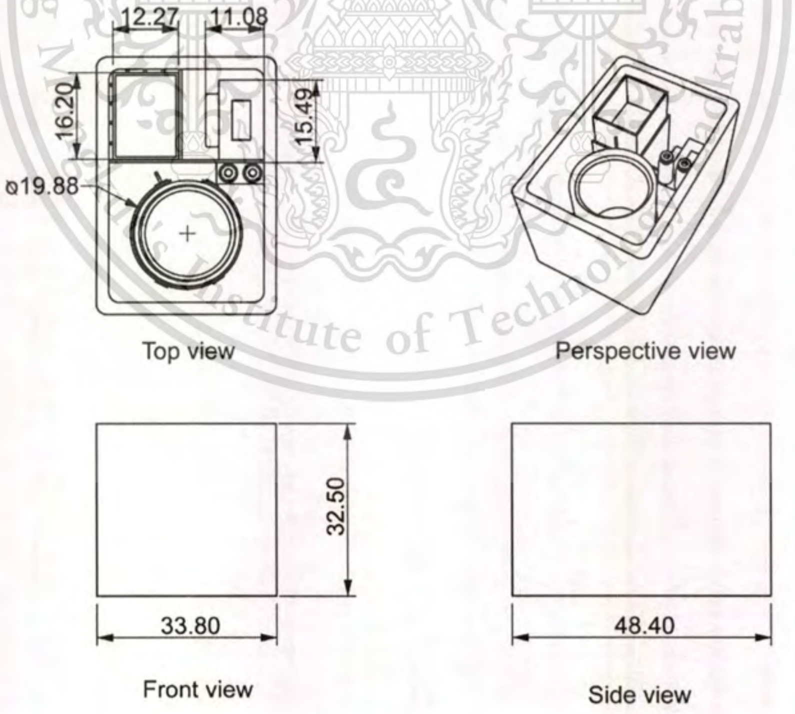


Figure 4.1 The overall design of the machine

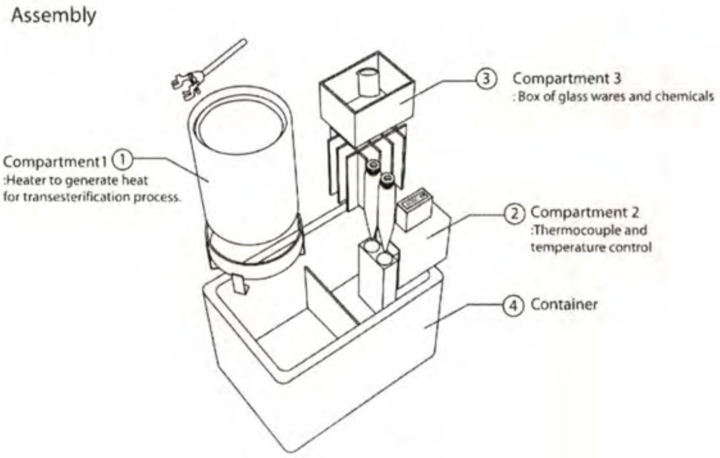


Figure 4.2 The assembly of the machine

4.2 Tools of machine and its cost

4.2.1 The cost of tool kit materials

All of the equipments were searched base on the cost and the convenient. It can be found in any retail shop. The tool kit box was divided into 3 parts by using foam slab, adhesive tape and adhesive glue. For the adhesive glue, it is the special glue that can use with foam called "UHU POR" because it does not melt foam [App.C-6].This version of boiler [App.C-5] was used because it is not expensive and its size is not over than necessary. Thermocouple and temperature controller were included in this tool kit because in the transesterification process, the chemical reaction was operate at 60 °C to prevent the loss of methanol [18]. The mechanism of thermocouple and temperature controller is the power supply from source of energy to boiler. If the temperature in boiler is more than temperature that is set by temperature controller, the temperature controller will stop to supply heat to the boiler. So thermocouple and temperature controller can help the water temperature in boiler be stable. The boiling locker was used to lock the boiler and prevent the others part to be damaged from the movement of boiler when tool kit was carried. And it also has a piece for standing the clamp that was used to hold the centrifuge tube.

Table 4.1 Cost of tool kits material

Tool of Machine	Baht
Boiler	750
Centrifuge tube	1700
Foam box	85
Beaker 50 ml.	20
Clamp and boiling locker	150
Foam slab	30
Thermocouple	550
Temperature controller	200
Socket outlet	150
UHU glue and 3M double sided glue tape	130
Chemical container	30
Total Cost	3,795

The total cost of the tool kit is 3,795 Baht as shown in Table 4.1. For the approximate testing in the quality of biodiesel, cost of this tool kit for biodiesel testing is more inexpensive than the others [App.C-8].

4.3 The assembly of tool kits model

4.3.1 Procedure for building tool kit

1. Design a box for storage everything such as boiler, thermocouple and temperature controller by using Rhinoceros program as shown in Figure 4.3 [App.C-7]

Figure 4.3 Rhinoceros program

2. Prepare and choose appropriate equipments for use in the box such as boiler, thermocouple, and glassware as shown in Figure 4.4.

Figure 4.4 All equipments for tool kits assembly

3. A foam box was divided into 2 sides by using foam slab as shown in Figure 4.5.

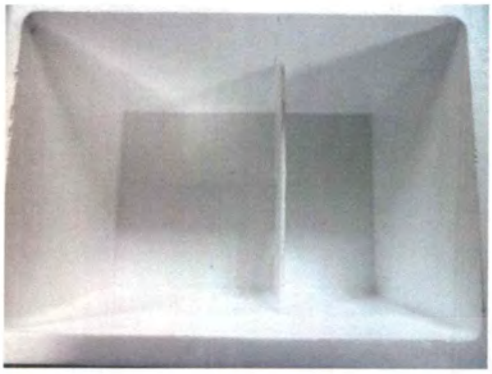


Figure 4.5 A foam box was divided into 2 sides

4. Install thermocouple and temperature controller in the box by using 3M tape for stick within one side of the box as shown in Figure 4.6.

Figure 4.6 The box with thermocouple and temperature controller

5. Stick 3M tape on boiling locker and take a tape another side off for preparing set in the box after that put boiling locker in another side of the box as shown in Figure 4.7.

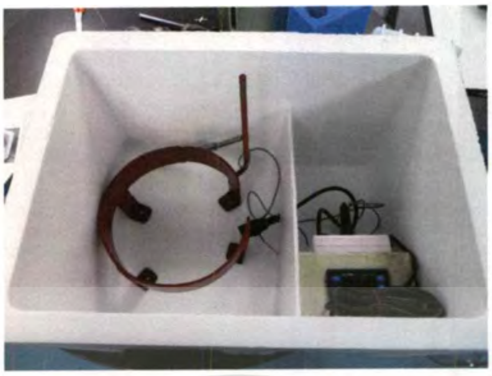


Figure 4.7 The box after install boiling locker

6. Put boiler on the boiling locker and connect with AC power as shown in Figure 4.8.

Figure 4.8 The box after install boiler

7. Set a glassware box at the opposite side of temperature controller as shown in Figure 4.9.

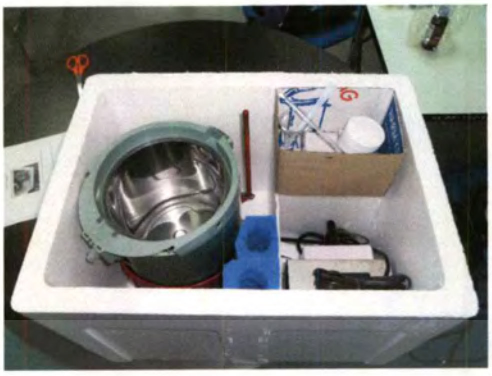


Figure 4.9 The box after install a glassware box

8. Finally everything was inserted in the box as shown in Figure 4.10.

Figure 4.10 Complete box

4.3.2 The completed tool kits box

Figure 4.11 Top view of tool kit

Figure 4.12 Perspective of tool kit

4.4 Biodiesel sample after tested with tool kit

Table 4.2 Data of precipitation

Biodiesel 100	Precipitate (ml.)	Y	G	E
No.1	4.30	1.72	1.94	98.06
No.2	5.80	2.34	2.56	97.44

Where; Y is the volume of observed glycerol

G is the percent of glyceride left

$G = (Y + 0.0136)/0.0611$

E is the percent of methyl ester after reaction

$E = 100 - G$

The equation $Y = 0.0611x - 0.0136$ is came from the trending graph plotted by percent of total value of glycerol from gas chromatography/mass spectrometer test. [App.B] The lowest value of percent of methyl ester from the standard is not less than 96.5% [Table 2.1] The highest limit value of the precipitate for good biodiesel from the calculation is 18.19 ml. or 18 ml. approximately [App.A-1]. The reason for measure the precipitate in volume (ml.) is easy to observe.

Biodiesel B100 in tube number 1

This sample is biodiesel (B100) from Maisonoop Company, Chonburi. The raw material of biodiesel sample was from waste cooking oil. After the reaction (Figure 4.13), the precipitate was 4.30 ml. and percent of methyl ester (E) was 98.06 percents. This percent is an acceptable value when compared with standard [Table 2.1].

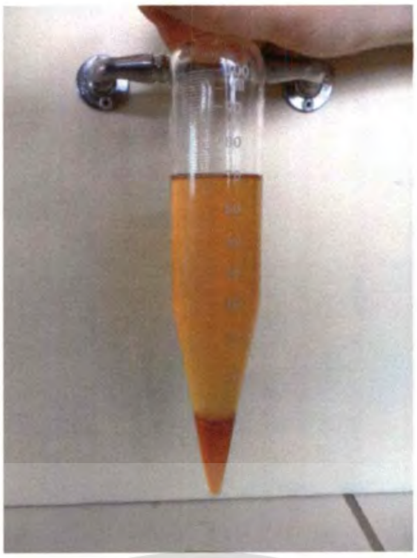


Figure 4.13 Biodiesel 100 no. 1

Biodiesel B100 in tube number 2

This sample is biodiesel (B100) from Transportation Company who make biodiesel to use in their organization for 5 years. Raw material that they used to make biodiesel is waste cooking oil. After the reaction (Figure 4.14), the precipitate was 5.80 ml. and percent of methyl ester (E) was 97.44 percents. This percent was an acceptable value when compared with standard [Table 2.1].

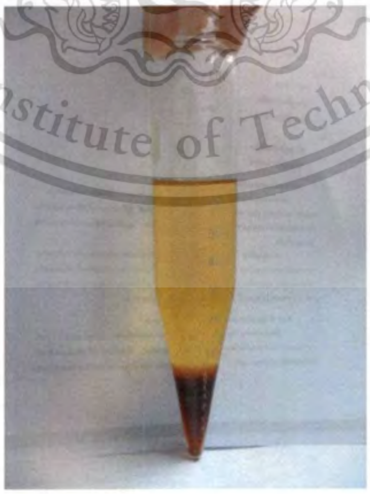


Figure 4.14 Biodiesel 100 no. 2

Chapter 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

Tool kit for testing biodiesel was created from the reason based on price and convenient of usage. Design of tool kit model was created by Rhinoceros program which help to create 3D picture of tool kit box and it can also create top view, front view, side view, perspective view and assembly. The equipments are used to install in the tool kit box can be found easily in any retail shops except the centrifuge tube and chemicals. These can be ordered from the specific company. Foam box was used because of its price. It was divided into 3 compartments. Compartment 1, it is the area for install the boiler and some part for storage the centrifuge tube. Compartment 2, it is the area for install thermocouple and temperature controller. Compartment 3, it is the area for install the box for glassware storage. The heater used for generate heat to the transesterification process is the Toshiba boiler pot because of its qualifications [App.C]. The adhesive glue which is used to connect all of equipment must be specific glue because it does not melt the foam box [App.C]. The total net cost of this tool kits is 3,795 Baht. It is more inexpensive than the other biodiesel testing method [App.C]. The completed tool kits has the inside equipment position as same as the overall design.

The testing tool kits for quality utilization with biodiesel, from the results and the calculations with equation Y = 0.0611x - 0.0136 [App.A-1] which is came from the calibration curve plotted [App.C-9] by value of percent of total glycerol from gas chromatography and mass spectrometer shown that biodiesel in tube number 1 has 98.06 percents of methyl ester that is more than tube number 2 which is 97.44 percents, it was meant that the biodiesel in tube number 1 had impurity lower than tube number 2. From the volume of the observed glycerol or Y value, it also confirms that the amount of glyceride left in the biodiesel sample was quite high, the glycerol or the precipitate after reaction was either high. The glycerol left after the reactions was approximately to the impurity in biodiesel. From standard, biodiesel should have methyl ester higher than 96.5 percents [Table 2.1] or 8.1 ml. from the calculation [App.A-1]. Therefore, both of biodiesels are pure enough to apply with the diesel engine.

5.2 Recommendation

1. This tool kit is approximately testing.
2. It cannot test with accurately component impurities.
3. Size of the box should be smaller and have handle for carrying the tool box.
4. Material of box should be changed if there are any other plastic boxes that have cheaper price because oil can melt foam. If there is any oil drops spill on the foam box, it must be wiped out immediately. Otherwise, the foam box will be damaged.

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APPENDIX

Appendix A : Experimental data

❖ Appendix A-1 : Calculation

- Calculate the volume of observed glycerol (Y value)

$$Y = \frac{Precipitate}{2.5}$$

- Biodiesel 100 No.1 :

$$Y = \frac{4.30}{2.5}$$

$$= 1.72$$

- Biodiesel 100 No.2 :

$$Y = \frac{5.80}{2.5}$$

$$= 2.34$$

- Calculate the percent of glyceride left (G value)

$$G = \frac{Y + 0.0136}{0.0611}$$

- Biodiesel 100 No.1 :

$$G = \frac{1.72 + 0.0136}{0.0611}$$

$$= 1.94$$

- Biodiesel 100 No.2 :

$$G = \frac{2.34 + 0.0136}{0.0611}$$

$$= 2.56$$

- Calculate the percent of methyl ester after reaction (E value)

$$E = 100 - G$$

- Biodiesel 100 No.1 :

$$E = 100 - 1.94$$

$$= 98.06$$

- Biodiesel 100 No.2 :

$$E = 100 - 2.56$$

$$= 97.44$$

- Calculate the precipitate limit

  - From standard [Table2.1], good biodiesel should have the percent of methyl ester at least 96.5%. Therefore, the convenient observation, this percent of methyl ester was converted into volume (ml.) by the calculation as shown as below.

From $$E = 100 - G$$

$$96.5 = 100 - G$$

$$G = 3.5$$

From $$G = \frac{Y + 0.0136}{0.0611}$$

$$3.5 = \frac{Y + 0.0136}{0.0611}$$

$$Y = 3.2774$$

Since $$Y = \frac{Precipitate}{2.5}$$

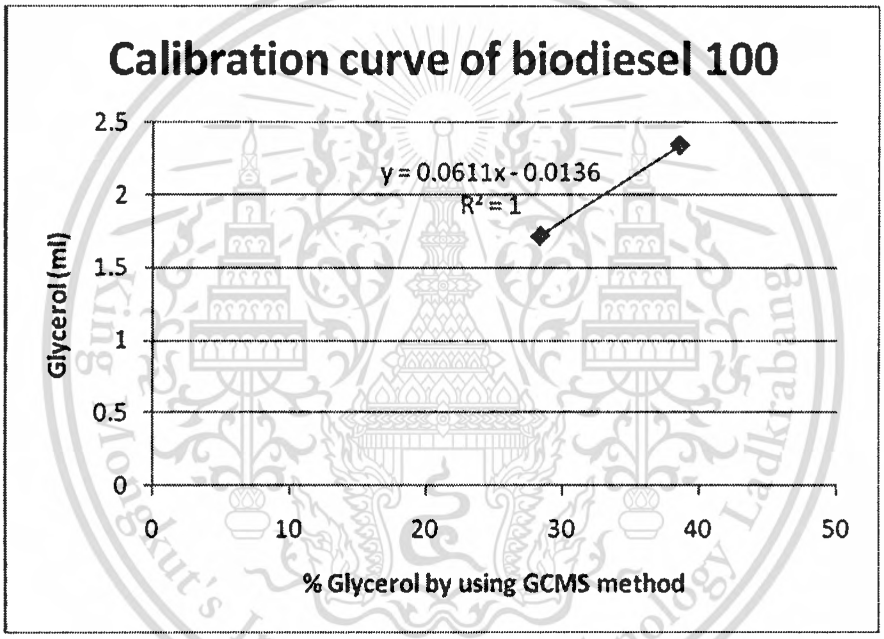
$$3.2774 = \frac{Precipitate}{2.5}$$

So, $Precipitate = 8.1935$

❖ Appendix A-2 : Calibration curve

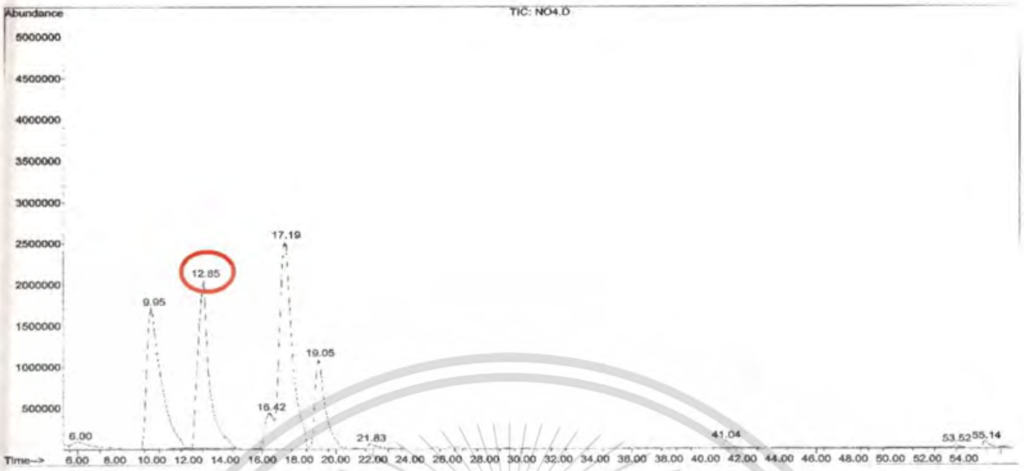
Table A.1: Data for plot calibration curve

	%Glycerol by using GCMS (x-axis)	Y value (y-axis)
Biodiesel 100 no.1	28.380	1.72
Biodiesel 100 no.2	38.530	2.34



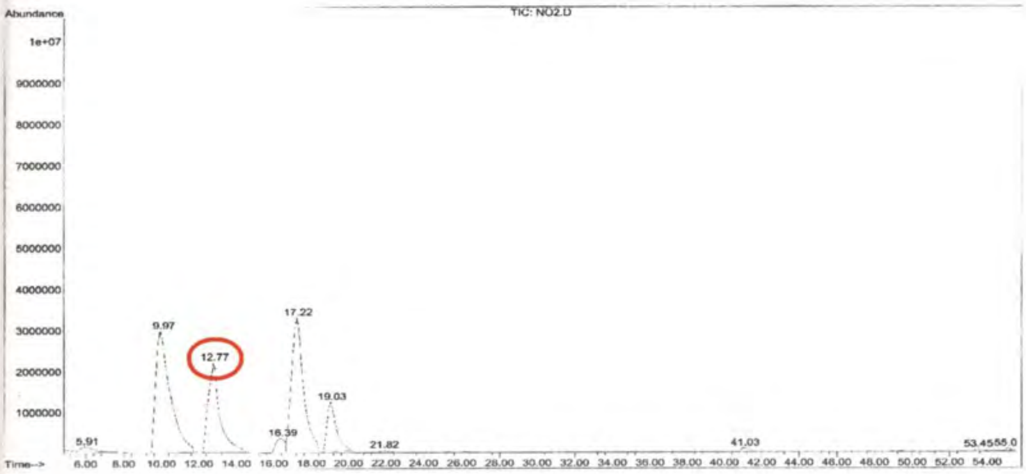
Appendix B : Gas Chromatography – Mass Spectroscopy (GC - MS)

Chromatogram for each biodiesel 100



```
peak  R.T. first  max last  PK   peak       corr.     corr.    % of
 #    min  scan  scan scan  TY  height      area     % max.   total
---  ----- ----- ---- ----  --- -------   -------   ------  -------
 1   5.998    81  155  495   M    80571   49388977    4.21%   1.360%
 2   9.947   733  821 1177   M5 1709824  927483918   79.13%  21.538%
 3  12.852  1186 1311 1606   M  2050020  873379476   74.51%  28.380%
 4  16.415  1827 1912 1957   M7  428451  135591078   11.57%   3.733%
 5  17.192  1957 2043 2268   M7 2518763 1172092506  100.00%  32.273%

 6  19.048  2280 2356 2545   M7 1080197  400043513   34.13%  11.015%
 7  21.828  2762 2825 3032   M7   60440   21082316    1.80%   0.580%
 8  41.044  6025 6066 6324   M7   89568   27035949    2.31%   0.744%
 9  53.518  8133 8170 8375   M7   41287    8902230    0.76%   0.245%
10  55.137  8401 8443 8658   M7   73216   16819732    1.44%   0.463%


                   Sum of corrected areas:   3631819695
```

Figure B.1: GC-MS Chromatogram of Biodiesel 100 No. 1



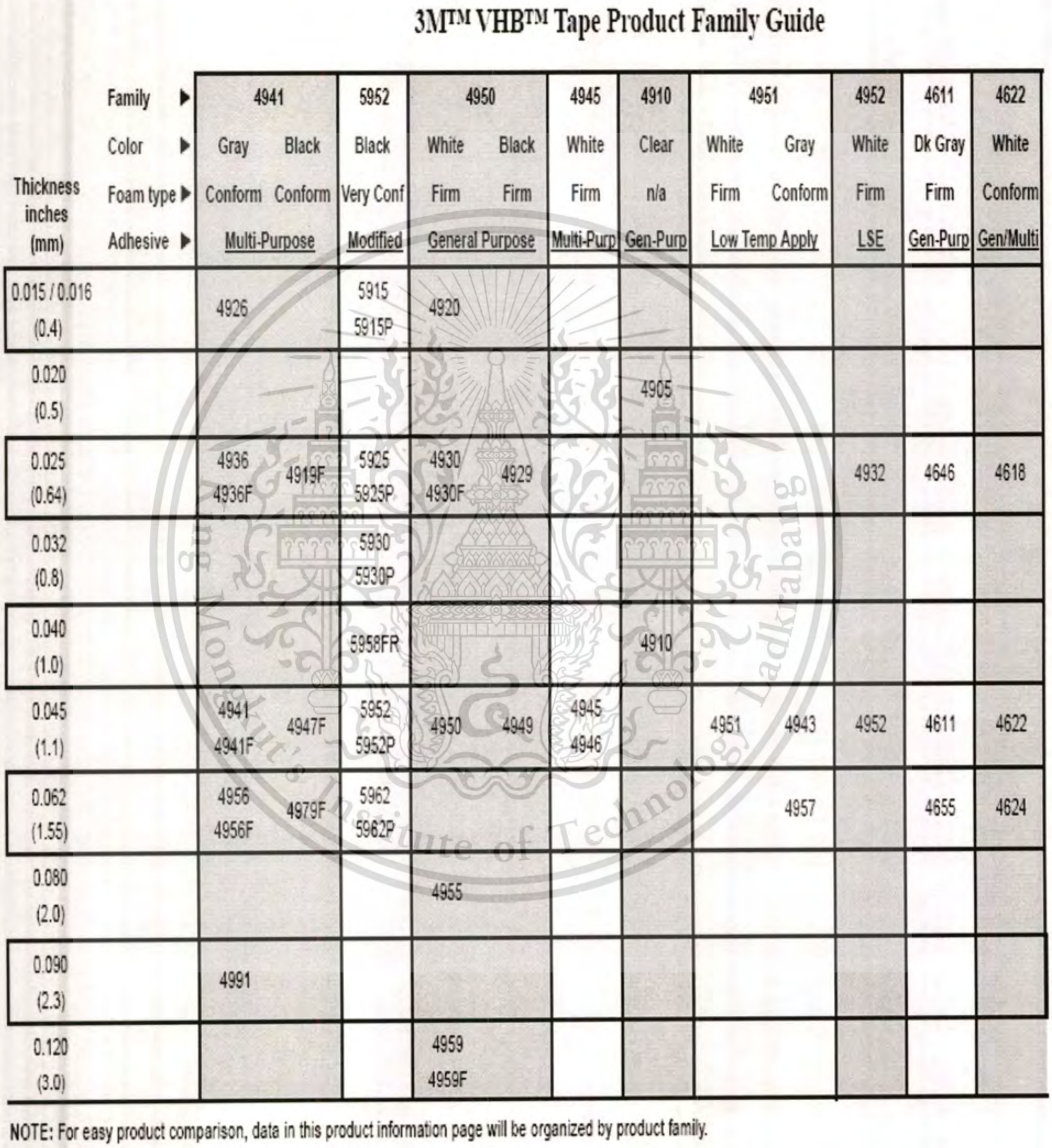
```
peak  R.T. first  max last  PK   peak        corr.   corr.    % of
  #   min   scan scan scan  TY  height       area    % max.   total
---  ----- ----- ---- ---- ---  -------   -------   ------  -------
 1    5.915   333  394  648   M9   120130   61989659   3.84%   1.334%
 2    9.970   989 1078 1408   M5  2971122 1612530801 100.00%  24.706%
 3   12.769  1449 1550 1865   M   2191456  951118510  58.98%  38.530%
 4   16.397  2083 2162 2202   M9   320944   96881381   6.01%   2.085%
 5   17.221  2204 2301 2497   M9  3262629 1445086867  89.62%  31.102%

 6   19.030  2541 2606 2797   M7  1218314  418057783  25.93%   8.998%
 7   21.822  3028 3077 3205   M7    56074   15599159   0.97%   0.336%
 8   41.032  6273 6317 6468   M7    89996   24788841   1.54%   0.534%
 9   53.453  8382 8412 8502   M7    47733    8597163   0.53%   0.185%
10   55.060  8652 8683 8751   M7    66265   11605211   0.72%   0.250%


                       Sum of corrected areas:    4646255375
```

Figure B.2: GC-MS Chromatogram of Biodiesel 100 No. 2

Appendix C: Specification of raw materials and cost

Appendix C-1: 3M tapes

Table C.1: 3M tape product family

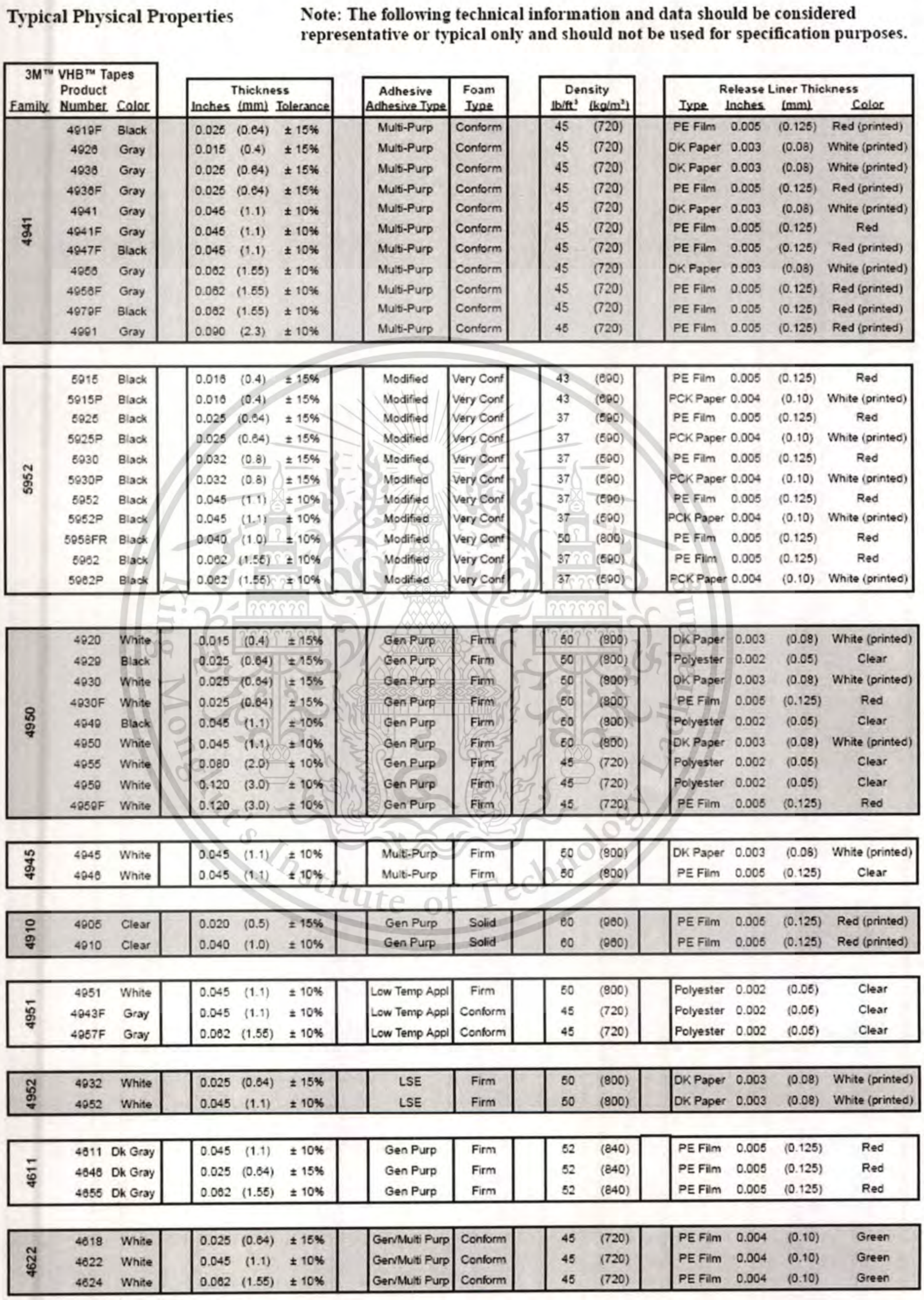


3M™ VHB™ Tape Product Family Guide

Thickness inches (mm)													
	Family ▶	4941		5952	4950		4945	4910	4951		4952	4611	4622
	Color ▶	Gray	Black	Black	White	Black	White	Clear	White	Gray	White	Dk Gray	White
	Foam type ▶	Conform	Conform	Very Conf	Firm	Firm	Firm	n/a	Firm	Conform	Firm	Firm	Conform
	Adhesive ▶	Multi-Purpose		Modified	General Purpose		Multi-Purp	Gen-Purp	Low Temp Apply		LSE	Gen-Purp	Gen/Multi
0.015 / 0.016 (0.4)		4926		5915 5915P	4920								
0.020 (0.5)								4905					
0.025 (0.64)		4936 4936F	4919F	5925 5925P	4930 4930F	4929					4932	4646	4618
0.032 (0.8)				5930 5930P									
0.040 (1.0)				5958FR				4910					
0.045 (1.1)		4941 4941F	4947F	5952 5952P	4950	4949	4945 4946		4951	4943	4952	4611	4622
0.062 (1.55)		4956 4956F	4979F	5962 5962P						4957		4655	4624
0.080 (2.0)					4955								
0.090 (2.3)		4991											
0.120 (3.0)					4959 4959F								

NOTE: For easy product comparison, data in this product information page will be organized by product family.

Table C.2: 3M Typical physical properties



Typical Physical Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

3M™ VHB™ Tapes Product			Thickness			Adhesive	Foam	Density		Release Liner Thickness			
Family	Number	Color	Inches	(mm)	Tolerance	Adhesive Type	Type	lb/ft³	(kg/m³)	Type	Inches	(mm)	Color
4941	4919F	Black	0.025	(0.64)	± 15%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red (printed)
	4926	Gray	0.015	(0.4)	± 15%	Multi-Purp	Conform	45	(720)	DK Paper	0.003	(0.08)	White (printed)
	4936	Gray	0.025	(0.64)	± 15%	Multi-Purp	Conform	45	(720)	DK Paper	0.003	(0.08)	White (printed)
	4936F	Gray	0.025	(0.64)	± 15%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red (printed)
	4941	Gray	0.045	(1.1)	± 10%	Multi-Purp	Conform	45	(720)	DK Paper	0.003	(0.08)	White (printed)
	4941F	Gray	0.045	(1.1)	± 10%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red
	4947F	Black	0.045	(1.1)	± 10%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red (printed)
	4956	Gray	0.062	(1.55)	± 10%	Multi-Purp	Conform	45	(720)	DK Paper	0.003	(0.08)	White (printed)
	4956F	Gray	0.062	(1.55)	± 10%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red (printed)
	4979F	Black	0.062	(1.55)	± 10%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red (printed)
	4991	Gray	0.090	(2.3)	± 10%	Multi-Purp	Conform	45	(720)	PE Film	0.005	(0.125)	Red (printed)
5952	5915	Black	0.016	(0.4)	± 15%	Modified	Very Conf	43	(690)	PE Film	0.005	(0.125)	Red
	5915P	Black	0.016	(0.4)	± 15%	Modified	Very Conf	43	(690)	PCK Paper	0.004	(0.10)	White (printed)
	5925	Black	0.025	(0.64)	± 15%	Modified	Very Conf	37	(590)	PE Film	0.005	(0.125)	Red
	5925P	Black	0.025	(0.64)	± 15%	Modified	Very Conf	37	(590)	PCK Paper	0.004	(0.10)	White (printed)
	5930	Black	0.032	(0.8)	± 15%	Modified	Very Conf	37	(590)	PE Film	0.005	(0.125)	Red
	5930P	Black	0.032	(0.8)	± 15%	Modified	Very Conf	37	(590)	PCK Paper	0.004	(0.10)	White (printed)
	5952	Black	0.045	(1.1)	± 10%	Modified	Very Conf	37	(590)	PE Film	0.005	(0.125)	Red
	5952P	Black	0.045	(1.1)	± 10%	Modified	Very Conf	37	(590)	PCK Paper	0.004	(0.10)	White (printed)
	5958FR	Black	0.040	(1.0)	± 10%	Modified	Very Conf	50	(800)	PE Film	0.005	(0.125)	Red
	5962	Black	0.062	(1.55)	± 10%	Modified	Very Conf	37	(590)	PE Film	0.005	(0.125)	Red
	5962P	Black	0.062	(1.55)	± 10%	Modified	Very Conf	37	(590)	PCK Paper	0.004	(0.10)	White (printed)
4950	4920	White	0.015	(0.4)	± 15%	Gen Purp	Firm	50	(800)	DK Paper	0.003	(0.08)	White (printed)
	4929	Black	0.025	(0.64)	± 15%	Gen Purp	Firm	50	(800)	Polyester	0.002	(0.05)	Clear
	4930	White	0.025	(0.64)	± 15%	Gen Purp	Firm	50	(800)	DK Paper	0.003	(0.08)	White (printed)
	4930F	White	0.025	(0.64)	± 15%	Gen Purp	Firm	50	(800)	PE Film	0.005	(0.125)	Red
	4949	Black	0.045	(1.1)	± 10%	Gen Purp	Firm	50	(800)	Polyester	0.002	(0.05)	Clear
	4950	White	0.045	(1.1)	± 10%	Gen Purp	Firm	50	(800)	DK Paper	0.003	(0.08)	White (printed)
	4955	White	0.080	(2.0)	± 10%	Gen Purp	Firm	45	(720)	Polyester	0.002	(0.05)	Clear
	4959	White	0.120	(3.0)	± 10%	Gen Purp	Firm	45	(720)	Polyester	0.002	(0.05)	Clear
	4959F	White	0.120	(3.0)	± 10%	Gen Purp	Firm	45	(720)	PE Film	0.005	(0.125)	Red
4945	4945	White	0.045	(1.1)	± 10%	Multi-Purp	Firm	50	(800)	DK Paper	0.003	(0.08)	White (printed)
	4946	White	0.045	(1.1)	± 10%	Multi-Purp	Firm	50	(800)	PE Film	0.005	(0.125)	Clear
4910	4905	Clear	0.020	(0.5)	± 15%	Gen Purp	Solid	60	(960)	PE Film	0.005	(0.125)	Red (printed)
	4910	Clear	0.040	(1.0)	± 10%	Gen Purp	Solid	60	(960)	PE Film	0.005	(0.125)	Red (printed)
4951	4951	White	0.045	(1.1)	± 10%	Low Temp Appl	Firm	50	(800)	Polyester	0.002	(0.05)	Clear
	4943F	Gray	0.045	(1.1)	± 10%	Low Temp Appl	Conform	45	(720)	Polyester	0.002	(0.05)	Clear
	4957F	Gray	0.062	(1.55)	± 10%	Low Temp Appl	Conform	45	(720)	Polyester	0.002	(0.05)	Clear
4952	4932	White	0.025	(0.64)	± 15%	LSE	Firm	50	(800)	DK Paper	0.003	(0.08)	White (printed)
	4952	White	0.045	(1.1)	± 10%	LSE	Firm	50	(800)	DK Paper	0.003	(0.08)	White (printed)
4611	4611	Dk Gray	0.045	(1.1)	± 10%	Gen Purp	Firm	52	(840)	PE Film	0.005	(0.125)	Red
	4646	Dk Gray	0.025	(0.64)	± 15%	Gen Purp	Firm	52	(840)	PE Film	0.005	(0.125)	Red
	4655	Dk Gray	0.062	(1.55)	± 10%	Gen Purp	Firm	52	(840)	PE Film	0.005	(0.125)	Red
4622	4618	White	0.025	(0.64)	± 15%	Gen/Multi Purp	Conform	45	(720)	PE Film	0.004	(0.10)	Green
	4622	White	0.045	(1.1)	± 10%	Gen/Multi Purp	Conform	45	(720)	PE Film	0.004	(0.10)	Green
	4624	White	0.062	(1.55)	± 10%	Gen/Multi Purp	Conform	45	(720)	PE Film	0.004	(0.10)	Green

Table C.3: 3M Typical performance characteristics

Typical Performance Characteristics

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

	3M™ VHB™ Tapes			Dynamic Adhesion Performance					
				90° Peel Adhesion		Normal Tensile		Dynamic Overlap Shear	
Family	Product Number	Color	Thickness Inches	lb/in	N/100 mm	lb/in²	kPa	lb/in²	kPa
4941	4919F	Black	0.025	17	(300)	90	(620)	80	(550)
	4926	Gray	0.015	14	(245)	95	(655)	90	(620)
	4936 (F)	Gray	0.025	17	(300)	90	(620)	80	(550)
	4941 (F)	Gray	0.045	22	(385)	85	(585)	70	(480)
	4947F	Black	0.045	22	(385)	85	(585)	70	(480)
	4956 (F)	Gray	0.062	22	(385)	80	(550)	70	(480)
	4979F	Black	0.062	22	(385)	80	(550)	70	(480)
	4991	Gray	0.090	22	(385)	70	(480)	65	(450)
5952	5915 (P)	Black	0.016	14	(245)	90	(620)	90	(620)
	5925 (P)	Black	0.025	17	(300)	90	(620)	90	(620)
	5930 (P)	Black	0.032	19	(330)	90	(620)	85	(585)
	5952 (P)	Black	0.045	22	(385)	90	(620)	80	(550)
	5958FR	Black	0.040	20	(350)	100	(690)	100	(690)
	5962 (P)	Black	0.062	22	(385)	90	(620)	80	(550)
4950	4920	White	0.015	15	(260)	160	(1100)	100	(690)
	4929	Black	0.025	20	(350)	160	(1100)	100	(690)
	4930 (F)	White	0.025	20	(350)	160	(1100)	100	(690)
	4949	Black	0.045	25	(440)	140	(970)	80	(550)
	4950	White	0.045	25	(440)	140	(970)	80	(550)
	4955	White	0.080	20	(350)	95	(655)	70	(480)
	4959 (F)	White	0.120	20	(350)	75	(520)	55	(380)
4945	4945	White	0.045	25	(440)	140	(970)	80	(550)
	4946	White	0.045	25	(440)	140	(970)	80	(550)
4910	4905	Clear	0.020	12	(210)	100	(690)	70	(480)
	4910	Clear	0.040	15	(260)	100	(690)	70	(480)
4951	4951	White	0.045	18	(315)	110	(760)	80	(550)
	4943F	Gray	0.045	20	(350)	85	(585)	70	(480)
	4957F	Gray	0.062	20	(350)	75	(515)	70	(480)
4952	4932	White	0.025	20	(350)	100	(690)	100	(690)
	4952	White	0.045	25	(440)	80	(550)	80	(550)
4611	4611	Dk Gray	0.045	18	(315)	90	(590)	65	(445)
	4646	Dk Gray	0.025	15	(250)	100	(690)	80	(550)
	4655	Dk Gray	0.062	18	(315)	80	(550)	60	(415)
4622	4618	White	0.025	17	(300)	85	(580)	80	(550)
	4622	White	0.045	20	(350)	70	(480)	65	(445)
	4624	White	0.062	20	(350)	55	(380)	60	(410)

90° Peel Adhesion - Based on ASTM D3330 -To stainless steel, room temperature, jaw speed 12 in/min (305 mm/min). Average force to remove is measured. 72 hour dwell.

Normal Tensile (T-Block Tensile) - ASTM D-897 - To aluminum, room temperature, 1 in² (6.45 cm²), jaw speed 2 in/min (50 mm/min.) Peak force to separate is measured. 72 hour dwell.

Dynamic Overlap Shear - ASTM D-1002 - To stainless steel, room temperature, 1 in² (6.45 cm²), jaw speed 0.5 in/min (12.7 mm/min.) Peak force to separate is measured. 72 hour dwell.

Typical Performance Characteristics

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

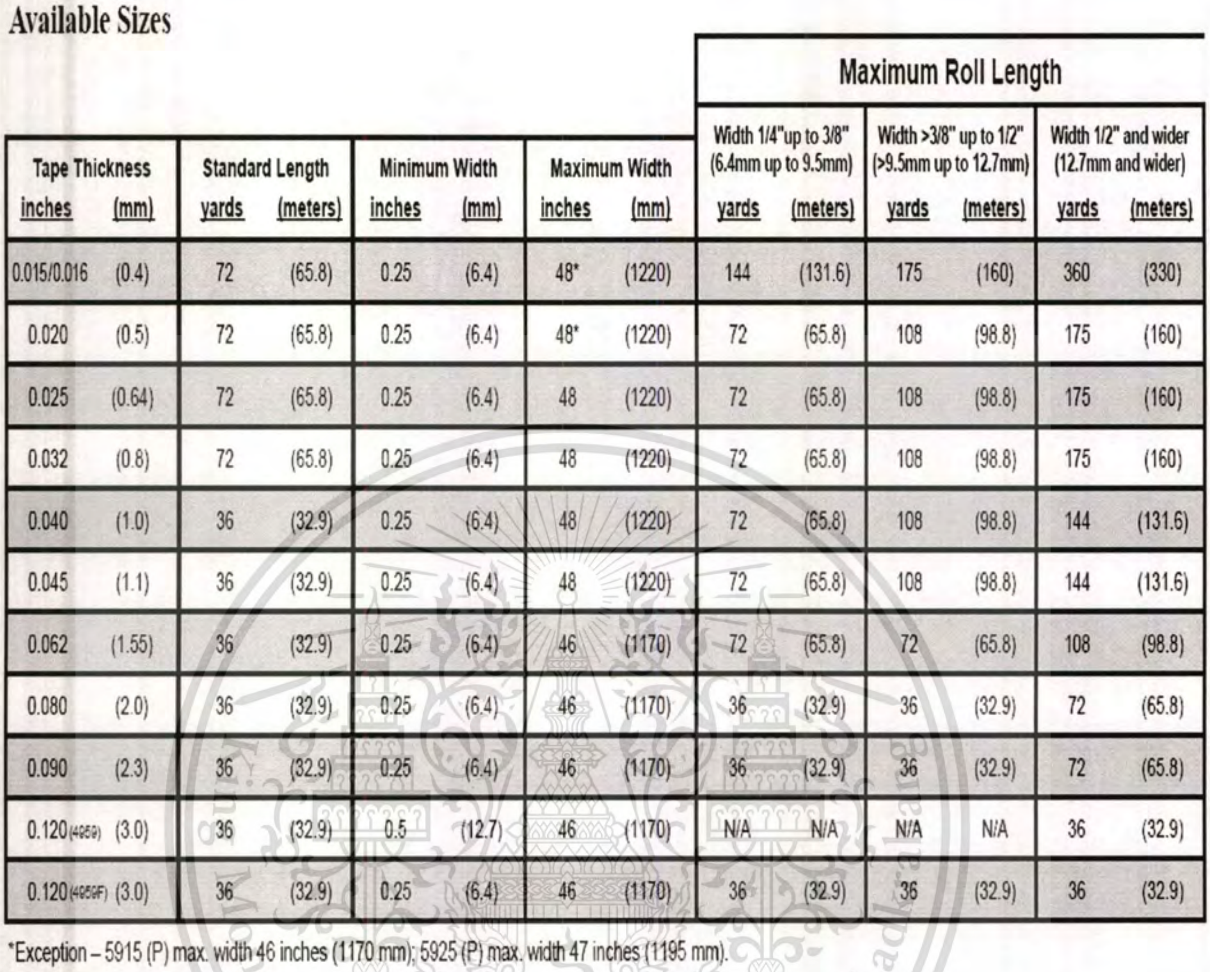
	3M™ VHB™ Tapes			Static Shear: Weight (grams) that 1/2 square inch will hold 10,000 minutes (7 days)					Temperature Tolerance: Short Term (Minutes, Hours)		Temperature Tolerance: Long Term (Days, Weeks)	
Family	Product Number	Color	Thickness Inches	72°F (22°C)	150°F (66°C)	200°F (93°C)	250°F (121°C)	350°F (177°C)	°F	°C	°F	°C
4941	4919F	Black	0.025	1000	500	500			300	(149)	200	(93)
	4926	Gray	0.015	1000	500	500			300	(149)	200	(93)
	4936 (F)	Gray	0.025	1000	500	500			300	(149)	200	(93)
	4941 (F)	Gray	0.045	1000	500	500			300	(149)	200	(93)
	4947F	Black	0.045	1000	500	500			300	(149)	200	(93)
	4956 (F)	Gray	0.062	1000	500	500			300	(149)	200	(93)
	4979F	Black	0.062	1000	500	500			300	(149)	200	(93)
	4991	Gray	0.090	1000	500	500			250	(121)	200	(93)
5952	5915 (P)	Black	0.016	1000	500	500	250		300	(149)	250	(121)
	5925 (P)	Black	0.025	1000	500	500	250		300	(149)	250	(121)
	5930 (P)	Black	0.032	1000	500	500	250		300	(149)	250	(121)
	5952 (P)	Black	0.045	1000	500	500	250		300	(149)	250	(121)
	5958FR	Black	0.040	1000	350	250			300	(149)	200	(93)
	5962 (P)	Black	0.062	1000	500	500	250		300	(149)	250	(121)
4950	4920	White	0.015	1500	500	500			300	(149)	200	(93)
	4929	Black	0.025	1500	500	500			300	(149)	200	(93)
	4930 (F)	White	0.025	1500	500	500			300	(149)	200	(93)
	4949	Black	0.045	1500	500	500			300	(149)	200	(93)
	4950	White	0.045	1500	1000	500			300	(149)	200	(93)
	4955	White	0.080	1500	1000	750	750	750	400	(204)	300	(149)
	4959 (F)	White	0.120	1500	1000	750	750	750	400	(204)	300	(149)
4945	4945	White	0.045	1500	500	500			300	(149)	200	(93)
	4946	White	0.045	1500	500	500			300	(149)	200	(93)
4910	4905	Clear	0.020	1000	500	500			300	(149)	200	(93)
	4910	Clear	0.040	1000	500	500			300	(149)	200	(93)
4951	4951	White	0.045	1250	500	500			300	(149)	200	(93)
	4943F	Gray	0.045	1000	500	500			300	(149)	200	(93)
	4957F	Gray	0.062	1000	500	500			300	(149)	200	(93)
4952	4932	White	0.025	1500	500				200	(93)	160	(71)
	4952	White	0.045	1500	500				200	(93)	160	(71)
4611	4611	Dk Gray	0.045	1500	750	750	750	750	450	(232)	300	(149)
	4646	Dk Gray	0.025	1500	750	750	750	750	450	(232)	300	(149)
	4655	Dk Gray	0.062	1500	750	750	750	750	450	(232)	300	(149)
4622	4618	White	0.025	1000	250	250			250	(121)	200	(93)
	4622	White	0.045	1000	250	250			250	(121)	200	(93)
	4624	White	0.062	1000	250	250			250	(121)	200	(93)

Static Shear - ASTM D3654 - To stainless steel, tested at various temperatures and gram loadings. 0.5 in² (3.22 cm²). Will hold listed weight for 10,000 minutes (approximately 7 days). Conversion: 1500 g/0.5 in² equals 6.6 lb/in²; 500 g/0.5 in² = 2.2 lb/in².

Short Term Temperature Tolerance - No change in room temperature dynamic shear properties following 4 hours conditioning at indicated temperature with 100 g/static load. (Represents minutes, hours in a process type temperature exposure).

Long Term Temperature Tolerance - Maximum temperature where tape supports at least 250 g load per 0.5 in² in static shear for 10,000 minutes. (Represents continuous exposure for days or weeks).

Table C.4: 3M Available sizes



Available Sizes

Tape Thickness		Standard Length		Minimum Width		Maximum Width		Maximum Roll Length					
								Width 1/4"up to 3/8" (6.4mm up to 9.5mm)		Width >3/8" up to 1/2" (>9.5mm up to 12.7mm)		Width 1/2" and wider (12.7mm and wider)	
inches	(mm)	yards	(meters)	inches	(mm)	inches	(mm)	yards	(meters)	yards	(meters)	yards	(meters)
0.015/0.016	(0.4)	72	(65.8)	0.25	(6.4)	48*	(1220)	144	(131.6)	175	(160)	360	(330)
0.020	(0.5)	72	(65.8)	0.25	(6.4)	48*	(1220)	72	(65.8)	108	(98.8)	175	(160)
0.025	(0.64)	72	(65.8)	0.25	(6.4)	48	(1220)	72	(65.8)	108	(98.8)	175	(160)
0.032	(0.8)	72	(65.8)	0.25	(6.4)	48	(1220)	72	(65.8)	108	(98.8)	175	(160)
0.040	(1.0)	36	(32.9)	0.25	(6.4)	48	(1220)	72	(65.8)	108	(98.8)	144	(131.6)
0.045	(1.1)	36	(32.9)	0.25	(6.4)	48	(1220)	72	(65.8)	108	(98.8)	144	(131.6)
0.062	(1.55)	36	(32.9)	0.25	(6.4)	46	(1170)	72	(65.8)	72	(65.8)	108	(98.8)
0.080	(2.0)	36	(32.9)	0.25	(6.4)	46	(1170)	36	(32.9)	36	(32.9)	72	(65.8)
0.090	(2.3)	36	(32.9)	0.25	(6.4)	46	(1170)	36	(32.9)	36	(32.9)	72	(65.8)
0.120 (4959)	(3.0)	36	(32.9)	0.5	(12.7)	46	(1170)	N/A	N/A	N/A	N/A	36	(32.9)
0.120 (4959F)	(3.0)	36	(32.9)	0.25	(6.4)	46	(1170)	36	(32.9)	36	(32.9)	36	(32.9)

*Exception – 5915 (P) max. width 46 inches (1170 mm); 5925 (P) max. width 47 inches (1195 mm).

Table C.5: 3M Temperature rating

3M™ VHB™ Tapes
UL746C Listings - File MH 17478

Category QOQW2 Component - Polymeric Adhesive Systems, Electrical Equipment

3M™ VHB™ Tapes/ Product Families	Substrates	Temperature Rating Minimum	Temperature Rating Maximum
4919F, 4926, 4936, 4936F, 4941, 4941F, 4947F, 4956, 4956F, 4979F	Ceramic	-35°C	110°C
	Aluminum, Galvanized steel, stainless steel, enameled steel, nickel coated ABS, glass (with or without silane coating) PVC, glass/epoxy, PBT, polycarbonate, acrylic/polyurethane paint, polyester paint	-35°C	90°C
	ABS	-35°C	75°C
4920, 4930, 4950	Aluminum, galvanized steel, enameled steel, stainless steel, ceramic, glass/epoxy	-35°C	110°C
	PBT, Acrylic	-35°C	90°C
	ABS, Polycarbonate, Rigid PVC	-35°C	75°C
4945, 4946	Phenolic, aluminum, galvanized steel, alkyd enamel	-35°C	110°C
	ABS, polycarbonate, polyimide, stainless steel, acrylic/polyurethane paint, polyester paint	-35°C	90°C
	unplasticized PVC	-35°C	75°C
5915, 5915P, 5925, 5925P, 5930, 5930P, 5952, 5952P 5962, 5962P	Polycarbonate, Primer 94 coated polycarbonate, aluminum, acrylic/ polyurethane paint, galvanized steel, steel, polyester paint, epoxy/polyester paint, epoxy paint, glass (with or without silane coating), stainless steel, enameled steel, glass epoxy, polybutylene terephthalate, Nylon®, Noryl® (PPE) polyphenenlene ether	-35°C	90°C
	Rigid PVC, ABS	-35°C	75°C
5915, 5925, 5930, 5952	Acrylic	-35°C	90°C
5962	Acrylic	-35°C	80°C
5952	Cellulose Acetate Butyrate	-35°C	90°C
4991	Polycarbonate, aluminum, acrylic/ polyurethane paint, polyester paint	-35°C	90°C
4611, 4646, 4655	Stainless steel, aluminum, galvanized steel, glass, glass/epoxy, phenolic	-35°C	110°C
	Nylon, polycarbonate	-35°C	90°C
	ABS, rigid PVC	-35°C	75°C
4905, 4910	Polycarbonate, aluminum, acrylic/polyurethane paint	-35°C	90°C

A current list can be found at www.ul.com (select certifications, search file MH17478)

Appendix C-2: Thermocouple type K

Appendix C-2: Thermocouple

Table C.6: Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.458	-6.457	-6.456	-6.455	-6.453	-6.452	-6.450	-6.448	-6.446	-6.444	-6.441	-260
-250	-6.441	-6.438	-6.435	-6.432	-6.429	-6.425	-6.421	-6.417	-6.413	-6.408	-6.404	-250
-240	-6.404	-6.399	-6.393	-6.388	-6.382	-6.377	-6.370	-6.364	-6.358	-6.351	-6.344	-240
-230	-6.344	-6.337	-6.329	-6.322	-6.314	-6.306	-6.297	-6.289	-6.280	-6.271	-6.262	-230
-220	-6.262	-6.252	-6.243	-6.233	-6.223	-6.213	-6.202	-6.192	-6.181	-6.170	-6.158	-220
-210	-6.158	-6.147	-6.135	-6.123	-6.111	-6.099	-6.087	-6.074	-6.061	-6.048	-6.035	-210
-200	-6.035	-6.021	-6.007	-5.994	-5.980	-5.965	-5.951	-5.936	-5.922	-5.907	-5.891	-200
-190	-5.891	-5.876	-5.861	-5.845	-5.829	-5.813	-5.797	-5.780	-5.763	-5.747	-5.730	-190
-180	-5.730	-5.713	-5.695	-5.678	-5.660	-5.642	-5.624	-5.606	-5.588	-5.569	-5.550	-180
-170	-5.550	-5.531	-5.512	-5.493	-5.474	-5.454	-5.435	-5.415	-5.395	-5.374	-5.354	-170
-160	-5.354	-5.333	-5.313	-5.292	-5.271	-5.250	-5.228	-5.207	-5.185	-5.163	-5.141	-160
-150	-5.141	-5.119	-5.097	-5.074	-5.052	-5.029	-5.006	-4.983	-4.960	-4.936	-4.913	-150
-140	-4.913	-4.889	-4.865	-4.841	-4.817	-4.793	-4.768	-4.744	-4.719	-4.694	-4.669	-140
-130	-4.669	-4.644	-4.618	-4.593	-4.567	-4.542	-4.516	-4.490	-4.463	-4.437	-4.411	-130
-120	-4.411	-4.384	-4.357	-4.330	-4.303	-4.276	-4.249	-4.221	-4.194	-4.166	-4.138	-120
-110	-4.138	-4.110	-4.082	-4.054	-4.025	-3.997	-3.968	-3.939	-3.911	-3.882	-3.852	-110
-100	-3.852	-3.823	-3.794	-3.764	-3.734	-3.705	-3.675	-3.645	-3.614	-3.584	-3.554	-100
-90	-3.554	-3.523	-3.492	-3.462	-3.431	-3.400	-3.368	-3.337	-3.306	-3.274	-3.243	-90
-80	-3.243	-3.211	-3.179	-3.147	-3.115	-3.083	-3.050	-3.018	-2.986	-2.953	-2.920	-80
-70	-2.920	-2.887	-2.854	-2.821	-2.788	-2.755	-2.721	-2.688	-2.654	-2.620	-2.587	-70
-60	-2.587	-2.553	-2.519	-2.485	-2.450	-2.416	-2.382	-2.347	-2.312	-2.278	-2.243	-60
-50	-2.243	-2.208	-2.173	-2.138	-2.103	-2.067	-2.032	-1.996	-1.961	-1.925	-1.889	-50
-40	-1.889	-1.854	-1.818	-1.782	-1.745	-1.709	-1.673	-1.637	-1.600	-1.564	-1.527	-40
-30	-1.527	-1.490	-1.453	-1.417	-1.380	-1.343	-1.305	-1.268	-1.231	-1.194	-1.156	-30
-20	-1.156	-1.119	-1.081	-1.043	-1.006	-0.968	-0.930	-0.892	-0.854	-0.816	-0.778	-20
-10	-0.778	-0.739	-0.701	-0.663	-0.624	-0.586	-0.547	-0.508	-0.470	-0.431	-0.392	-10
0	-0.392	-0.353	-0.314	-0.275	-0.236	-0.197	-0.157	-0.118	-0.079	-0.039	0.000	0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023	40
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096	90
°C	0	1	2	3	4	5	6	7	8	9	10	°C

°C	0	1	2	3	4	5	6	7	8	9	10	°C
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138	140
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540	150
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941	160
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340	170
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739	180
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138	190
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	8.539	200
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	8.940	210
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	9.343	220
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	9.747	230
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	10.153	240
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820	400
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243	410
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667	420
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091	430
440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516	440
450	18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898	18.941	450
460	18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324	19.366	460
470	19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750	19.792	470
480	19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175	20.218	480
490	20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602	20.644	490

Appendix C-3: Temperature controller

Table C.7: Model FOX-2C1

Figure C.1: Temperature controller

DESCRIPTION	FOX-2C1
External Size(mm)	77(W) × 35(H) × 77(D)
Operating Range	0~1200℃
Input Sensor	CA(K)
Display Accuracy	±1% rdg ± 1 digit
Output	1relay(1C) 250VAC 3A
Control Method	ON/OFF
Cutting Size(mm)	71(W) × 29(H)
Power Supply	100~240VAC 50/60Hz
Programming	Set/Up/Down Key
Ambient Temp/Humi	0~55℃(32~131℉), 35~80%RH
1PCS Weight(Include Box)	140g

Functions	lock function of programs
	Setting function for the highest & lowest limit of temperature range
	correction of the present temperature &humidity / output delay time

Appendix C-4: Centrifuge tube

Table C.8: KIMAX Petrochemical Centrifuge Tube

Item No.	Capacity (mL)	Subdivision (mL)	Tolerance (mL)	O.D. x Length (mm)	Case Qty.	Case Price
45241-100	100	0-1 in 0.05	0 to 0.1 - ±0.02	37 x 203	12	$600.24
		1-3 in 0.1	Above 0.1 to 0.30 - 0.03			
		3-6 in 0.2	Above 0.3 to 1 - 0.05			
		6-10 in 0.5	Above 1 to 3 - 0.10			
		10-100 in 1	Above 3 to 5 - 0.20			
			Above 5 to 10 - 0.50			
			Above 10 - 1.00			

Appendix C-5: Toshiba hot pot

Figure C.2: Toshiba Hot Pot PLK-G26.

Description:

- Plate is on the bottom of pot give over heat.
- Warm heater system can keep the water hot all the time.
- Create from a material that can stay heated up to 120 degrees.
- The internal rubber sheets can keep the heatedness well and internal pressure will help the water flow to be smooth.
- The internal material is made of stainless steel.
- The rotary Base system and electric kettle can rotate 360 degrees around themselves.
- The security system is safe by Thermo Fuse Magnet Plug of Detachable Cordsystem.

It is automatic power off when short-circuited.

- Size: 2.6 liters.
- Color available are 6 colors which are Methacrylate Acrylic Pink (P), meta acrylic green (GR), metaacrylic blue (B), Graphic leaf pattern (G), leaf pattern (L) and flower (F).

Appendix C-6: UHU glue

Figure C.3: UHU por

Product detail

UHU por is a quick-setting special adhesive for bonding expanded polysterene, e.g. Styropor® also in combination with other materials. It forms an elastic adhesive film which is highly resistant to age, colorless and waterproof.

Table C.9: Container

Container	Content
Tube	40g
Tube/Blister	40g
Can	570g

Materials

Glue expanded Styrofoam® also in combination with other materials, e.g. wood, paper, metal, ceramic, plaster, fabric and various plastics. Also for photos.

Use and Handling Instructions

Apply adhesive to both parts and let dry. Once dry to the touch (after approx. 10 minutes) press together very firmly for a short time being careful not to damage the rigid foam film.

Appendix C-7: Rhinoceros 3D Program

Rhinoceros (Rhino) is a stand-alone, commercial NURBS-based 3-D modeling tool, developed by Robert McNeel & Associates. The software is commonly used for industrial design, architecture, marine design, jewelry design, automotive design, CAD / CAM, rapid prototyping, reverse engineering as well as the multimedia and graphic design industries. A model created in Rhino, illustrating free-form NURBS surfaces (Rendered in Flamingo).Rhino specializes in free-form non-uniform rational B-spline (NURBS) modeling. Plug-ins developed by McNeel include Flamingo (raytracerendering), Penguin (non-photorealistic rendering), Bongo, and Brazil (advanced rendering). Over 100 third-party plugins are also available. There are also rendering plug-ins for Maxwell Render, V-ray and many other engines. Additional plugins for CAM and CNC milling are available as well, allowing for toolpath generation directly in Rhino.Like many modeling applications, Rhino also features a scripting language, based on the Visual Basic language, and an SDK that allows reading and writing Rhino files directly. Rhinoceros 3d gained its popularity in architectural design in part because of the Grasshopper plug-in for computational design. Many new avant-garde architects are using parametric modeling tools, like Grasshopper.

Rhino's increasing popularity is based on its diversity, multi-disciplinary functions, low learning-curve, relatively low cost, and its ability to import and export over 30 file formats, which allows Rhino to act as a 'converter' tool between programs in a design workflow.

Development: Rhino was originally distributed as a free, closed-source, open beta. A broad community of users; whose input; debugged and added features to the program developed as a result. The development is on-going; version 4.0 Service Release 8 is the most recent with version 5.0 expected in 2011. Development of a Mac OS X version in progress http://www.irhino3d.com; .Beta version on request. Rhino owners can download the latest beta versions and participate in the development process. Free trial versions are available for download.

File format: The Rhino file format (.3DM) is useful for the exchange of NURBS geometry. The Rhino developers started the openNURBS Initiative to provide computer graphics software developers the tools to accurately transfer 3-D geometry between applications. An open-source toolkit, open NURBS includes the 3DM file format specification, documentation, C++ source code libraries and .NET 2.0 assemblies to read and write the file format, on supported platforms (Windows, Windows x64, Mac, and Linux). The McNeel Wiki has more current information.

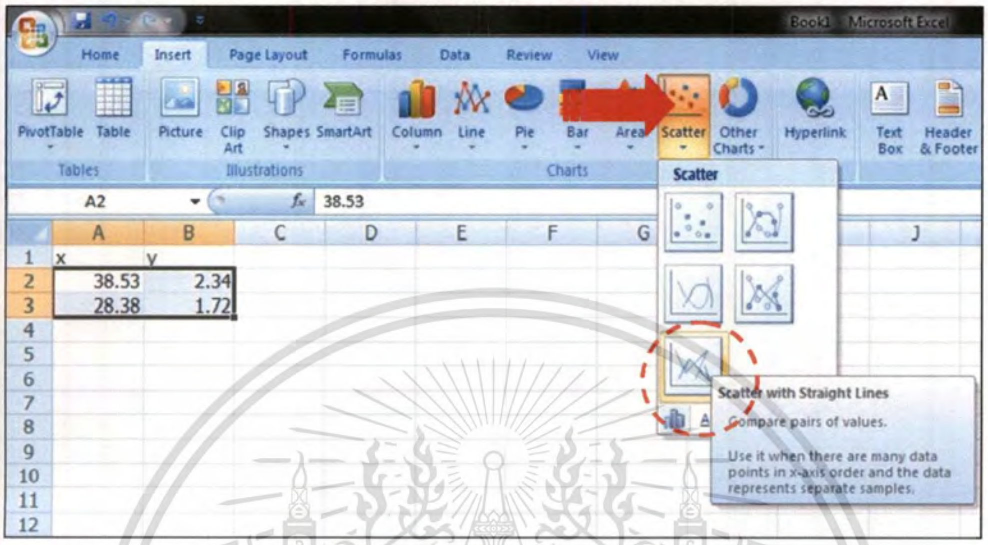
Appendix C-8: Analysis quality of biodiesel fee

Table C.10: Compare price of analysis quality of biodiesel

Company	List of items (amount)	Price (Baht)
PTT Public Company Limited	23	38000
Department of Science Service	21	14500
B.T. Biotec (Thailand) Co.,Ltd.	24	20000

Appendix C-9: Calibration curve

1. Open Microsoft excel
2. Add information in table
3. Choose insert and select the graph that appropriate with selected data



A2 f_x 38.53

	A	B
1	x	y
2	38.53	2.34
3	28.38	1.72

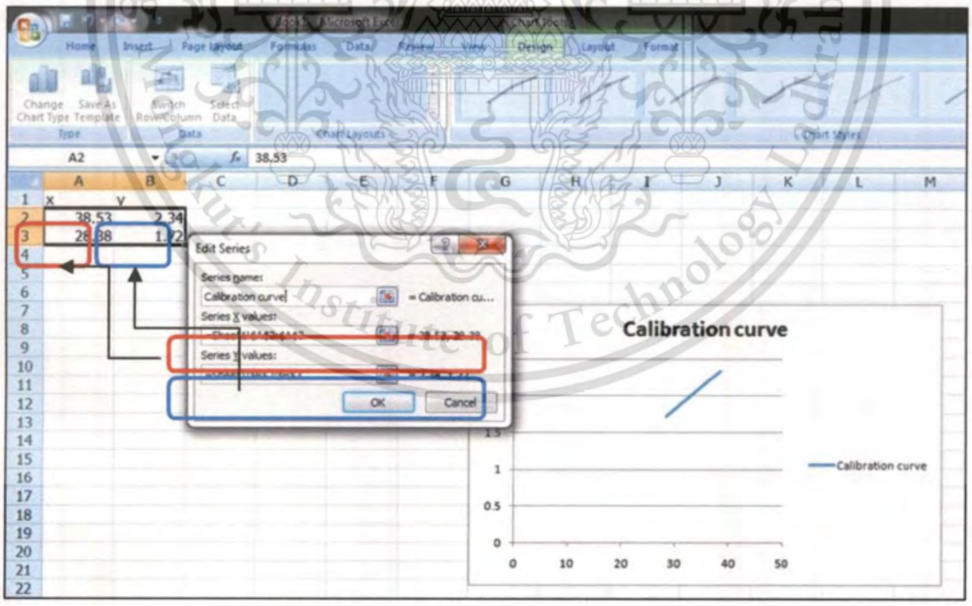
Scatter with Straight Lines

Compare pairs of values.

Use it when there are many data points in x-axis order and the data represents separate samples.

Figure C.4: Select the graph

4. Select data for x-axis and y-axis.



A2 f_x 38.53

	A	B
1	x	y
2	38.53	2.34
3	28.38	1.72

Series name:

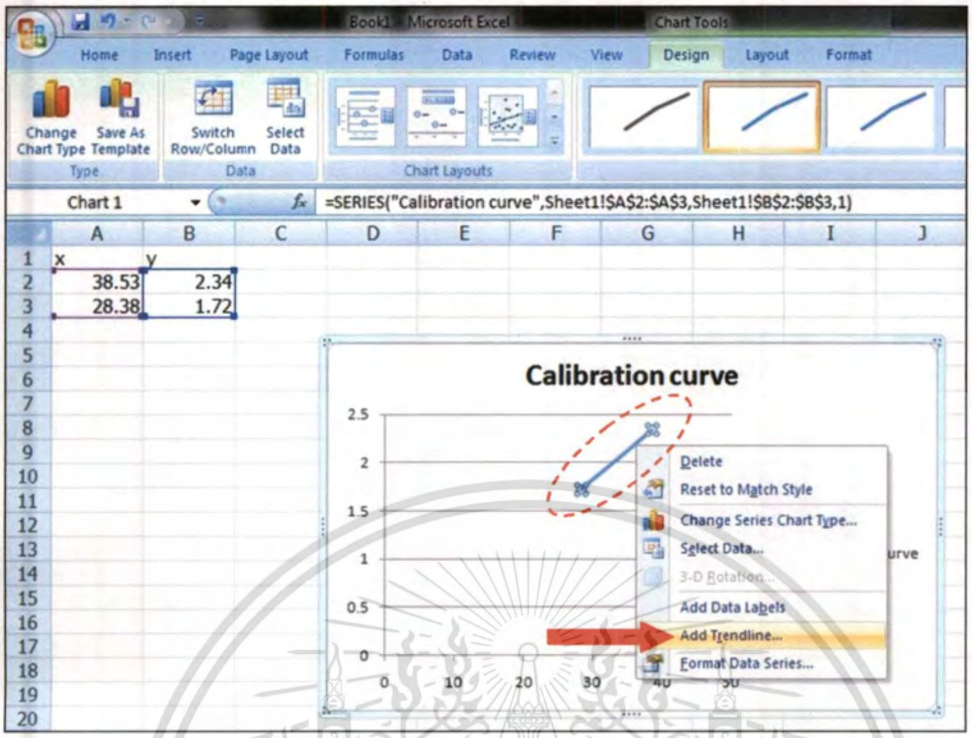
Calibration curve = Calibration cu...

Series X values:

Series Y values:

Figure C.5: Select data for x-axis and y-axis

5. Select a line in graph and right click then choose "Add Trendline".

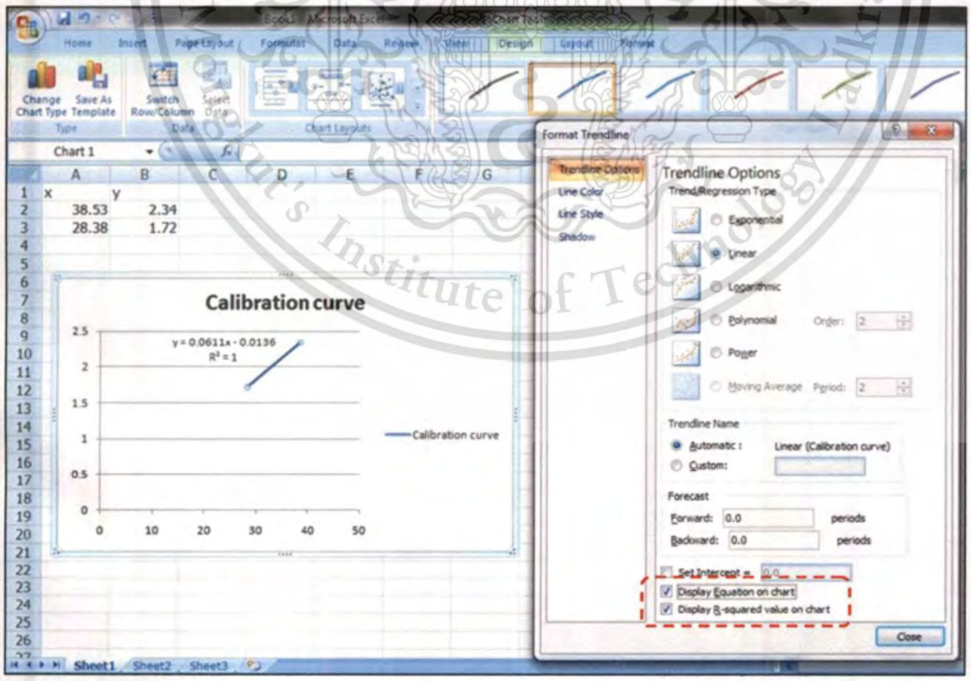


=SERIES("Calibration curve",Sheet1!$A$2:$A$3,Sheet1!$B$2:$B$3,1)

	A	B
1	x	y
2	38.53	2.34
3	28.38	1.72

Figure C.6: Trendline

6. Choose Display Equation on chart and Display R square value on chart for show the linear equation and R square value on chart.



	A	B
1	x	y
2	38.53	2.34
3	28.38	1.72

Trendline Options

Trend/Regression Type

○ Exponential
● Linear
○ Logarithmic
○ Polynomial Order: 2
○ Power
○ Moving Average Period: 2

Trendline Name

● Automatic : Linear (Calibration curve)
○ Custom:

Forecast

Forward: 0.0 periods
Backward: 0.0 periods

☐ Set Intercept = 0.0
☑ Display Equation on chart
☑ Display R-squared value on chart

Figure C.7: Linear equation