FEASIBILITY STUDY FOR BIODIESEL PRODUCTION FROM CRUDE PALM OIL

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ABSTRACT

Biodiesel is well known as fatty acid alkyl methyl esters. It is a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils, animal fats, or mixtures of vegetable oils and animal fats. It is produced by transesterification, with glycerol being produced as a by-product. Biodiesel is an environmentally friendly fuel which can be used in diesel engine without modification. Malaysia is a leading palm oil producers. Therefore, this study analyses the economic feasibility of producing palm oil based biodiesel in Malaysia in order to replace the diesel fuel consumption. The demand and cost production of palm oil biodiesel is estimated. It is found that the present price for biodiesel is RM 3.54 according to the optimum yield found in this study (88%) and this cost still consider high cost. But, in the future it might be considered reasonable price according to the market prices of fossil fuel and crude palm oil price. In current situation, Malaysia is sustaining all the challenges and issues. In future, palm biodiesel might be replaced with other feedstock diesel or biomass energy while palm diesel may face feedstock availability issue.

ABSTRAK

Biodiesel dikenali sebagai fatty acid alkyl methyl esters. Ia merupakan bahan api yang mengandungi rangkaian asid lemak mono-alkyl esters yang panjang terbitan daripada minyak sayuran, lemak haiwan atau campuran daripada minyak sayuran dan lemak haiwan. Ia dihasilkan melalui proses transesterification, dengan glycerol sebagai hasil sampingan. Biodiesel merupakan bahan api yang mesra alam iaitu boleh digunakan dalam enjin diesel tanpa pengubahsuaian. Malaysia merupakan salah satu negara utama yang mengeluarkan hasil kelapa sawit. Oleh hal yang demikian, kajian ini menganalisis kebolehlaksanaan ekonomi bagi penghasilan biodiesel daripada kelapa sawit di Malaysia bagi menggantikan penggunaan bahan api diesel. Keperluan dan kos penghasilan biodiesel kelapa sawit telah dianggarkan. Ini menunjukkan bahawa harga bagi biodiesel pada masa sekarang ialah RM 3.54 berdasarkan kadar penghasilan yang optimum dihasilkan dalam kajian ini iaitu 88%. Harga ini boleh dikatakan harga yang tinggi. Tetapi, pada masa akan datang, harga ini mungkin harga berpatutan berdasarkan harga pasaran bagi bahan bakar fossil berbanding harga minyak mentah kelapa sawit. Dalam situasi sekarang, Malaysia dapat menangani semua cabaran dan isu yang timbul. Pada masa akan datang, biodiesel kelapa sawit sepatutnya digantikan dengan lain-lain bahan mentah biodiesel atau tenaga biomass ketika biodiesel kelapa sawit menghadapi masalah ketidakcukupan bahan mentah.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CPO	Crude Palm Oil
EU	European Union
FFA	Free Fatty Acid
MPIC	Ministry of Plantation Industry of Plantation Industries and Commodities
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
NBP	National Biofuel Policy
PKO	Palm Kernel Oil
PME	Palm Methyl Ester
POME	Palm Oil Methyl Ester
PPO	Processed Palm Oil
RBD	Refined Bleached Deodorised
TC	Total Production Cost
TFC	Total Fixed Cost
TVC	Total Variable Cost
UNFCC	United Natons Framework Convention on Climate Change
US	United State
USDA	United State Department of Agriculture

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Based on world energy scenario, some 85 to 90 % of world primary energy consumption will continue till 2030 on fossil fuels. However, usage renewable energy, natural gas, and nuclear energy will be increased after 2015 because of stringent emissions regulations and limited fossil fuel reserves. Demand of total renewable energy will increase from 2% (2002) to 6% (2030), and fuel from biomass will be one of the major resources, followed by solar and hydropower generation (Kalam and Masjuki, 2005). Fuel from biomass conversion which is biodiesel, become a new alternative, renewable fuel to be used for heating, transportation and electricity generation.

Increasingly, renewable energy like biodiesel is getting more attention world wide as it is environmentally friendly, and can be used as diesel engine fuel without requiring any complex modification to the engine itself. Biodiesel also has advantage of plenty of raw stock which confirms continuous raw material supply. Biodiesel does not contain any sulphur or aromatic compounds and it gives lower emission of carbon monoxide, hydrocarbons and particulates in combustion results (Karmakar et al., 2010).

Lately, world has been paying interest to biofuel, mainly for biodiesel. European countries are playing significant role in importing and exporting of biodiesel. Biodiesel is also known as a non-petroleum diesel. It is produced biologically from vegetable oil and animal fats by transesterification process. Varieties of feedstock have been recognized as potential biodiesel raw stocks like rapeseed and soybeans in US, and palm oil and jatropha in Asian countries. In recent years, biodiesel from palm oil and jatropha has been recognized as renewable energy source with high potential in the future (Mekhilef et al., 2011).

Malaysia is a top palm oil producer. Therefore Malaysia have paying attention to palm oil as raw stock used for biodiesel production. Palm oil turns out as most potential biodiesel feedstock. Palm oil have a high yield factor, need low fertilizer, water and pesticide consumption. Palm oil methyl ester (POME) have low engine emissions, high oxidation stability apart from NO_x emission which is higher (Mekhilef et al., 2011).

In order to produce biodiesel using palm oil, the price of crude palm oil must be measured. To reduce the cost production of biodiesel in industry, the method and material use should be economical. The appropriate way to produce biodiesel is by transesterification, which is catalyzed chemical reaction involving vegetable oils (palm oils) and alcohol to produce fatty acid alkyl methyl esters (biodiesel) and glycerol. The alcohols that can be used in the transesterification reaction are methanol, ethanol, propanol, butanol, and amyl alcohol. Methanol and ethanol are used most commonly. Ethanol is the preferred alcohol in the transesterification process compared to methanol because it is derived from agricultural products and is renewable and biologically less offensive in the environment; however, methanol is used because of its low price and its physical and chemical advantages (Dong et al., 2009).

1.2 Problem Statement

Biodiesel from crude palm oil (CPO) is reported by Malaysian Palm Oil Board in year 2008 but no feasibility study has been done recently. Therefore, it is important to know what is the yield and how much it cost to decide on production of biodiesel from crude palm oil.

1.3 Objective of Study

To investigate the feasibility of biodiesel production from crude palm oil.

1.4 Scope of Study

The scope of this study is to produce pure biodiesel with high yield that match international criteria and to analyze how it worth to produce this biodiesel in Malaysia.

1.5 Rationale and Significance of Study

It is believed that Malaysia is one of the top producers of palm oil biodiesel with extensive of raw palm. Therefore, Malaysia can be one of top countries in the production of biodiesel using palm oil according to the feasibility study provided.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Diesel engines are the major mover of alternative for applications where fuel economy, durability, and reliability are important. They are used almost totally in the agricultural construction, logging, trucking and railroad industries (Gerpen, 2010; Lapuerta et al., 2008).

Diesel fuel is usually produced from higher-boiling point fractions of crude petroleum than that used for gasoline, and it incorporate the long, straight-chain alkanes that provide good ignition characteristics in the engines. When it was initially introduced, an important benefit of the diesel engine, it could use the portion of crude petroleum that was not needed for gasoline and included by product streams of gasoline refining. As a result, diesel engines can operate with economical costs. However, nowadays, diesel fuel is normally more expensive than gasoline and must meet likewise stringent quality requirements (Lapuerta et al., 2008).

As the cost of petroleum increases and easily-extracted petroleum becomes more difficult to discover, there is a need for alternatives so that the key industries in the world economy have the fuel needed to carry on with their operations. Vegetable oils provide a fuel source that utilizes well-known technologies, and that integrates simply into the existing diesel fuel infrastructure. Moreover, they provide the additional advantage of decreased net carbon dioxide emissions, since the plants that give the oil can recycle atmospheric carbon dioxide (Shahbaz et al., 2011).

The use of the esters from vegetable oils or animal fats under the name of "biodiesel" appears to be the most capable alternative for petroleum-based diesel fuels. In general, the major advantages of using biodiesel are such as: (1) lower dependence on crude oil, (2) renewable fuel, (3) favorable energy balance, (4) reduction in greenhouse gas emission, (5) lower harmful emission, (6) biodegradable and non-toxic, (7) the use of agricultural surplus and (8) safer handling with higher flash point than conventional diesel fuel (Meher et al., 2006a).

Table 2.1 lists the specification requirements for ASTM D 6751, as set by the American Society for Testing and Materials (ASTM, 2008). Many properties of D 6751 are identifying the levels of contaminants in the biodiesel. For example, limits are given for sulfur, phosphorus, calcium, magnesium, sodium and potassium, even though these elements are not found in the methyl ester molecules. These elements will give higher emissions or interfere with the operation of the engine's emissions control equipment by plugging the particulate trap or the exhaust catalyst. Furthermore, the methanol content of the biodiesel is controlled by limiting the flash point. The flash point, which usually is very high for biodiesel, can be lowered to unsafe levels if residual amounts of methanol are present. These contaminants are removed by moreover washing the fuel with water, or with water-less processes (Gerpen, 2010).

Table 2.1: ASTM D 6751 Specification Requirements.

Property	Test Method	Limits	Units
Flash point (closed cup)	D93	93 min	^oC
Alcohol control: One of the following must be met:			
a) Methanol content	EN 14110	0.2 max	% Volume
b) Flash point	D 93	130 min	^oC
Water and Sediment	D 2709	0.050 max	% Volume
Kinematic viscosity at 40 ^oC	D 445	1.9 – 6.0	mm^2s^{-1}
Sulfated ash	D 874	0.020 max	% Mass
Copper strip corrosion	D 130	No. 3 max	
Cetane number	D 613	47 min	
Cloud point	D 2500	Report	^oC
Carbon residue	D 4539	0.050 max	% Mass
Acid number	D 664	0.50 max	mg KOH g^{-1}
Free glycerin	D 6584	0.020	% Mass
Total glycerin	D 6584	0.240	% Mass
Phosphorus content	D 4951	0.001 max	% Mass
Distillation temperature, atmospheric equivalent temperature, 90% recovered.	D 1160	360 max	^oC
Sodium and potassium, combined	EN 14538	5 max	ppm (µg g^{-1})
Calcium and magnesium, combined	EN 14538	5 max	ppm (µg g^{-1})
Oxidation stability	EN 14112	3 min	hours
Sulfur	D 5453	15 ppm for S15 grade; 500 ppm for S500 grade	ppm (µg g^{-1})
Cold soak filterability	Annex 4.1	360 max	seconds

Source: ASTM, 2008

2.2 Production of Biodiesel

2.2.1 Raw Material

Biodiesel can be formed from any material that contains fatty acids, either bonded to other molecules or present as free molecules. Thus, a variety of vegetable fats and oils, animal fats, waste greases, and edible oil processing wastes can be used as feedstocks for biodiesel production. The selection of feedstock is based on such variables as local availability, cost, government support, and performance as a fuel. Different countries are finding different types of fats and oils as feedstocks for biodiesel. For example, soybean oil in the United States, rapeseed and sunflower oils in Europe, palm oil in Southeast Asia (mainly Malaysia and Indonesia), and coconut oil in Philippines are being identified (Ghadge and Raheman, 2005; Meher et al., 2006a, b; and Sarin et al., 2007). Figure 2.1 shows the production oil yield for various source of biodiesel feedstock (Karmakar et al., 2010). Palm oil give high productivity which produce about 6000 litres/ha compared to other feedstock.

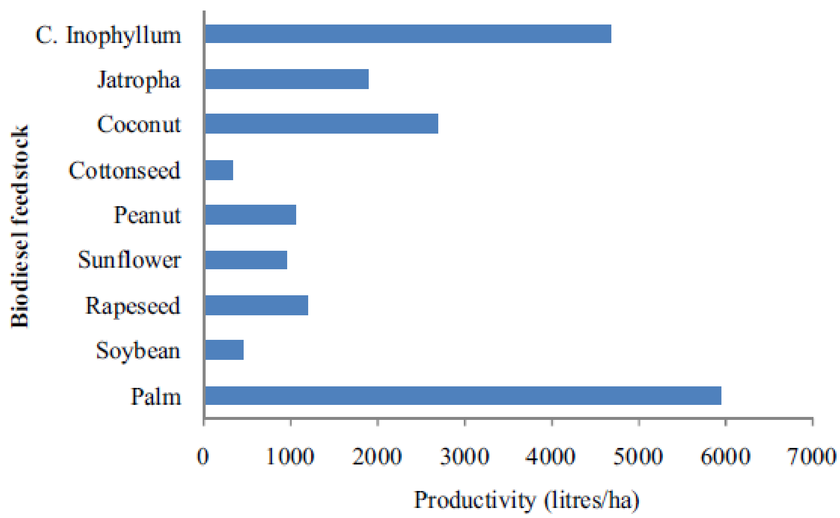

Figure 2.1: Production Oil Yield for Various Source of Biodiesel Feedstock

Source: Karmakar et al., 2010

Fats and oils are mostly water-insoluble, hydrophobic substances in the plant and animal kingdom. The major constituent of oils and fats is triglycerides, which compose about 90% - 98% of total mass (Srivastava and Prasad, 2000). In a triglyceride molecule, the weights of the glycerol is about 41 g while the weights of fatty acid radicals are in the range of 650-790 g. Thus, it is understood that fatty acid radicals contain most of the reactive groups in the triglyceride molecule, and they greatly affect the characteristics of oils and fats. As the result, the physical and chemical properties of biodiesel essentially depend on the fatty acid distribution of the triglyceride used in the production.

Palm oil is the most potential biodiesel feedstock compared to other oilseeds. Palm oil has higher production yield, low fertilizer, less water and pesticide required for the plantation. The palm oil tree is shown in Figure 2.2. Palm oil production takes fewer sunlight in term of energy balance to produce a unit of oil as it produces more oil per hectare. Figure 2.3 shows palm oil fruit and Figure 2.4 shows longitudinal section of palm oil fruit. Nevertheless, in term of the basis of palm oil yield per man in a day, it is not as competitive as other oilseeds because of the complexity of labor plantation management and harvesting of the fruit. Comparatively in Indonesia, it is less an issues because the general labor market readily available in Indonesia compared to Malaysia (Guo and Lua, 2003).

Figure 2.2: Palm Oil Tree

Figure 2.3: Palm Oil Fruit

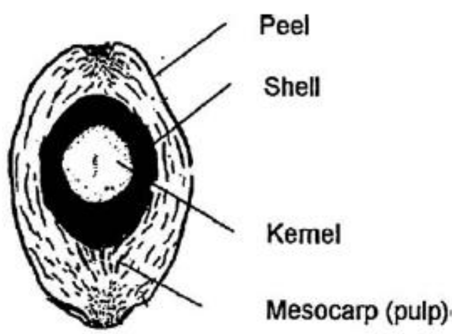

Figure 2.4: Longitudinal Section of Palm Oil Fruit

Source: Guo and Lua, 2003

Among the vegetable oils in the world market today, crude palm oil and refined palm oil are on top of the list. Palm oil is well-known for its nutrient fact that makes it suitable as vegetable oil used for daily cooking. Palm fruit is known as *Elaeis Guineensis.* The inside wall of the fruit called mesocarp which is fleshy and must be processed in order to obtain the palm oil. The step by step process of palm oil transformed into crude palm oil is shown in Figure 2.5 which is then processed into other products including biodiesel. Amount of CPO obtained from palm is reliant on palm tree variety and also the age of the tree. From a palm bunch, about 25-28% of CPO can be obtained (Biofuel Industries, 2011).

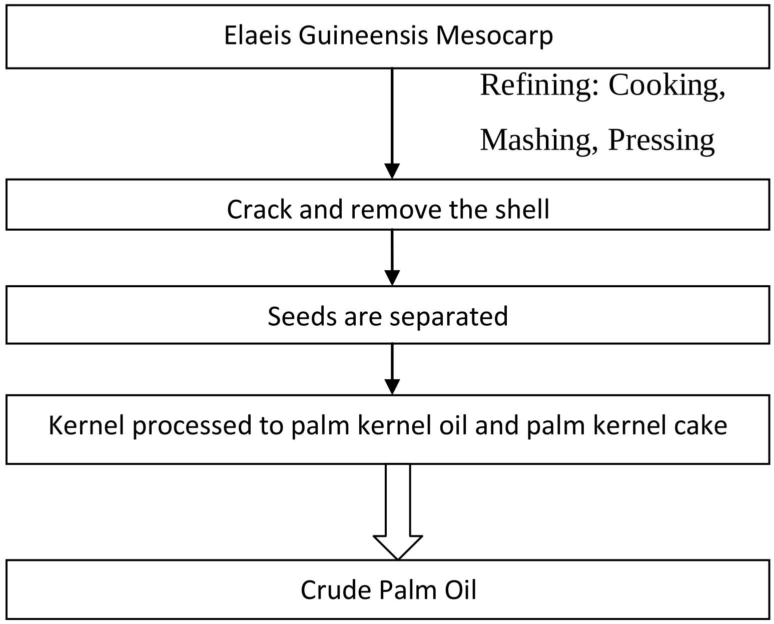

Figure 2.5: Palm Plant to Crude Palm Oil Process.

Source: Biofuel Industries, 2011

Worldwide demand for edible oil is increasing in this few decades which cause a tremendous raise in the area of oil crop agriculture especially soybean and palm oil. The world production of palm oil is 45 million tones and highest production is in South East Asia with a total 89% of total oil production (40% in Malaysia, 46% in Indonesia, 3% in Thailand) as shown in Figure 2.6 (USDA, 2010). In Malaysia, total 4.5 million hectares of land is occupied under oil palm cultivation. It produces 17.73 million tonnes of palm oil and contributed about RM 65.19 billion to the Malaysia export in 2008. Malaysia has about 362 palm oil mills, processing 71.3 million tonnes of fresh fruit bunch and producing an likely 19 million tonnes of crop residue yearly in the form of empty fruit bunch, fiber and shell. Palm oil is one of the most capable oil bearing crops in terms of land utilization, efficiency and productivity (Ong et al., 2011).

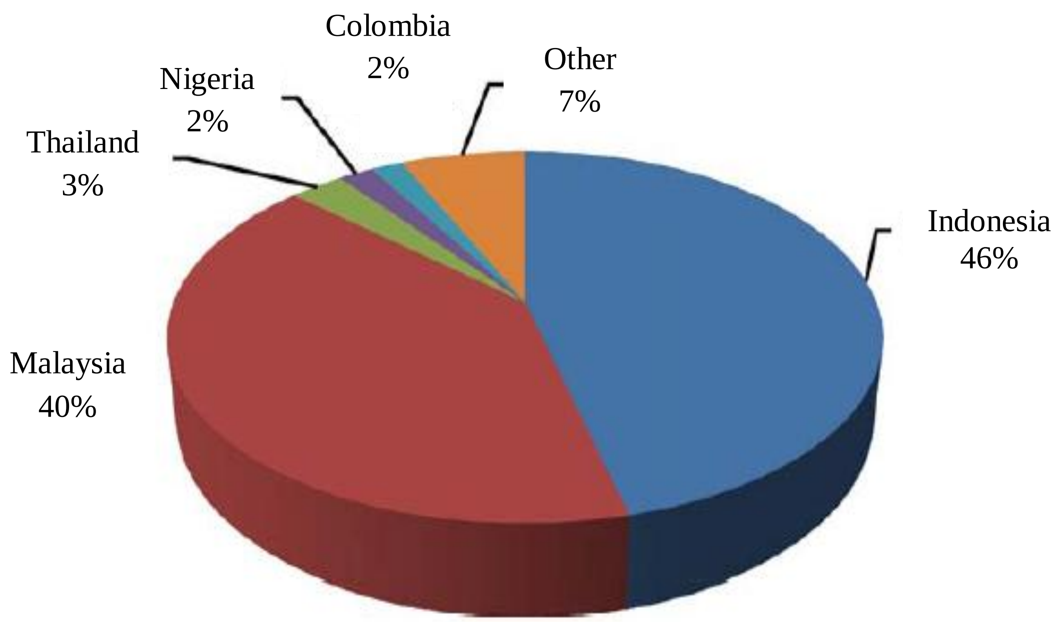

Figure 2.6: World Palm Oil Production 2009

Source: USDA, 2010

2.2.2 Transesterification

Biodiesel is mostly produced from oils and fats. The oils have higher levels of unsaturated fatty acids and thus are liquids at room temperature. Their shortest uses as fuel were tried more than a 100 years ago. But the problems with straight using oils as fuel are mostly associated with their high viscosities, low volatilities, and polyunsaturated character. However, fats contain more saturated fatty acids. They are solid in room temperature and cannot be used as fuel in a diesel engine in their original structure. Because of the problems, such as carbon deposits in the engine, engine durability, and lubricating oil contamination, associated with the direct use of oils and fats as inside combustion engine fuels, they must be derived to be compatible with existing engines (Dong et al., 2009).

Transesterification means taking a triglyceride molecule or a complex fatty acid, neutralizing the Free Fatty Acid (FFA), removing the glycerin, and creating an alkyl ester. The transesterification process is called alcoholysis (original ester is reacted with an alcohol). Generally, there are two methods of transesterification, one employs a catalyst and another method is non-catalyst option such as supercritical process, and co-solvent system. A lot of catalyst used are base catalyst that include NaOH, KOH, and NaMeO, acid catalyst that include H_2SO_4, H_3PO_4 and $CaCO_3$ and lipase enzyme. Methanol and ethanol are two major light alcohols used for transesterification process (Dong et al., 2009).

Generally, a catalyst is used to initiate the esterification reaction for making biodiesel. The catalyst is necessary as alcohol insoluble in oil or fat. The catalyst improve the solubility of alcohol and hence increases the reaction rate. The transesterification process for biodiesel production is normally achieved using homogeneous acid or base catalyst. Alkali catalytic method is followed when FFA content of the fed stock is less than 1%; while acid catalytic process is followed when FFA content is more than 1% followed by alkali catalytic process. Figure 2.7 shows the process flowchart of generalized biodiesel production methods (Karmakar et al., 2010).

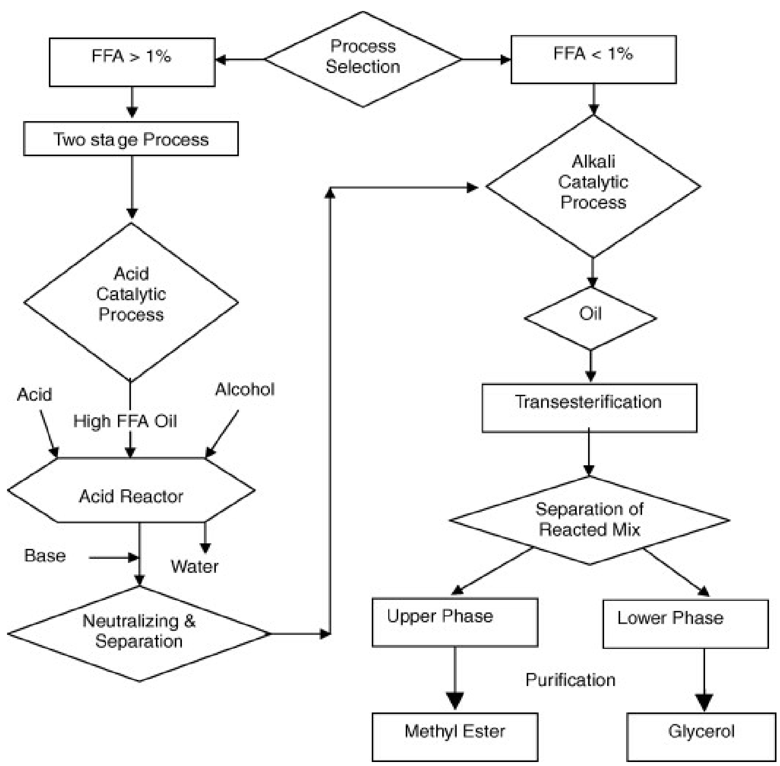

Figure 2.7: Process Selection and Step for Biodiesel Product

Source: Karmakar et al., 2010

Most of the existing commercial biodiesel production is dominated by base catalytic process. Heterogeneous catalysis is getting much attention as the solid acid or solid basic catalysts that could be used in a heterogeneously catalyzed process, does not produce soap through FFA acid neutralization and triglyceride saponification. The rate of transesterification reaction is strongly influenced by the temperature; the higher the temperature the faster reaction rate and the shorter reaction time. However, the reaction is conducted below the boiling point of the alcohol used, generally 60^{o}C for methanol and 78^{o}C for ethanol (Karmakar et al., 2010).

Transesterification consists of a number of consecutive, reversible reactions: the triglyceride is transformed stepwise to diglyceride, monoglyceride, and lastly glycerol. The overall reaction consists of three consecutive and reversible reactions: (1) the formation of diglycerides; (2) the formation of monoglycerides; (3) the formation of glycerol (Dong et al., 2009).

2.2.2.1 Acid-Catalytic

Acid catalyst systems are characterized by slow reaction rate and high ratio of alcohol and triglyceride condition (20:1 and more). Usually, acid-catalyzed reactions are used to convert FFAs to ester, or soap to ester as a pretreatment step for high FFA feedstocks (Gerpen et al., 2004). The acid-catalyzed procedure, being a one-step process, is more economical than the alkali-catalyzed process, which requires an extra step to convert FFAs to methyl esters, thus avoiding soap formation (Zhang et al., 2003a and 2003b). Acid catalyst process requires excess alcohol, hence the transesterification reactor and alkali distillation column of acid-catalyzed process are bigger than alkali-catayzed process for same biodiesel production capacity. A high conversion efficiency with acid-catalyzed transesterification can be achieved by increasing the molar ratio of alcohol to oil, reaction temperature, concentration of acid catalyst and the reaction time (Canakci and Gerpen, 1999)

2.2.2.2 Alkali-Catalytic

The base-catayzed process is relatively fast but can be affected by water content and free fatty acids of oils or fats. Free fatty acids can react with base catalyst to form soap and water. Soap not only lower the yield of alkyl ester but it also increases the difficulty in the separation of biodiesel and glycerol and also the water washing because of formation of emulsions. It was observed that methoxide catalyst give higher yields than hydroxide catalysts, and potassium-based catalyst give better biodiesel yield than sodium-based catalyst (Singh et al., 2006).

The use of homogeneous catalyst like sodium hydroxide and potassium hydroxide has been successful at industrial level for the production of biodiesel. Nevertheless, the biodiesel and glycerol produced has to be purified to eliminate the basic catalyst and need its separation by washing with hot distilled water twice or three times. Therefore, heterogeneous catalyst has also been tried by researchers to overcome this drawback of time consumption and large consumption of water (Singh et al., 2006).

2.2.2.3 Bio catalytic

Bio catalyst like immobilized lipase can be used as transesterification reaction agents. Yet, the enzyme reaction are highly specific and chemically clean, the reaction are very slow requiring from 4h – 40h. or more at temperature of 35 to 45^{o}C (Gerpen et al., 2004). Enzyme catalysis process is very promising if feedstocks having very high FFA content. But, this process has not yet been commercialized because of high cost of operation. Lately, lipase-catalyzed transesterification for biodiesel production has received much attention since it has many advantages over chemical method such as mild reaction conditions, specificity, reuse, and enzymes or whole cells can be immobilized, can be genetically engineered to improve their efficiency, are more thermostable, and are considered natural, and the reactions they catalyze are considered “green” reactions, and separation of product will be easier (Casimir et al., 2007).

2.2.2.4 Heterogeneous Catalytic

Heterogeneous catalysts like calcium oxide and calcium methoxide are insoluble in organic solvents. The reaction become very slow when these catalysts are used. It is because of the three phase mixture of oil-alcohol-heterogeneous catalyst has poor mass transfer. A co-solvent like tetrahydrofuran has a boiling point very close to that of methanol, is added for enhancing the mass transfer between the reactants. This results in a fast reaction which is 5 – 10 min at a temperature of 30^{o}C, no residues of catalyst in either the ester or the glycerol phase (Karmakar et al., 2010).

2.2.2.5 Supercritical Methanol Transesterification

Supercritical methanol transesterification is designed to overcome the reaction initiation lag time caused by the extremely low solubility of the alcohol in the triglyceride phase. There is no longer separated phases, when a solvent subjected to temperature and pressures in excess of its critical point. Only a fluid phase is present. The reaction is completed in a very short time (2-4 min) under supercritical condition (350-400 ^{o}C and >80 atm pressure) and at a very high molar ratio of methanol to oil (42:1). Therefore, absence of catalyst makes the glycerol recovery and biodiesel purification much easier, trouble free and environment-friendly (Encinar et al., 1999)