CHAPTER II
THEORETICAL BACKGROUND AND LITERATURE REVIEW

Theoretical Background

2.1 Glycerol

Glycerol, or 1,2,3-propanetriol, is a trihydric alcohol. It is a colorless, odorless, sweet-tasting, syrupy liquid. It melts at 17.8 °C, boils with decomposition at 290 °C, and it is miscible with water and ethanol (Perry and Green, 1997). The chemical formula for glycerol is $C_3H_5(OH)_3$. It is hygroscopic—it absorbs water from air—this property makes it valuable as a moistener in cosmetics. Moreover, glycerol is in the form of its esters (glycerides) in all animal and vegetable fats and oils (Pachauri et al., 2006).

2.1.1 The role of glycerol as commodity chemicals feedstock.

Since the petroleum-based fuel is irrecovable energy source and has environmental and human effects, biodiesel is a very attractive alternative fuel because it is obtained from renewable, domestic resource and friendly environment. One of commercial production routes of biodiesel is transesterification of vegetable oil with alcohol which provide glycerol as a byproduct about 10% by weight (Figure 2.1).

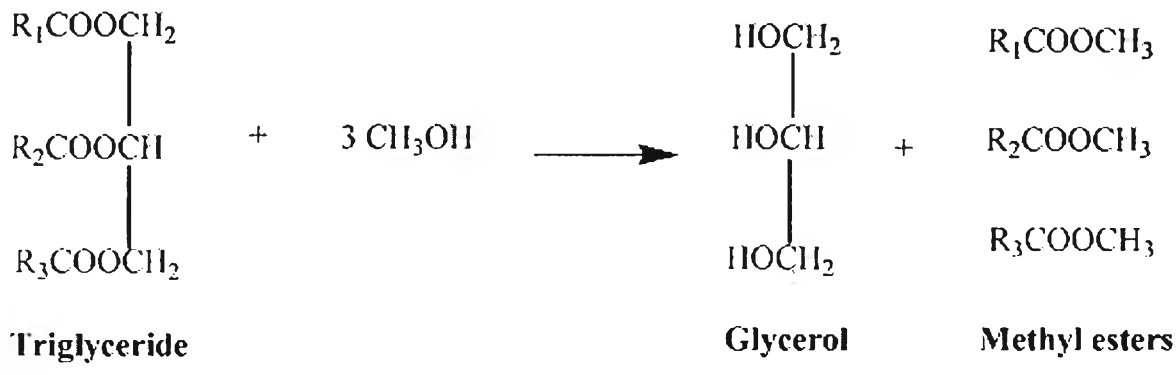


Figure 2.1 Transesterification of triglyceride with methanol.

The global production of biodiesel has been dramatically increased. As a result, a large surplus of glycerol from biodiesel process causes a decline in glycerol price leading to the entire biodiesel production process to be less competitive. However, glycerol can be used as a feedstock in many processes, therefore, more use of glycerol can help relief pricing decline problem.

A number of opportunities for glycerol utilization have been identified as summarized in Figure 2.2. This figure provide an overview analogous to similar diagrams developed for petrochemical unit operations. Within the context of biorefinery, Figure 2.2 is suggested as a starting point for definition of "glycerol family" (Zheng et al., 2008).

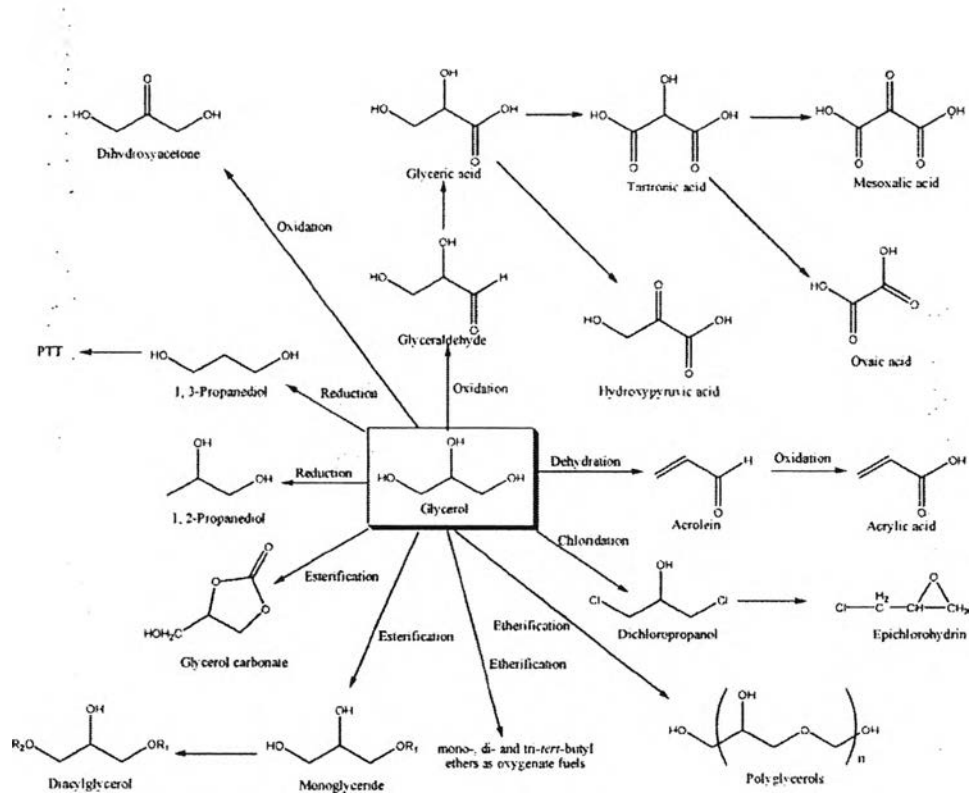


Figure 2.2 Commodity chemicals from glycerol (Zheng et al., 2008).

2.2 Monoglyceride

A monoglyceride, one of glycerol derivatives, is a glyceride consisting of one fatty acid chain (and two hydroxyl groups) bonded to a glycerol molecule through an ester linkage. Monoglycerides can be classified into two groups; 1-monoglyceride and 2-monoglyceride, based on the position of the ester bond on glycerol moiety. This esters have many applications, such as emulsifying agents in food, cosmetics, pharmaceuticals or detergents (Sagalowicz et al., 2006).

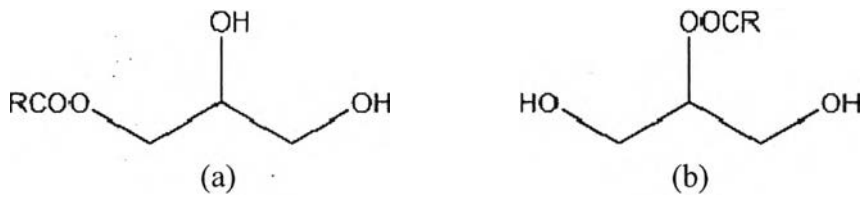


Figure 2.3 Structure of momoglycerides: (a) 1-monoglyceride, (b) 2-monoglyceride.

In food science, stability of food emulsion systems are necessary. Pichot and coworkers (2009) studied the stability against coalescence of vegetable oil-in-water "food grade" emulsions in the presence of surfactant (monoolein or monooleate-1-glycerine) and colloidal particles (hydrophilic silica). They found that these mixed emulsifier systems were found to induce long-term emulsion stability against coalescence via a synergistic "two part" mechanism in which both the surfactant and colloidal particles components have specific functions. The role of monoolein is to initially delay the re-coalescence phenomena and induce further droplet break-up during emulsification by rapidly covering the new interface and reducing interfacial tension in order to allow the time for the hydrophilic silica particles to assemble at the oil/water interface and provide long-term stability.

2.2.1 Monoglyceride Production

There are many way to manufacture monoglyceride but on the industrial scale only three processes are popular: (1) Direct esterification of glycerol with fatty acid, (2) Transesterification of triglycerides with alcohol and (3) Glycerolysis of triglycerides.

2.2.1.1 Direct esterification of glycerol with fatty acid

Main consumer of monoglyceride is the food industry and quantities required are so high that several worldwide companies have specialized on monoglyceride as their main production. Monoesters with C_{16}/C_{18} acid groups are preferred. Products with 40-60% mono content can be achieved by direct esterification which is shown below.

Main Reaction:

Secondary Reaction:

Secondary reaction of direct esterification which reduces the concentration of monoglycerides cannot be avoided as it happens simultaneously. The concentration of monoglycerides at the end of reaction is 40-60%. It should be noticed that water, is created by direct esterification, make uncontrolled foaming occurred by too sudden water formation.

2.2.1.2 Transesterification of triglycerides

Transesterification is the reaction of triglycerides (or other esters) with alcohol to produce alkyl esters and glycerol, typically in the presence of acid or base catalysts (Huber et al., 2006).

Traditionally, basic catalysts such as KOH and $Ca(OH)_2$ can be industrially used in these processes. However, the drawbacks which are resulted

from the use of basic catalysts are: (i) neutralization step is required, (ii) the formation of salts and (iii) the high reaction temperature.

For this route, the monoglycerides can be achieved via the reactions are shown below:

Main Reaction:

$(RCOO)_3C_3H_5$ + $C_3H_8O_3$ ⇌ $RCOOC_3H_7O_2$ + $(RCOO)_2C_3H_6O$

Triglyceride Glycerine Monoglyceride Diglyceride

Secondary Reaction:

1 $(RCOO)_2C_3H_6O$ + 1 $C_3H_8O_3$ ⇌ 2 $RCOOC_3H_7O_2$

Diglyceride Glyceride Monoglyceride

2.2.1.3 Glycerolysis of triglycerides

Glycerolysis is the process of breaking a chemical bond with the use of glycerin. These reactions are often catalyzed by the addition of an acid or base. Glycerolysis is a special case of transesterification which is used for synthesizing emulsifiers or lipophilic surfactants from simple esters, fats, triglycerides, carboxylic acid anhydrides, or free fatty acids. The process is used to produce monoglycerides and diglycerides, and, in rare cases, polymers (when dicarboxylic acids are used).

The reverse of this process, breaking apart to release glycerin, is saponification or hydrolysis if water is used and is transesterification if a different alcohol or glycol is used. (http://en.wikipedia.org/wiki/Glycerolysis)

Glycerolysis of fats and oils with glycerol has been intensively patented as widening industrial uses were found for monoglyceride in the 1940s and 1950s (Noureddini et al., 1997). This reaction can be occurred at high temperature in the presence of basic catalyst. Industrial glycerolysis was carried out at temperature above 473 K, with NaOH or KOH as a catalyst (Corma et al., 1997).

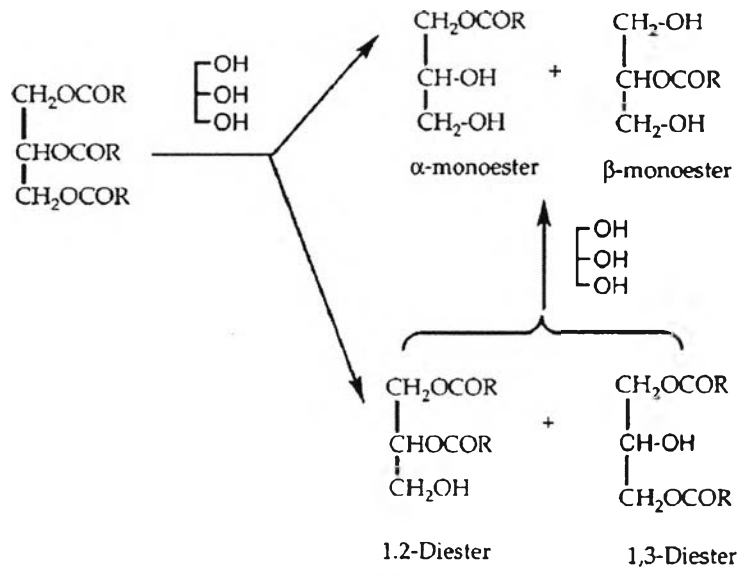


Figure 2.4 Glycerolysis of triglycerides with glycerol (Corma et al., 1997).

2.3 Protecting group in organic synthesis

A protecting group or protective group is introduced into a molecule by chemical modification of a functional group in order to obtain chemoselectivity in a subsequent chemical reaction. It plays an important role in multistep organic synthesis. In many preparations of reactive organic compounds, some specific parts of their molecules cannot be stable in the required reagents or chemical environments. Then, these parts, or groups, must be protected. When the protecting group or protective group is introduced into a desired functional group, this step is called introduction or protection step. After the desired step is completed, the protective group is removed and giving back the original functional group. This step is called cleavage or deprotection step.(http://en.wikipedia.org/wiki/Protecting_group)

Another role of protective group is when a chemical reaction is to be carried out selectively at one reactive site in a multifunction compound, other reactive sites must be temporarily blocked. A protective group must fulfill a number of requirements. It must react selectively in good yield to give a protected substrate that is stable to the projected reactions. The protective group must be selectively removed

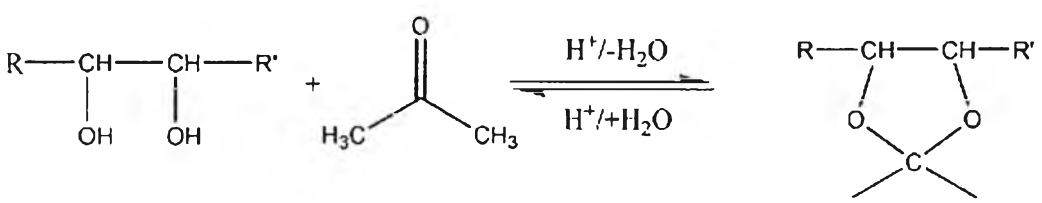
in good yield by readily available, preferably nontoxic reagents that do not attack the regenerated functional group. The protective group should form a derivative that can easily be separated from side products associated with its formation or cleavage. The protective group should have a minimum of additional functionality to avoid further sites of reaction (Greene et al., 2007).

2.3.1 Hydroxy Protecting Group

This study focuses on hydroxyl protecting group because the glycerol, a triol compound, is the protection target. There are many compounds that can be used as a protecting group for glycerol, such as acetals, ethers, silyl ethers, esters, carbo-nates and many others.

2.3.1.1 O-alkylidene group

The O-alkylidene group is well-known as the most useful groups on carbohydrates and polyols such as glycerin and its homologs. O-alkylidene groups can form acetal/ketal compounds via the reaction of aldehydes/ketones with *cis* vicinal hydroxyl groups on polyols (Bhati et. al., 1980). One typical O-alkylidene group, O-isopropylidene group, is easily obtained through reaction of *cis* vicinal hydroxyl groups with acetone in the presence of and acid catalyst, as shown in Figure 2.5 (Urata et. al., 1998).



Polyols **Acetone** **O-isopropylidene**

Figure 2.5 O-isopropylidene group formation via the reaction of *cis* vicinal hydroxyl groups with acetone

Such compounds can be crystallized and also distilled in high vacuum without decomposition (Schmidt, 1963). They are usually stable in alkali, but are hydrolyzed in aqueous acid. Furthermore, hydrolysis of such O-

isopropylidene compounds leads to regeneration of acetone, which can be recycled if effective separation methods are used.

Literature Reviews

Choudhury et al., (1962) studied the direct esterification reaction with various saturated and unsaturated fatty acids at 180 °C the reaction temperature and in the presence and absence of alkali catalysts. The resulting monoglyceride is in the range of 55-60% of the fatty product at equilibrium stage of the reaction. The NaOH , as a catalyst, increases the initial rate of reaction and helps in depressing diglyceride formation.

Table 2.1 Esterification of 1 mole fatty acid with 3 mole glycerol at 180 °C with/ without alkali catalyst (Choudhury et al., 1962)

Type of saturated/ unsaturated fatty acids	% Composition (Without catalyst)			% Composition (With catalyst)		
	Mono-	Di-	Tri-	Mono-	Di-	Tri
1. Lauric acid	52.3	44.1	3.6	60.4	37.5	2.1
2. Myristic acid	50.1	47.3	2.6	59.2	36.9	3.9
3. Palmitic acid	49.9	46.8	3.3	58.8	38.4	2.8
4. Stearic acid	48.1	46.8	5.1	57.2	38.1	4.7
5. Oleic acid	53.2	43.1	3.7	61.2	37.0	1.8
6. Linoleic acid	53.6	44.0	2.7	61.5	36.5	2.0

Mukherjee et al., (1989) studied esterification or acidolysis reaction of oleic acid with glycerol, monooleoylglycerols, dioleoylglycerols and trioleoylglycerol using two immobilized microbial lipase preparations: "Lipase G" from Penicillium sp. And sn-1,3-specific "Lipozyme" from Mucor miehei. Lipase G effectively catalyzes the esterification of oleic acid with glycerol yielding monooleoylglycerols

as most predominant product. Lipozyme also catalyses but provides lower esterification rate and predominant products formed are dioleooylglycerols, followed by monooleoylglycerols and trioleoylglycerol. This study shows that Lipased esterification is a suitable alternative for the preparation of mono- and diacylglycerols under mild conditions. However, in the industrial scale, the cost of lipase and the capacity are concerned.

Barrault et al., (1997) reported the activity of Amberlyst 31, providing a monooleins yield of 49% after 24 hours at 363 K, with molar ratio of reactant of 6.3. The advantages are lower reaction temperature and easy catalyst removal. However, there are many drawbacks also such as too long reaction time and low yield of monooleins.

Because the reaction conditions affect the production of 1-monoglyceride when using a zeolite of faujasite type as solid catalyst. Sánchez and coworkers (1997) reported the effects of quantities of catalyst, temperature range of industrial interest and acid/alcohol ratio. They found that the rate of reaction increases with temperature and the concentration of catalyst. However, the rate of reaction decrease for long reaction time. Moreover, when the ratio of acid/alcohol is decreased, the rate of reaction is increased.

Bancquart et al., (2001) studied the use of solid basic catalysts (MgO, CeO_2, La_2O_3 and ZnO) for glycerol transesterification in absence of solvent. They found that these catalyst are active but the selectivity of mono-, di- and triglyceride is similar to homogeneous basic catalyst.

Corma et al., (1997) studied glycerolysis of triolein and rapeseed oil using solid base catalysts such as Cs-MCM-41, Cs-Sepiolite, MgO and calcined hydrotalcites with different Al/Al-Mg ratios. The results show that at 513 K, MgO and low Al hydrotalcites are sufficiently basic for carrying out the transesterification with monoglyceride yields higher than 90% and more than 75% selectivity.

Abro et al., (1997) studied the use of various solid catalysts (zeolite, clay and ion-exchanged resin) for esterification of glycerol with oleic acid. The results show that cationic exchanged resin is the best catalyst for selective preparation of monooleyl glyceride in mild condition. It seems that the activity is influenced by the

resin structure; depending on its crosslinking, acts as a shape selective catalyst. The benefits of the sweeling of ion-exchanged resins on the overall catalyst performance in glycerol esterification evidence the positive influence of increasing of accessibility of the reactant to the active centers. Hence, the series of the ordered mesoporous materials is concerned for the alternative solid catalysts which offer the possibility to overcome the pore-size limitation characteristic of zeolite materials (Márquez-Alvarez et al., 2004).

Bossaert et al., (1998) reported for the first time the preparation of mesoporous sulfonic acid as selective heterogeneous catalysts and compared the catalytic activity, for esterification of glycerol with lauric acid, of siliceous mesoporous materials (silica gel, MCM-41, and HSM) with propylsulfonic acid groups to H-USY and Amberlyst-15. The authors found that mesoporous materials with sulfonic groups were more active, but they could not correlate the activity with the number of acid groups, nor could observed the shape-selectivity. However, it can be concluded that the good accessibility to active sites seemed to be an important catalytic factor.

Corma et al., (1992) reported the activity of zeolite for esterification between oleic acid and glyceride over HY zeolite, at 453 K, obtaining a monooleins yield of 83% after 5 hours of reaction, with a molar ratio of reactant of 1.

Jérôme et al., (2004) reported "one-pot" and selective synthesis of monoglyceride which was catalyzed at 383 K by guanidine catalysts either in a solvent or without. The results shown that the supported guanidine derivatives affect to increasing of monoglycerides yield. Moreover, at the end of transesterification, the solid catalyst was reused.

Several research groups employed protected glycerols. For example, using 1,2-O-isopropylidene glycerol instead of glycerol, highly pure monoglycerides was synthesized (Yu et al., 2003). Yu and coworkers (2003) studied the transesterification of 1,2-O-isopropylidene glycerol with methyl strearate and Na_2CO_3 was used as the catalyst as shown in Figure 2.6. The results show that the yield and purity of monoglyceride are very high (overall yield: 92%). The selective

and efficient deprotection of the acetonide was accomplished by using Amberlyst-15-Ethanol system in which the purification of procedure was very simple.

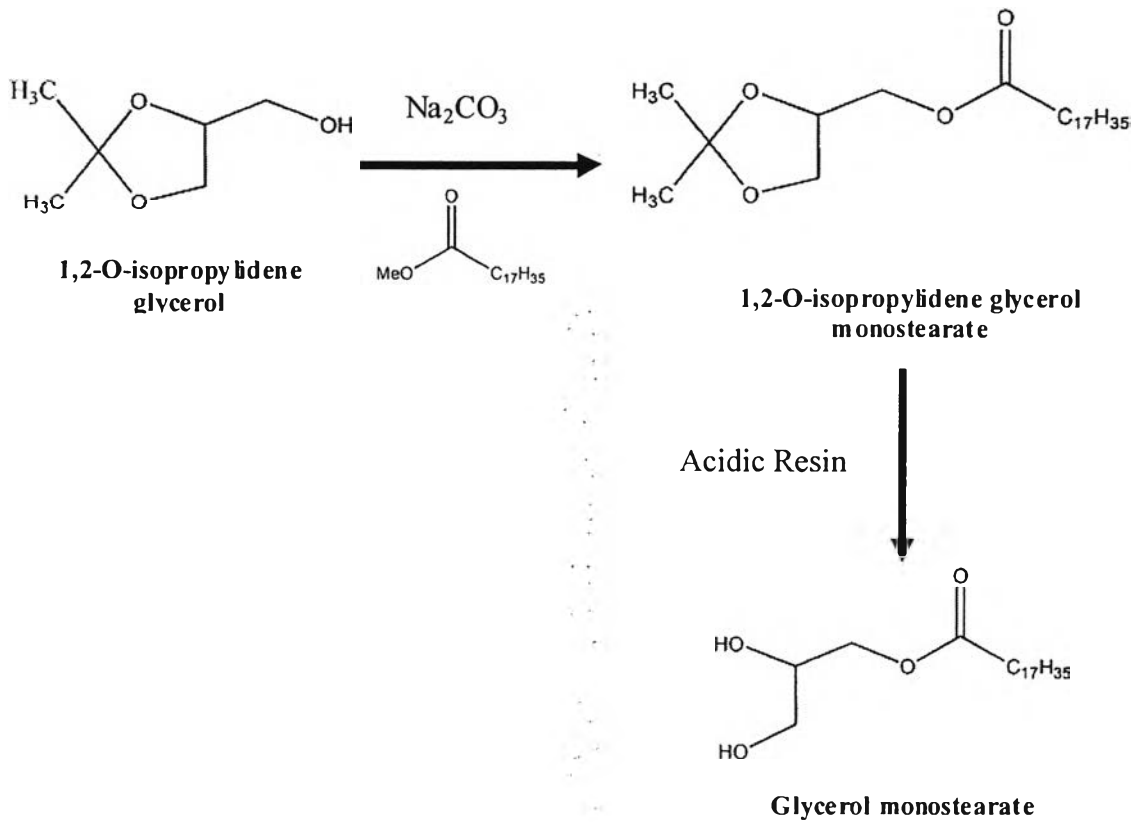


Figure 2.6 Transesterification of 1,2-O-isopropylidene glycerol and methyl stearate.

Corma et al., (2008) studied the esterification of ketalized sorbitol with oleic acid over various solid acid catalysts, as shown in Figure 2.7. They found that the formation of ketalized sorbitols make the formation of undesired products like di- and triesters decreased, especially when mordenite was used as a catalyst, and have a good selectivity to monoester. However, the reaction temperature affect the formation of undesired reaction like etherification and anhydrization so the reaction temperature should not above 200 °C. Moreover, the relative small amount of acid sites make the long reaction time required

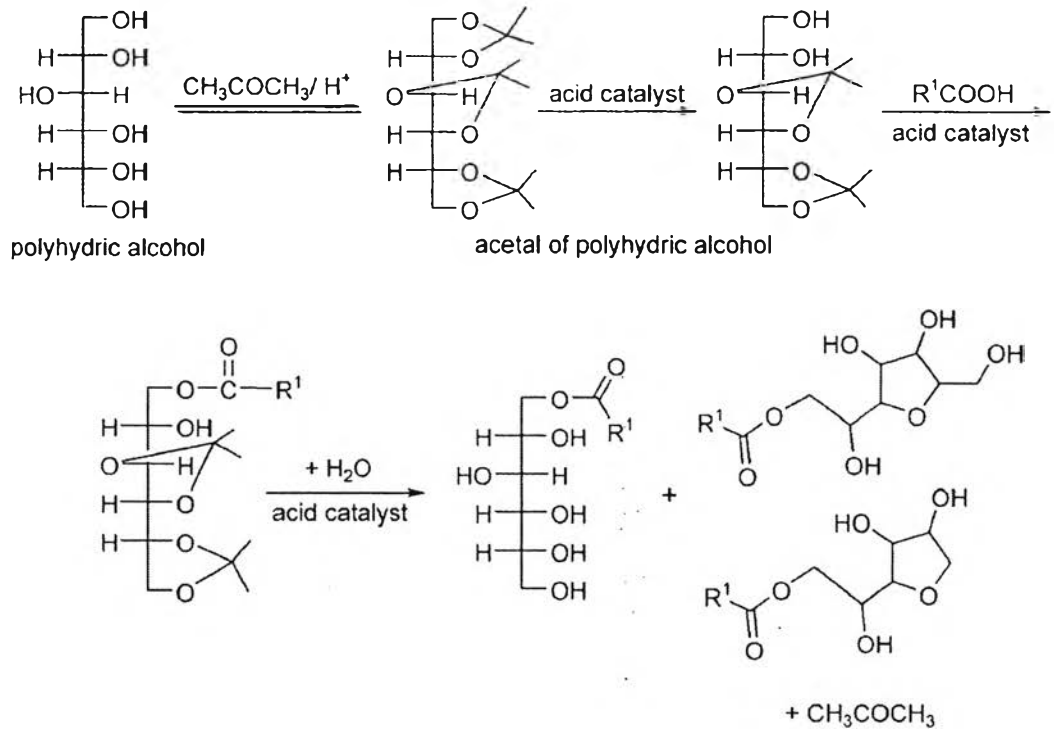


Figure 2.7 Two-Step process for sorbitol ester production.

There are many research which concern about how to synthesize 1,2-O-isopropylidene glycerol. Moreover it is a raw material for monoglycerides production. It is the intermediate for diesel and biodiesel additive synthesis. García and coworkers (2008) studied on new acetal (2,2-dimethyl-1,3-dioxolan-4-yl)methyl acetate for diesel and biodiesel additive which is not only improves biodiesel viscosity but also meets the requirements established by diesel and biodiesel fuels by European and American Standards (EN 14214 and ASTM D6751, respectively) for other important parameters such as flash point and oxidation stability. To reach that aim, they started with Acetonation of glycerol and followed by Acylation of hydroxy group as shown in Figure 2.8.

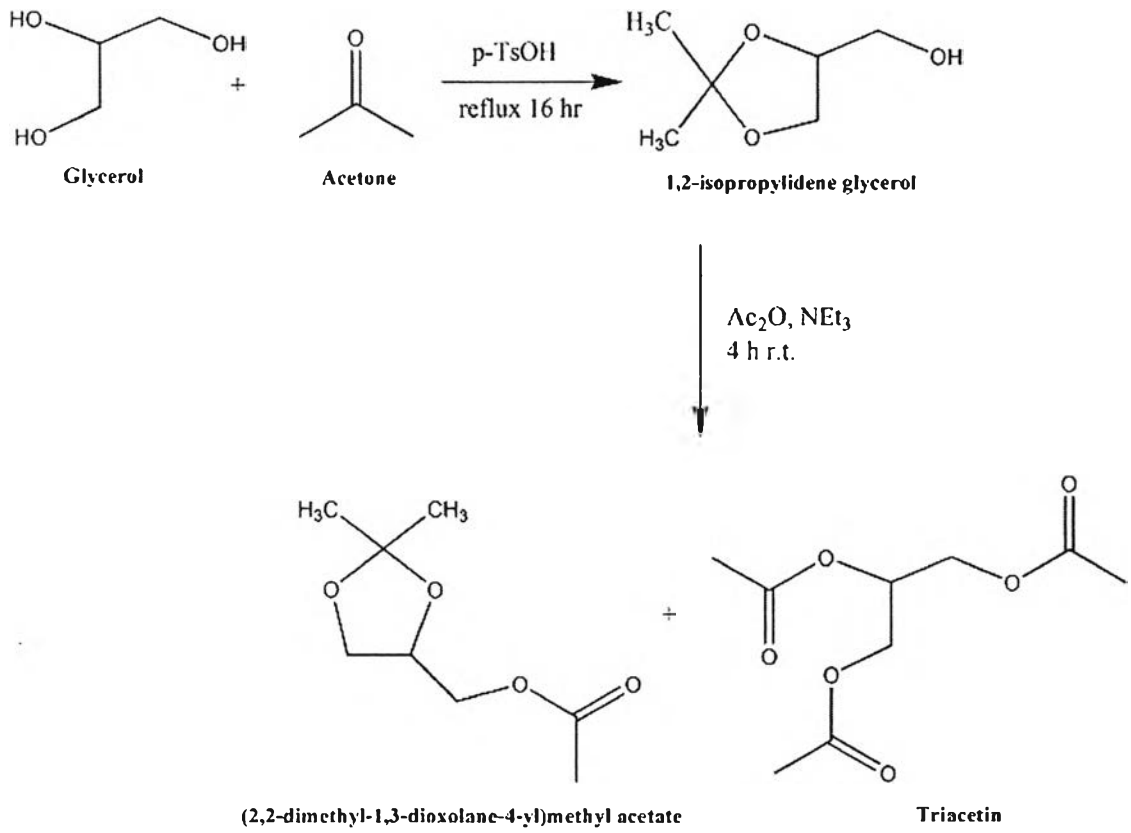


Figure 2.8 Acetonation of glycerol and Acylation of hydroxy group

As same study, characterization of 1,2-isopropylidene glycerol was suceeded by gas chromatography with a flame ionization detector (FID), for reaction monitoring as shown in Figure 2.9 and Fourier-Transform Infrared Spectroscopy (FT-IR) and gas chromatography with mass spectroscopy, for identification as shown in Figure 2.10 and 2.11, respectively.

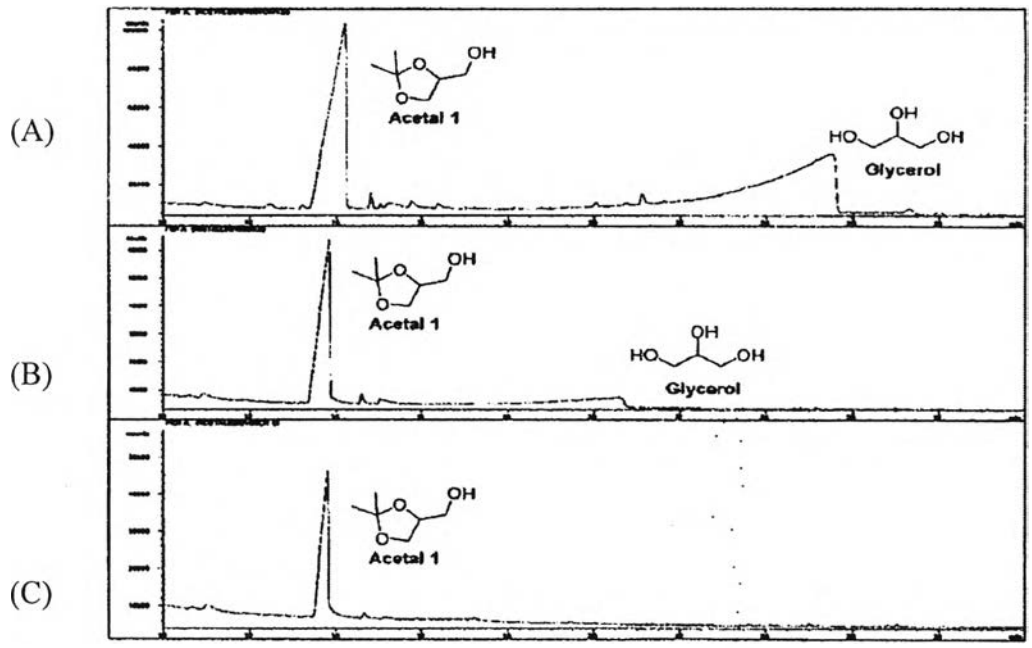


Figure 2.9 Synthesis monitoring of 1,2-isopropylidene glycerol by Gas chromatography with FID: (A) 5 h. of reaction time, (B) 10 h. of reaction time, and (C) 16 h. of reaction time.

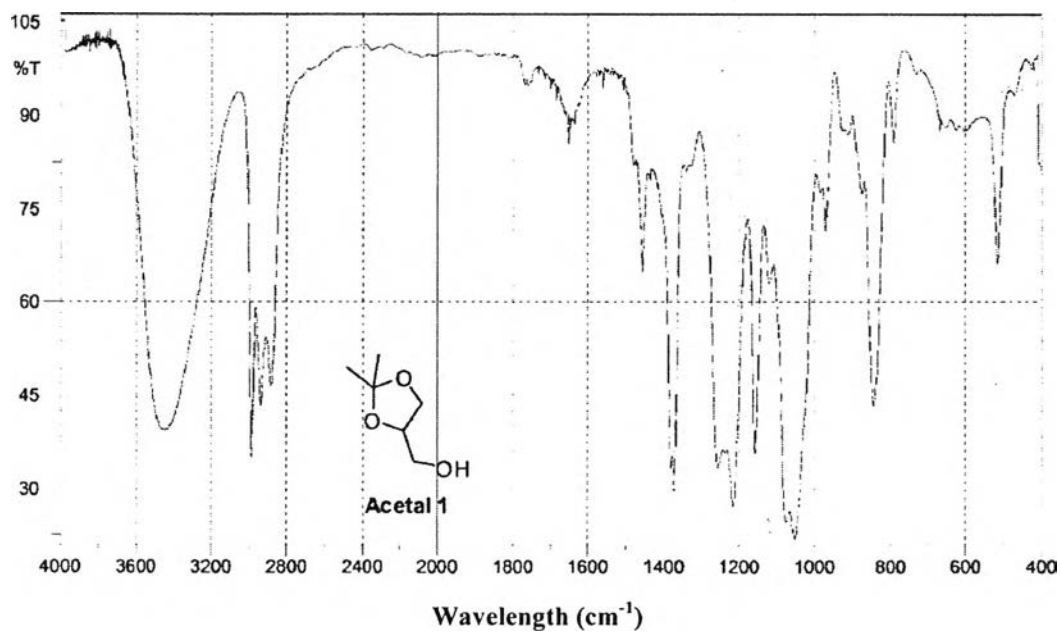


Figure 2.10 IR spectrum of 1,2-isopropylidene glycerol.

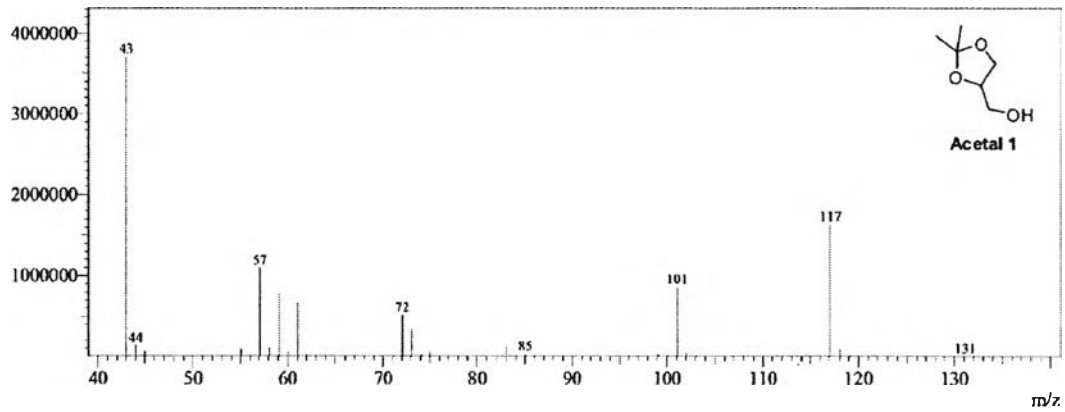


Figure 2.11 Mass spectrum of 1,2-isopropylidene glycerol.

Yu and coworkers (2003) studied on using 1,2-O-isopropylidene glycerol instead of glycerol for transesterification with methyl stearate in order to avoid acylation problem, moreover, highly pure glycerol monostearate was synthesized.

Analysis of Monoglycerides

One of difficult problems in glycerides analysis is differentiation and characterization of 1- and 2-monoglycerides. In 1961, Susi and coworkers investigated the mixture of 1- and 2-monoglycerides (in absence of di- and triglycerides) using Near-Infrared spectroscopy. The main difference between the two isomers is OH groups in different intramolecular environment so this method, where greatest emphasis is on chemical groups and bonds involving hydrogen atoms, is well suited to investigation.

The absorbance of a mixture of 1- and 2-monoglycerides at a given wavelenght is given by the relationship:

(1) $A = (c_1k_1+c_2k_2)b$

(2) $c = c_1 + c_2$

Where, A is the total absorbance; c_1 and c_2 are the molar concentrations of 1- and 2-monoglycerides; k_1 and k_2 are the molar absorptivities of 1- and 2-monoglycerides; b is the path length in cm. Rearrangement and yields:

$$(3)\quad \%\text{monoglycerides} = \left(\frac{c_1 \times 100}{c_2}\right) = \frac{(A - ck_2b)100}{(k_1 - k_2)bc}$$

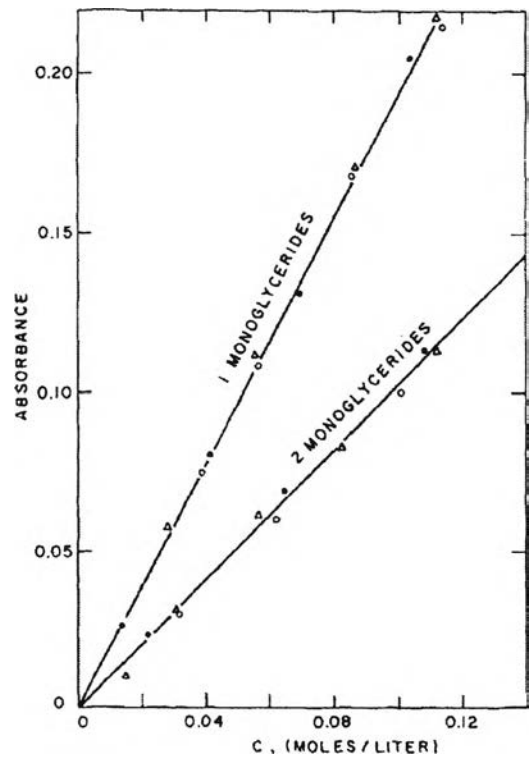


Figure 2.12 Absorbance of 1- and 2-monoglycerides at 1.430 microns as a function of concentration. Open circles—monopalmitin; closed circles—monostearins; triangles—monooleins.

From comparison between composition data calculation (from equation(3)) and known amount of 1- and 2-monoglycerides, Susi and coworkers concluded that the computed data are more exact than that could be expected from measurements in fundamental infrared region and approach the accuracy attainable in UV region on samples with comparable differences in absorbance. Although the procedure is not suitable trace analysis, it constitutes a rapid method for rather accurate estimation of the abundance of position isomers in mixture of 1- and 2-monoglycerides.

Moreover, the structure of 1- and 2-monoglycerides were readily differentiated by Nuclear Magnetic Resonance spectroscopy (NMR), a technique well established in organic chemical analysis, and may also be used to distinguish 1,2- and 1,3- diglycerides and triglycerides. Figure 2.13 illustrates the general pattern

of peaks produced by protons attached to glycerol carbons of mono-, di- and triglycerides. This diagram indicates only approximate positions of peaks and not their proper splitting. The chemical shift of protons attached to glycerol carbons may be altered slightly by the chemical structure of the fatty acids attached to the glycerol, but the patterns should in general resemble those depicted in this figure (Serdarevich et. al., 1966).

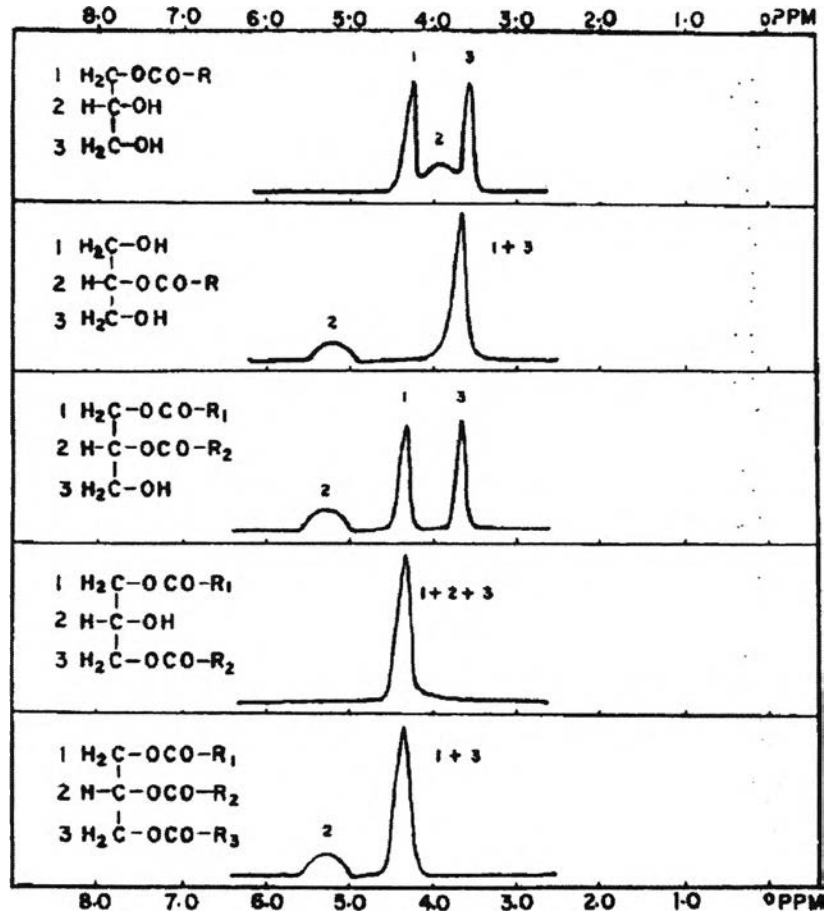


Figure 2.13 Diagram showing approximate positions of peaks due to protons attached to glycerol carbons in NMR spectra of mono-, di- and triglycerides.

Pouilloux et al., (1999) studied the reaction of glycerol with fatty acids in the presence of ion-exchange resins preparation of monoglycerides. They analyzed the product of esterification with high performance liquid chromatography equipped with a light scattering detector use for detection of high molecular weight

compounds such as fatty compounds. The chromatographic column and two types of eluents: (i) chloroform (stabilized with ethanol) and (ii) mixture of methanol, water, chloroform and ammonia were used.

In 2001, Holčapek and coworkers studied on chromatographic techniques which are compared with respect to their suitability for analysis of acylglycerols and methyl esters of fatty acids. They reviewed about chromatogram of rapeseed oil partially transesterified with methanol under condition: combined aqueous-organic and nonaqueous reversed-phase gradient elution (linear gradient from acetonitrile/water=70:30 in 0 min to 100% acetonitrile in 20 min, hold-up step to 36 min, then to 2-propanol/acetonitrile=6:4 in 132 min) as shown in figure 2.14.

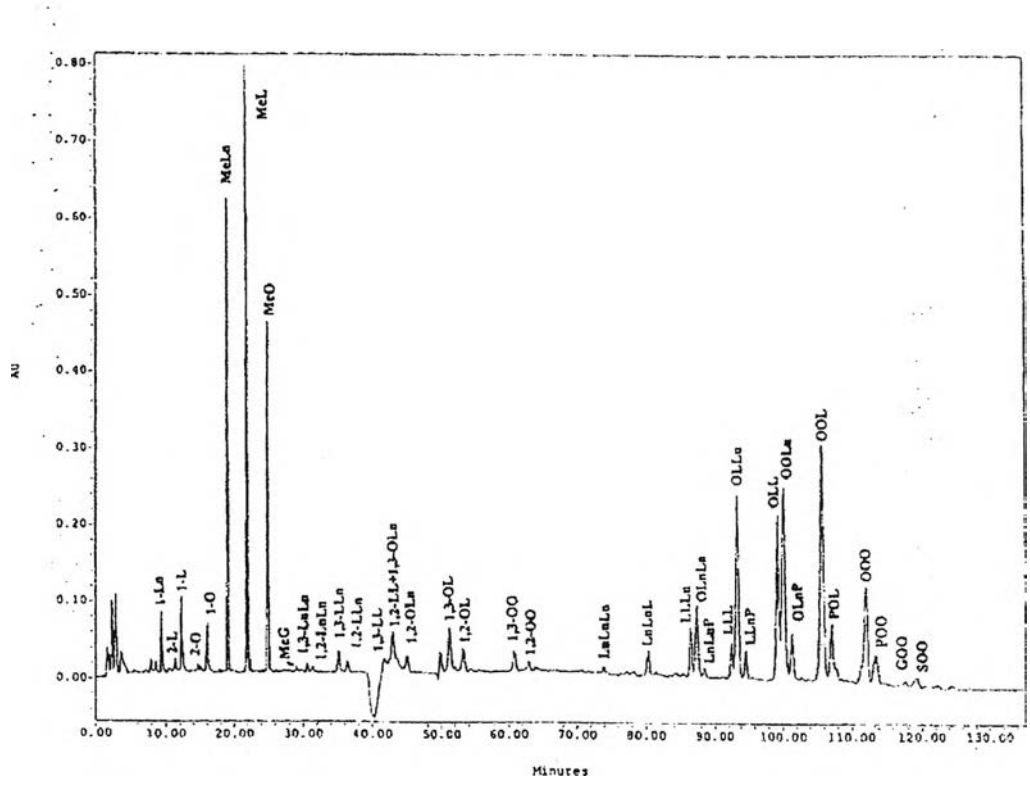


Figure 2.14 The chromatogram of rapseed oil partially transesterified with methanol.

Corma et al., (2005) studied glycerolysis of glycerolysis of fatty methyl oleate over various heterogeneous catalysts. The products were analyzed by gas chromatography. The fatty methyl ester conversion to the different reaction products is given by the following equation:

$$\text{Molar Conversion (\%)} = \frac{(100)(A_{mono}/rF_{mono} + 2A_{di}/rF_{di} + 3A_{tri}/rF_{tri})}{A_{mono}/rF_{mono} + 2A_{di}/rF_{di} + 3A_{tri}/rF_{tri} + A_{ME}/rF_{ME}}$$

Also, the selectivity to monoglycerides was calculated according the following equation:

$$\text{Selectivity to monoglyceride (\%)} = \frac{100\ (A_{monon}/rF_{mono})}{A_{mono}/rF_{mono} + 2A_{di}/rF_{di} + 3A_{tri}/rF_{tri}}$$

Where : A_{mono}, A_{di}, A_{tri} and A_{ME} = the respective areas of the peaks corresponding to monoglycerides , diglycerides, triglycerides and fatty acid methyl esters and rF are their respective response factors.

Mazor et al., (1991) investigated regioselectivity of the esterification by using C-13 NMR spectroscopy. Positional isomers of mono-, diglycerides are easy to detect because each isomer gives a distinctive resonance pattern of the glycerol backbone carbon atoms.