

# **CHAPTER II**

## **THOERY AND LETERATURE REVIEW**

### **2.1 Lubricant**

A lubricant is a substance used to reduce the coefficient of friction between the rubbing surfaces in machinery, in order to reduce frictional energy losses. The lubricant also prevents direct contact of the rubbing surface since under proper conditions of lubrication film of the lubricant is maintained between these surfaces. This prevents failure due to seizure and also reduces wear. The frictional heat generated by the rubbing surfaces is removed by the lubricant acting as a coolant or heat transfer fluid. In internal combustion engines, the lubricant also seal the piston and cylinder wall at the compression rings so that the high pressure gas in the combustion chamber will not leak past the rings and cause power losses. Briefly, the lubricant reduces energy losses from friction, reduces wear, serves as a coolant and may also seal.

#### **2.1.1 The basic function of lubricant**

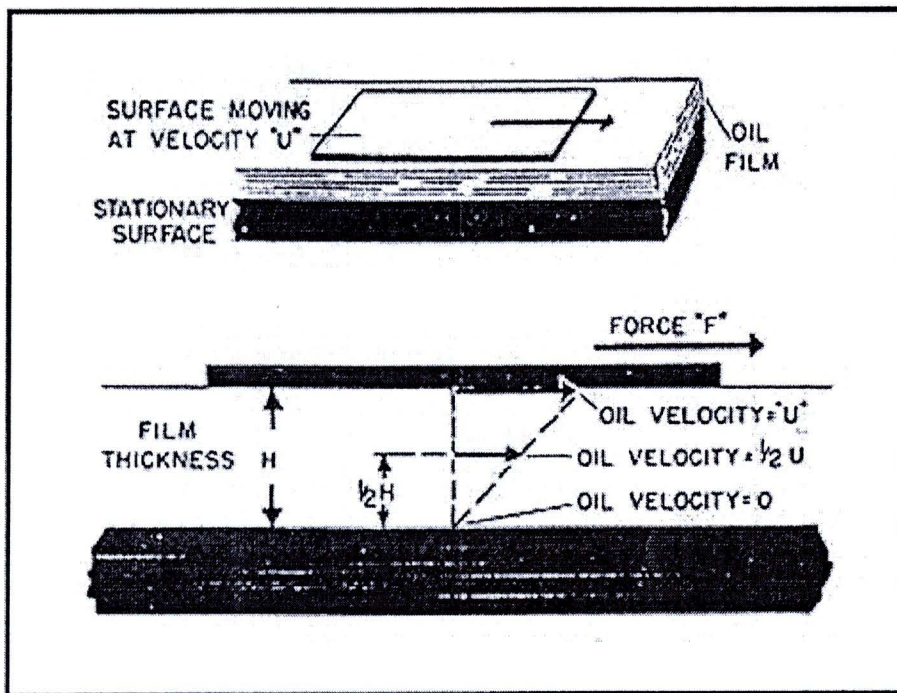
The basic functions of lubricant are: (1) friction reduction (2) heat removal and (3) containment of contaminants.

##### **2.1.1.1 The reduction of friction**

Simple stated friction reduction is accomplished by maintaining a film of lubricant between surfaces which are moving with respect to each other, thereby preventing these surfaces from coming in contact and subsequently causing surface damage.

One of the most important properties of lubricating oil is its viscosity. It forms lubricating films under both thick and thin film conditions. Viscosity effects heat generation in bearing, cylinders and gears related to fluid internal friction. It governs the sealing effect of oils and the rate of oil consumption. It determines that machines may be started under varying temperature conditions, particularly at cold temperature. For many given piece of equipment, satisfactory results are obtained only with the use of an oil of proper viscosity under the operated condition.

The basic concept of viscosity is shown in Figure 2.1, where a plate is being drawn at uniform speed over a film of oil. The oil adheres to both the moving surface and the stationary surface. Oil in contacted with the moving surface travels at the same velocity ( $U$ ) as that on surface, while oil in contact with the stationary surface is at zero velocity.



**Figure 2.1** Concept of dynamic viscosity (George, 1980)

In between the oil film may be visualizes as made up of many longer, each being drawn by the layer above it is a friction of velocity that is proportional to its distance above the stationary plate. A force (F) must be applied to the moving plate to overcome the friction between the fluid layers. Since the friction is the results of velocity, the force is proportional to viscosity.

#### **2.1.1.2 Heat removal**

Another important function of a lubricant is to act as a coolant, removing heat generated either by friction or other sources such as via combustion process or transfer by contacting with substances at higher temperatures. In forming this function, it is important that the lubricant remain in a relatively unchanged condition. The variation in thermal and oxidation stability which affect its ability to reach the areas involved will materially decreases its efficiency in this respect.

#### **2.1.1.3 Containment of contaminants**

The ability of a lubricant to remain effective in the presence of outside contaminants is quite important. Among these contaminants are water, acidic combustion products, particular matter, etc., which generally find their way into lubricants employed in various applications. Here again additives are generally the answer in accomplishing these objectives.

### **2.1.2 The constituent of lubricating oil**

Typically lubricants contain 90% base oil and less than 10% additives. The additive is a substance used to improve the base oil into a better performing lubricant to suitable for application. The main families of additive are antioxidants, detergents, anti-wear, anti-forming agent, friction modifier, viscosity index improver, corrosion inhibitors, rust inhibitions, pour point depressants, etc.

The base oil has several functions but primarily it is the lubricants. Many of the properties of the lubricant are enhanced or created by the additive



of special chemical additives to the base oil. The base oil also functions as the carrier for these additives and must therefore be able to keep the additives in solution under all normal working conditions.

The majority of lubricant base oil is produced by the refining of crude oil. Crude oil is the end result of physical and chemical process on the buried remains of plants and animal. Each accumulation or oilfield contains a different type of crude oil, varying chemical composition and physical properties. Obviously only some of these crude oil constituents are desirable in lubricant base oil. Other process steps involving chemical reactions may also be used to enhance properties of the oil. Different types of base oil are produced at refineries; oil which have different viscosities or chemical properties are needed for different application. The base oil can be separated into 3 types as follow:

#### **2.1.2.1 Vegetable or animal oil**

There is less usage of this type of oil due to its low stability, easy decomposition during use and the fact that it has to pass the quality improvement processes before it can be used, which makes its costs very expensive. Thus, it is currently used as only an additive to improve the lubricity of some lubricating tasks that require specific qualities.

#### **2.1.2.2 Mineral oil**

Mineral oil is the most favorable because of its high quality and low price. It is the product from crude oil distillation, in which the heavy fraction at the bottom of the tower will be used as raw material in base oil manufacturing through vacuum distillation process. The type and quality of mineral oil that is separated depends on type of crude oil that is distilled. Some crude oils have to pass other processes to eliminate undesirable things and to obtain good stability.



### **2.1.2.3 Synthetic oil**

This type of base oil is synthesized by chemical processed and is mainly used as base oil that requires specific properties i.e., high viscosity index, low pour point and low volatility. The favorable synthesized base oils are polyglycol, polyalphaolefin (PAO), halogenated hydrocarbon, polyglycol, etc.

## **2.2 Synthetic Base oil**

Synthetic lubricants have been used for many years but they were not commercialized due to the inherent cost of the new synthetic base fluids. In general, the improved properties of lubricant, achieve with the early synthetic base stocks, could be obtained more cost effectively by improved formulation based on mineral oil. However, the requirement for lubricants has simulated the continuing development of synthetic lubricant technology.

### **2.2.1 Performance requirement or operation environment**

This is the most common factor in the selection of a synthetic lubricant over a non-synthetic. There are synthetic-based lubricants which have unique properties that make them the lubricant of choice over non-synthetics. For example, viscosity versus temperature properties, oxidation stability, etc. other synthetic fluids still exhibit improved stability at elevated temperatures resulting in longer life lubricants requiring less maintenance in equipment using them.

### **2.2.2 Lubricant availability**

The reduced availability of high quality, specialty grade mineral oil base stocks has led to the development of synthetic base stocks with similar chemical composition and behavior as mineral oil for incorporation into

lubricants for existing or future applications. The reason for reduced availability of these quality non-synthetic base fluids has led to the development of a number of synthetic-based lubricants.

### **2.2.3 Safety**

The most often used factor involved in the selection of synthetic lubricants is probable the aspect of enhanced fire resistance, resulting in improved safety. A number of synthetic lubricant development programs have addressed this issue and a variety of fire-resistant and/or nonflammable synthetic-base lubricants/hydraulic fluids have been developed. This is an area of increasing importance.

### **2.2.4 Cost**

This is usually the last often used factor in selecting a synthetic lubricant over a non-synthetic. The exception to this is generally when a high quality, limited volume non-synthetic base fluid is required and either the need for special processing of a high degree of segregation of crude oil results in a very high price for non-synthetic base oil. It is necessary to bring in factors like longer lubricant life, reduced maintenance costs, etc.

## **2.3 Selection of synthetic base oil**

Many compounds have been investigated as possible base stocks for synthetic lubricants. The major types are polyalphaolefins, alkylate aromatics, polybutenes, aliphatic diesters, polyolester, polyalkyleneglycols and phosphate ester. Other materials such as silicones, borate esters, perfluoroethers and polyphenylene ethers are also of importance, but their applications are restricted due either to high cost or to performance limitation. Some of the primary applications for synthetic lubricants are listed in Table 2.1.

The primary performance advantage of synthetic lubricants is the extended range of service temperatures. Their outstanding flow characteristics

at extremely low temperatures and their stability at extremely high temperatures mark the preferred use of these lubricants. The comparisons of some important physical and chemical properties of the most important synthetic lubricating base oil are shown in Table 2.2

**Table 2.1** The primary applications for synthetic lubricants (George, 1980)

Field of service	Synthetic lubricants
<b><u>Industrial</u></b> Circulating oils Gear lubricants Hydraulic fluids(fire resistant) Compressor oils Gas turbine oils Greases	Polyglycol, SHF, Synthetic ester Polyglycol, SHF Phosphate ester, Polyglycol Polyglycol, Synthetic ester, SHF SHF, Synthetic ester SHF
<b><u>Automotive</u></b> Passenger car engine oils Commercial engine oils Gear lubricant Brake fluids	SHF, Synthetic ester SHF, Synthetic ester SHF Polyglycol
<b><u>Aviation</u></b> Gas turbine oils Hydraulic fluids greases	Synthetic ester Phosphate ester, Silicones, SHF Silicones, Synthetic ester, SHF

SHF: Synthesized Hydrocarbon Fluids such as polyalpholefins, alkylated aromatics and polybutenes



Table 2.2 Properties of synthetic base fluids compared to mineral oil (Leslie et al., 1999)

Properties	Types of lubricating base oil							
	Mineral oil	Poly i-butenes	Poly-alpha olefin	Alkylated aromatics	Polyalkylene glycols	Dicarboxylic acid esters	Polyol esters	Phosphate esters
Viscosity Index	F	P	VG	F	VG	VG	VG	G
Pour Point	P	F	E	G	G	E	VG	G
Liquid range	F	P	VG	G	G	VG	VG	VG
Oxidation stability	F	F	VG	F	G	VG	VG	G
Thermal stability	F	F	F	F	G	G	VG	VG
Volatility	F	F	VG	G	G	E	E	VG
Flash temperature	P	P	P	P	F	F	F	VG
Hydrolytic stability	E	E	E	E	G	F	F	G
Corrosion protection	E	E	E	E	G	F	F	F
Miscibility with mineral oils	-	E	E	E	P	VG	VG	F
Solubility of additive	E	E	VG	E	F	VG	VG	E
Toxicity	G	E	E	P	G	G	G	F
Biodegradability	F	P	P	P	VG	E	E	VG

\*Letter signifies performance level: P = Poor, F= Fair, G= Good, VG= Very Good and E= Excellent

**Table 2.3** The properties of synthetic esters lubricating base oil (Leslie et al., 1999)

Properties	Diester	Phthalates	Trimellititates	C <sub>36</sub> dimer ester	Polyols	Polyoleates
Kinetatic viscosity, cSt at 40°C at 100°C	6 to 46	29 to 94	47 to 366	13 to 20	14 to 35	8 to 95
	2 to 8	4 to 9	7 to 22	90 to 185	3 to 6	10 to 15
Viscosity Index	90 to 170	40 to 90	60 to 120	120 to 150	120 to 130	130 to 180
Pour point, °C	-70 to -40	-50 to -30	-55 to -25	-50 to -15	-60 to -9	-40 to -5
Flash point, °C	200 to 260	200 to 270	270 to 300	240 to 310	250 to 310	220 to 280
Thermal stability	Good	Very good	Very good	Very good	Excellent	Fair
Conradson carbon	0.01 to 0.06	0.1 to 0.03	0.01 to 0.40	0.20 to 0.70	0.01 to 0.10	-
% Biodegradability	75 to 100	46 to 88	0 to 69	18 to 78	90 to 100	80 to 100
Costs(PAO=1)	0.9 to 2.5	0.5 to 1.0	1.5 to 2.0	1.2 to 2.8	2.0 to 2.5	0.6 to 1.5

## **2.4 Synthetic ester lubricating base oil**

In the past, the main lubricating base oil were natural ester contained in animal fat or vegetable oil, but due to the reason of low stability and easy to decompose during use. Esters of long chain alcohols and acids were proved to be excellent for low temperature lubricating base oil. The ester is an organic, oxygen-containing material resulting from the reaction of an alcohol and an organic acid. Selected esters for lubrication application have excellent physical properties such as low volatility, low pour point and good low temperature fluidity. They also excel in certain chemical characteristics, such as oxidative and thermal stability. Esters are now uses in many applications including automotive and marine engine oil, compressor oil, hydraulic fluids, rear oil and grease. The inherent biodegradability of ester molecules offers added benefits to those of performance.

The major types of esters with their feedstock and physical property of these esters are reviewed in Table 2.2

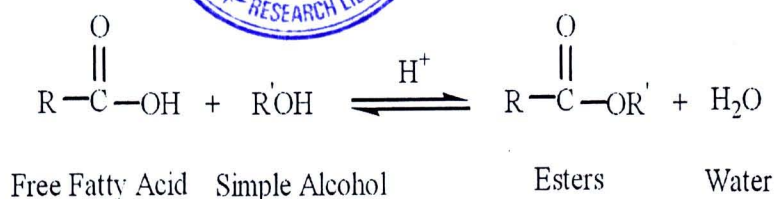
## **2.5 Production of esters**

The manufacturing process of esters consists of two processes which are (a) esterification and (b) transesterification

### **2.5.1 Esterification**

The formations of esters occur through a condensation reaction known as esterification. The esterification requires two reactants, carboxylic acids (fatty acids) and alcohols. Esterification reactions are acid catalyzed and proceed slowly in the absence of strong acids such as sulfuric acid, phosphoric acid, sulfonic acid and hydrochloric acid. The equation of esterification reaction is shown in Equation 2.1.

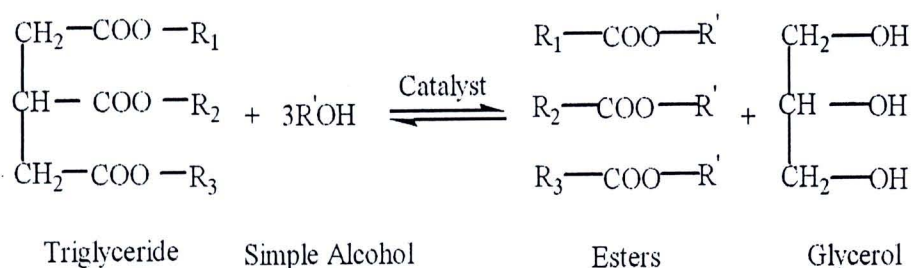




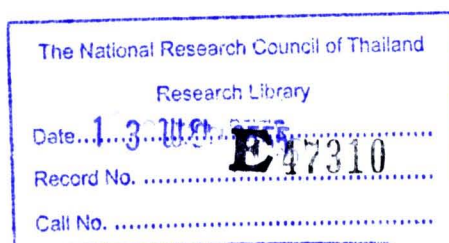
**Equation 2.1** Esterification of carboxylic acid with an alcohol

### 2.5.2 Transesterification

Transesterification is the reaction of triglyceride with an alcohol in the presence of catalyst (such as acid, base and enzyme) to producing a mixture of fatty acids alkyl ester and glycerol. The reaction of transesterification is shown in Equation 2.2.



**Equation 2.2** Transesterification of triglyceride with an alcohol



## **2.6 Palm fatty acid distillate (PFAD)**

Palm fatty acid distillate (PFAD) is one of products from palm oil, which was obtained from refinery process of crude palm oil. It is light brown solid in room temperature, can be melted into liquid phase at 43 °C. The components of palm fatty acid distillate (PFAD) are palmitic acid, oleic acid, stearic acid and lenoleic acid.

## **2.7 The principle properties of lubricating base oil**

The most commonly testing for physical and chemical properties of lubricating base oil are outlined in the following sections, with brief explanations of the significance of the test from the standard point of the refiner and consumer. For detailed information on the methods of test, the reader are referred to the American Society for Testing and Materials handbooks of “Annual Standard for Petroleum Products and Lubricants”, The British Institute of Petroleum handbook “Standard Methods for Testing Petroleum and its Products”, The United States Federal Test Method Standard No. 791 and similar types of publications used in a number of other countries.

There are multitudes of physical and chemical properties test which yield useful information on the characteristics of lubricating base oil. However, the quality of the performance features of lubricating base oil cannot be adequately described on the base of physical and chemical properties test alone. Thus, major consumers of lubricating base oil, such as military purchasing agencies and many commercial consumers, include performance test as well as physical and chemical properties tests in their purchase specifications. Physical and chemical properties tests are considerable value in maintaining uniformity of products during manufacture. Also, they may be applied to a used oil to

determine changes that have occurred in service and to indicate possible causes for those changes.

### **2.7.1 Physical properties**

#### **2.7.1.1 Specific Gravity, ASTM D1298**

Specific gravity is defined as the ratio of the mass of a volume of substance to the mass of the same volume of water. As it ratio there are no units. It is dependent on the temperature of both the substance and water. The standard temperatures for specific gravity are 15.6°/15.6°C (60°/60°F). In the petroleum industry, the API gravity scale is almost universally used as the measure of the density of a petroleum product. API gravity is an arbitrary scale, calibrated in degrees and related to the specific gravity by

$$\text{API gravity} = \frac{141.5}{\text{Sp.Gr.15.6°/15.6°C}} - 131.5$$

The API gravity value increases as the specific gravity decrease. Since both density and gravity change with temperature, determinations are made at a controlled temperature and then corrected to the standard temperature by using specific table.

#### **2.7.1.2 Viscosity, ASTM D445**

Viscosity is the most significant property of lubricating oil. To meet a particular application, viscosity is generally the most important controlled the properties for manufacture and selection. Viscosity is an index for measuring of internal resistance to the motion of the fluid by reason of the cohesion force between molecules. It decreases with increasing temperature and increase considerably with large increasing pressure. The extent of the



viscosity change depends upon the crude oil source and molecular weight of the constitute components.

Kinematic viscosity is the more common and measured by timing the flow rate of the fixed amount of oil through a capillary tube under gravitational force at a standard temperature. The test temperatures are usually at 40 and 100°C. The unit of viscosity used in conjunction with this method is the centistokes (cSt, mm<sup>2</sup>/s). This unit may be converted to the other viscosity systems (Saybolt, Redwood, Engler) by using a suitable table.

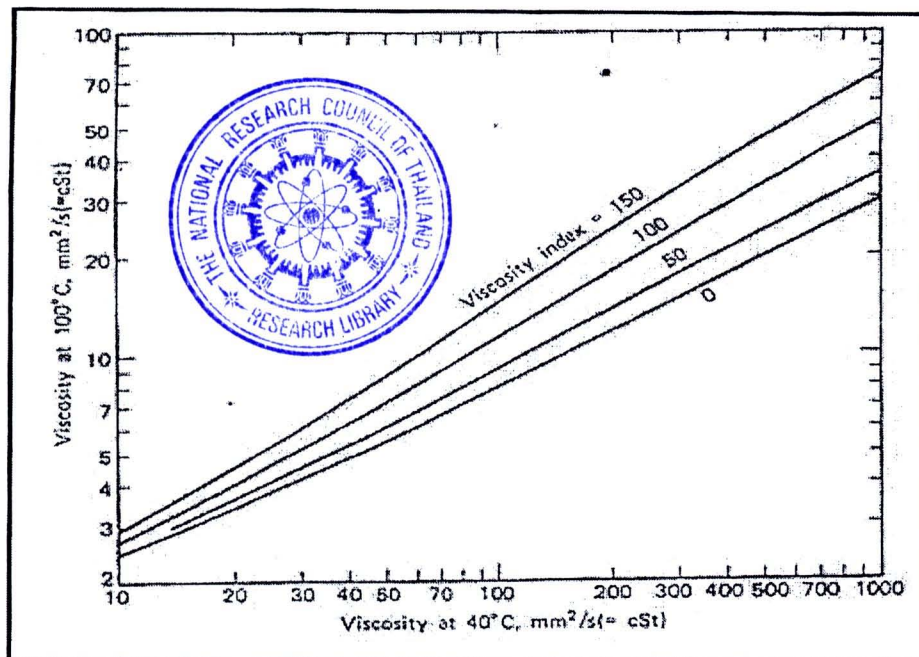
The main objective of lubrication is to provide a film between load-bearing surfaces, the selection of the correct viscosity for the oil is aimed at the balance between a viscosity high enough to prevent the lubricated surfaces from contacting and low enough to minimize energy losses caused by having too viscous a lubricant.

#### **2.7.1.3 Viscosity Index, ASTM D2270**

The viscosity index (VI) is a method of applying a numerical value to this rate of change, based on comparison with the relative rates of change of two arbitrarily selected types of lubricating base oils that differ widely in this characteristic. When the temperature increases, all lubricating oil film “thin out” or have lower viscosity. Likewise, oils become thicker or more viscous as the temperature decreases. Oil having a higher VI is less sensitive to temperature than does the oil with the lower VI. The VI of oil is calculated from viscosities determined at two temperatures by means of tables published by ASTM. Tables based on viscosities determined at both 40°C (100°F) and 100°C (212°F), are available as shown in Appendix E.

The lubricating base oils are made by conventional methods range in VI from somewhat below 0 to slightly above 100. Some synthetic lubricating base oils have VI both below and over this range. Therefore, the additives called Viscosity Index Improvers can be blended into lubricating base

oils to adjusted VI well above 100. The relationship of kinematic viscosity at 40 and 100 °C are show in figure 2.2.



**Figure 2.2** Relationship of kinematic viscosity at 40 and 100 °C (George, 1980)

#### 2.7.1.4 Pour point, ASTM D97

The pour point of lubricating oils is the lowest temperature at which it will pour or flow when it is chilled without disturbance under prescribed conditions. Definition of pour point from ASTM is the temperature at which a measured volume of fluid does not flow for 5 seconds when tilted horizontally. Most oil contains some dissolved wax and, as oil is chilled, this wax begins to separate as crystals that interlock to form a rigid structure which traps the oil in small pockets in the structure. When this wax crystal structure become sufficiently complete, the oil will no longer flow under the condition of test. The pour point of the oil will just flow under specified test conditions and is roughly equivalent to the tendency of oil to cease flowing from a gravity-fed

system or container. Since the size and shape of the containers, the head of oil, and the physical structure of the solidified oil all influence the tendency of the oil to flow, the pour point of the oil is not an exact measure of the temperature at which flow ceases under the service condition of a specific system.

From the consumer's viewpoint, the importance of the pour point is limited to applications where low temperature is likely to influence oil flow. For example, the pour point of winter grade engine oil must be low enough so that oil can be dispensed readily, and will flow to the pump suction in the engine at the lowest anticipated ambient temperatures.

#### **2.7.1.5 Flash point, ASTM D92**

The flash point of lubricating oil is the temperature at which the lubricating oil releases enough vapor at its surface to ignite when an open flame is applied. For example, if lubricating base oils are heated in a closed container; ignitable vapors are released in increasing quantities as the temperature rises. When the concentration of vapors at the surface becomes great enough, exposure to an open flame will result in a brief flash as the vapors ignite. When a test of this type is conducted under certain specified conditions, as in the Pensky-Martens Closed Cup (PMCC) method, the bulk oil temperature at which this happens is reported as the flash point. The releases of vapors at this temperature are not sufficiently rapid to sustain combustion, so that flame immediately dies out. However, if heating is continued, a temperature will be reached at which vapors are released rapidly enough to support combustion. This temperature is called the fire point. For any specific product, both flash and fire point will vary depending on the apparatus and the heating rate.

Flash and fire tests are of value to refiners for control purposes and significant to consumers under certain circumstances for safety consideration. Also, in certain high temperature applications, use of oils with a



low flash point, indicating higher volatility, may result in higher oil consumption rates.

#### **2.7.1.6 Color, ASTM D1500**

The color of lubricating oil as observed by light transmitted through them varies from practically clear or transparent to opaque or black. Usually, the various methods of measuring color are based on a visual comparison of the amount of light transmitted through a specified depth of oil with the amount of light transmitted through one of a series of colored glasses. The color is then given as a number corresponding to the number of the colored glass. In finished, the color of lubricating oil has little significance except in the case of medicinal and industrial white oil, which are often compounded into or applied to products where staining or discoloration would be undesirable.

#### **2.7.1.7 Four-ball test, ASTM 2266**

The four ball test is used to test the Wear Preventive (WP) and Extreme Pressure (EP) characteristics of lubricating oils in sliding steel-on-steel applications. The point contact interface is obtained by rotating a 12.7 mm diameter steel ball under load against three stationary steel balls immersed in the lubricant. The normal load, frictional force, and temperature can be monitored using trop. The rotating speed, normal load, and temperature can be adjusted in accordance with published ASTM and IP test standards. For evaluating the Wear Preventive characteristics of lubricants, the subsequent wear scar diameters on the balls can be measured using a graduated-scale microscope. The wear scar can also be captured using an optional digital camera and measured using our Wear Scar Analysis Software. For evaluating the Extreme-Pressure (load-carrying) capacity of lubricants, the normal load at which welding occurs at the contact interface can be recorded.

## **2.7.2 Chemical properties**

### **2.7.2.1 Copper Strip Corrosion, ASTM D130**

The copper strip corrosion test was measured to study the relative degree of corrosives of a sample according to ASTM D130. A polish copper strip is immersed in a given quantity of sample and heated at a temperature and for a time characteristic of the material being tested. At the end of this period the copper strip is removed, washed and compared with the ASTM Copper Strip Corrosion Standards.

## **2.8 Literature reviews**

Phattanaphakdee (1995) produced synthetic ester lubricating base oil from palm oil. Palm oil was transesterification reaction with an alcohol such as 1-butanol, 1-hexanol, cyclohexanol and 2-ethyl-1-hexanol by using sulfuric acid as a catalyst. The ester product was then hydrogenated using 3% wt. of platinum supported on alumina as a catalyst. The synthetic ester had physical properties in the range that can be used as lubricating base oil. The synthetic 1-butyl ester was obtained from transesterification reaction with 1-butanol and after hydrogenation was blended with petroleum lubricating base oil 150 SN. The viscosity index of the blended oil was increased from 103.86 to 130.12 when it contained the hydrogenated 1-butyl ester 24% wt. This result indicated that the synthetic ester obtained from the hydrogenation can be used as viscosity index improve.

Tungwongcharoen (1995) produced synthetic ester lubricating base oil from castor oil via transesterification reaction with 2-ethyl-1-hexanol at 80 °C for 3 hours by using sulfuric acid as a catalyst and then hydrogenation. The catalyst for hydrogenation contained 3% wt. of platinum supported on alumina. The optimum operating condition included 4% catalyst concentration by weight of oil at 100 °C under hydrogen pressure of 100 psi for 3 hours. The

monoester product was expected that synthetic ester could be used as lubricating base oil because its high viscosity index, low pour point and good thermal and oxidation stability.

Suwanprasert (1996) produced synthetic ester lubricating base oil from soybean oil via transesterification reaction with an alcohol such as isopropanol, 1-butanol, 1-hexanol, 4-methyl-2-pentanol and 2-ethyl-1-hexanol at the reaction temperature of 80 °C for 3 hours by using sulfuric acid as a catalyst. Then each monoester product was subjected in hydrogenation process under hydrogen gas pressure of 150 psi and reaction temperature of 150 °C for 3 hours by using 1% platinum supported on alumina as a catalyst. The hydrogenated 2-ethyl-1-hexyl ester had tendency to use as synthetic lubricant such as hydraulic lubricant in industries because it has good physical and chemical properties. Furthermore, each monoester was blended with petroleum lubricating base oil 150 SN to give higher viscosity index than pure petroleum lubricating base oil. This result was shown that it could also be used as viscosity index improver in lubricating industry.

Tubthim (1996) ) produced synthetic diester lubricating base oil via esterification reaction of palm oil and its free fatty acids such as oleic acid, stearic acid and palmitic acid with 1,3-propanediol, 1,5-pentanediol, 2,2-dimethyl-1,3-propanediol, 1,4-butanediol and 2-ethyl-1,3-hexanediol by using sulfuric acid as a catalyst. The product from these reactions had 2 phases, i.e., a liquid phase and solid phase. Due to inability to determine the physical properties (e.g., kinematic viscosity and pour point) of the solid phase, they were deemed to be unsuitable as automotive lubricants. Each products from transesterification and esterification reaction with 2-ethyl-1,3-hexanediol was liquid phase and had good physical and chemical properties. These results indicate that the synthetic diesters obtained from transesterification reaction of palm oil and esterification reaction of its free fatty acids with 2-ethyl-1,3-hexanediol are suitable to used as automotive lubricating base oil.



Vatanaputi (1996) produced synthetic ester lubricating base oil from coconut oil via transesterification reaction with an alcohol such as 1-hexanol, cyclohexanol, 1-octanol and 2-ethyl-1-hexanol by using sulfuric acid as a catalyst and hydrogenation. The transesterification reaction of coconut oil with cyclohexanol was carried out at 90°C for 3 hours. The cyclohexanyl ester was potential used as a lubricating base oil with possesses its high viscosity index, low pour point and good thermal and oxidation stability.

Thomas et al. (1997) studied low-temperature properties of alkyl esters of tallow. In this work, researcher study about pour point of alkyl esters from tallow which alkyl esters used in this study included methyl, ethyl, propyl, butyl, isopropyl and 2-butyl esters. The report shows that pour point of alkyl esters decrease from 15 °C to 6 °C when chain length of alcohol increase from methanol, ethanol, propanol and butanol, respectively. This is understandable because, with in increasing chain length in the alcohol portion of saturated fatty acid esters, there is a concomitant decrease in their crystallization temperature. The formation of solid particles will also hinder the smooth flow of the alkyl esters molecules. Branching in the alcohol moiety of esters helps to augment this affect. The pour point of the isopropyl ester is lower than propyl ester and 2-butyl ester is lower than butyl ester.

Eiamsupasawat (1999) produced synthetic ester lubricating base oil from rice bran oil via transesterification reaction with an alcohol such as 1-butanol, 1-hexanol, 1-octanol, 2-ethyl-1-hexanol and 4-methyl-2-pentanol by using sulfuric acid as a catalyst. This reaction was carried out at the boiling point of the mixture, for 2, 3 and 4 hours. The 2-ethyl-1-hexyl ester was the monoester, which had good physical and chemical properties due to high viscosity index, good oxidation stability and a low pour point. With these properties, it could be used as lubricating base oil. Furthermore, when the small amount of 2-ethyl-1-hexyl ester was blended with petroleum lubricating base oil 150 SN, the viscosity index of the blended oil was increased when

compared with petroleum lubricating base oil. This result was shown that it could also be used as viscosity index improver in lubricating industry.

Panchoowong (1999) produced synthetic diester lubricating agent were prepared by esterification reaction of fatty acid such as lauric acid, myristic acid, palmitic acid and stearic acid with 1,2-ethanediol and 1,2-propanediol using sulfuric acid as a catalyst. Most of diester products were solid expect diester lauric acid with 1,2-propanediol. The solid products were wax-like nature and had good chemical and physical properties, i.e., high flash point and good thermal and oxidation stabilities. These types of diester could be possible to use in various industrial applications, for example, as emulsifier, antifoaming agent and friction modifier in processing polymer, cosmetic, pharmacy and lubricating technology.

Lee et al. (2000) studied about reason of the reducing of the tendency of alkyl esters to crystallize at low temperatures, branched-chain alcohols were used to esterify various fat and oil, and the crystallization properties of branched ester were compared with those of methyl esters by using differential scanning calorimetry (DSC), cloud point and pour point. Compared with the methyl esters, branched-chain esters greatly reduced the crystallization of neat esters and their corresponding methyl ester blends.

Lang et al. (2001) produced methyl esters, ethyl esters, isopropyl esters and 1-butyl esters from canola and linseed oil through transesterification reaction by using potassium hydroxide and/or sodium alkoxide as catalysts. In addition, methyl esters and ethyl esters were prepared from rapeseed and sunflower oil by using the same catalysts. The bio-alkyl esters were characterized for their physical and chemical properties including density, kinematic viscosity, iodine value, acid value, cloud point, pour point, gross heat of combustion and volatility. Methyl ester and ethyl ester prepared from a particular vegetable oil had similar viscosities, cloud point and pour point,



whereas methyl ester, ethyl ester, isopropyl ester and 1-butyl ester derived from a particular vegetable oil had similar gross heating values.

Glyglewicz et al. (2003) studied of the possibility of using some nature fats such as rapeseed oil, olive oil and lard as starting material for the preparation of neopentyl glycol (NPG) and trimethyl propane (TMP) esters is reported. The syntheses of final products were performed by transesterification reaction fatty acid methyl esters, obtained from nature fat with the appropriate polyhydric alcohol using calcium methoxide as a catalyst. The basic physicochemical properties of the NPG and TMP esters synthesized were the following: kinematic viscosity, pour point and viscosity index. Generally, the esters of NPG and TMP were characterized by higher stability in thermo-oxidative conditions in comparison to native triglycerides.

Dörmö et al. (2004) produced bio-lubricant via esterification reaction of fusel oil with oleic acid, where immobilized Novozym 435 lipase enzyme was used as a biocatalyst. The oleochemical ester produced does not have aquatic toxicity and the determined tribological, physic-chemical properties of the lubricant proved that it is an environmental friendly product.

Choo et al. (2005) produced methyl ester and ethyl ester of crude palm oil and crude palm stearin via transesterification reaction and subsequently evaluated for their properties such as kinematic viscosity, density, sulfur content, pour point, cloud point, distillation, gross heat of combustion and flash point.

Hong et al. (2005) produced synthetic lubricating base oil from epoxidized soybean oil via transesterification reaction with guerbet alcohol such as C12, C14, C16 and C18-guerbet alcohol by using sulfuric acid as a catalyst. The alkyl esters were characterized for their physical and chemical properties including pour point, oxidative stability and kinematic viscosity compared with



mineral base oil and synthetic oil such as polyalphaolefins, diisdodecyl adipate.

Glyglewicz et al. (2005) produced dibasic acid ester with varied chemical structure. These include didecyl carbonate, didecyl adipate and didecyl sebacate as well as modern oligomeric esters of adipic acid and sebacic acid. These esters were tested in term of their suitability as additives of fully synthetic engine oil. It was noted that an addition 10% of the respective esters to oil based on polyalphaolefins led to an improvement of their properties. The pour point of the oil as well as their low temperature viscosity was reduced. The viscosity index rose and oil lubricity improved. Esters of oligomeric structures synthesized by the transesterification reaction of dimethyl adipate or dimethyl sebacate with a mixture of neopentyl glycol and decanol shown particularly suitable properties. The tested esters were compatible with the other oil components, forming a stable solution in a wide temperature range.

Csilla et al. (2006) produced Conjugated linoleic acid esters (CLA esters) via esterification reaction of CLA with C<sub>6</sub>-C<sub>22</sub> alcohols which Novozym 435 lipase enzyme was used as a biocatalyst. Reactions were carried out at equimolar amounts of starting materials with 8.9% Novozym 435 (w/w<sub>CLA</sub>) at 65°C in vacuum (20 mbar) for 1.5 hrs. They found that at room temperature, CLA esters with long chain ( $\geq 18^\circ\text{C}$ ) saturated alcohols are solids which CLA-octadecyl ester is semi-solid (mp. 25-27°C), whereas CLA-C20 and CLA-C22 alkyl esters are real solids at room temperature (mp.'s are 34°C and 40°C, respectively).

Garhard et al. (2007) studied kinematic viscosity of biodiesel components (fatty acid alkyl esters) at low temperatures. This work reports on the kinematic viscosity of biodiesel and variety of fatty acid alkyl esters at temperatures from 40 °C down to -10 °C. Alkyl esters tested included ethyl, propyl and butyl esters of lauric, oleic, linoleic and linolenic acids. The report shows that trend of the kinematic viscosity increase when temperature decrease

from 40 °C to -10 °C but the kinematic viscosity increase when molecular weight of alcohol increase from ethanol, propanol and butanol, respectively. Esters of oleic acid have the highest viscosity of all biodiesel components that are liquids at low temperatures.

Kanyaprasarnkit (2007) produced synthetic ester lubricating base oil from palm stearin via transesterification reaction with an alcohol such as 1-propanol, isopropanol, 1-butanol, 1-hexanol, 1-octanol and 2-ethyl-1-hexanol by using sulfuric acid as a catalyst. The reactions are carried out with 100% excess alcohol from its stoichiometric ratio, sulfuric acid was used 3% by weight of palm stearin. The reaction temperature for each sample depends on the types and boiling point of alcohol are 97, 82, 117, 130, 130 and 130°C, respectively. The retention time is 3 hours per step until the reaction completed. These results indicate that the types of alcohol affect on physical and chemical properties of alkyl esters which the kinematic viscosity at 40 and 100°C, flash point are increased when molecular weight of straight-chain alcohol (1-propanol, 1-butanol and 1-octanol) increase, but pour point and API gravity are decreased when molecular weight of straight-chain alcohol increase. The kinematic viscosity at 40 and 100°C are increased when molecular structure change from straight-chain alcohol to branched-chain alcohol, but viscosity index, flash point, pour point and API gravity are decreased.