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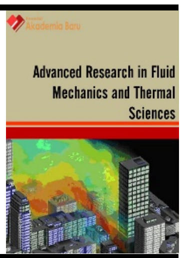

A Comprehensive Review on Palm Oil and the Challenges using Vegetable Oil as Lubricant Base-Stock

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ABSTRACT

Many researchers have discovered that palm oil and most of the vegetable oils have a potential to be the main sources for environmentally favourable lubricant, due to its properties that showed excellent lubrication performance, biodegradability and also renewability. Poor low-temperature behaviour, low oxidation and thermal stability, and narrow range of available stabilities will create a boundaries of bio-lubricant to be apply as a good lubricant. Bio-lubricant can be used in many types of applications such as automotive transmission fluids, metal working fluids, cold rolling oils, fire resistant hydraulic fluids, industrial gear oils, neat cutting oils and automotive gear lubricants. This review will address the challenge of using vegetable oil as a lubricant base-stock and also the palm oil as a potential lubricant. There are many advantages and disadvantages using vegetable oil as a lubricant that will be discussed in this paper. The aim of this paper also to study the past, current and future of vegetable oil and the use of palm oil as a lubricant.

Keywords:
Vegetable oil, Palm oil, Renewable Energy

1. Introduction

The depleting trend of conventional, non-renewable, fossil- based fuel has triggered research and development of alternative renewable energy. Vegetable based oil product is one of the most promising renewable energy in this century [1]. Vegetable oils are superior than in terms of biodegradability, especially when compared to mineral oils. Attention has been focused on technologies that incorporate vegetable oils as biofuels and industrial lubricants [2]. Nowadays there is a growing interest in the use of vegetable oil as a lubricant in industry [3]. The chemical composition of the natural fats and oils and their specific properties have allowed them to be used in production of foods, fuels and lubricants [4]. In the development of sustainable green chemistry, renewable raw material are going to play a very important part. Usually vegetable oil has some properties that are rarely to be met in petrochemistry with a large number of possibilities [5]. In

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addition, vegetable oil based lubricant clearly show the possibility to minimize carbon monoxide also hydrocarbon emissions when used in IC engines [6].

Campanella *et al*. [7] stated that the increase over the usage of the petroleum-based products caused by the progressive depletion of the world reserves of fossil fuels and also owing to concerns on their environmental impact. Many researchers such as Erhan *et al*. [8] and Zulkifli *et al*. [9] agreed that most of the current lubricants which contain petroleum base stocks are difficult to dispose after use and also toxic towards the environment. Environmental concerns continues to increase due to the pollution exerted by the excessive lubricant use and disposal, especially total loss lubricant.

2. Scope of the paper

There is no argument on the performance of vegetable oil as lubricant. It had also been proven that vegetable oil has good performance in term of lubrication and has potential to reduce the dependency on mineral based oil lubricants.

The scope of this paper is to study the palm oil production, composition of the palm oil, previous research of the palm oil as a lubricant or biofuel and also to study the challenge of using vegetable oil as a lubricant or biodiesel.

2.1 Background
2.1.1 Vegetable oil as a lubricant

The lubricating property of fuel is defined as the quality that prevents wear when two moving metal parts come into contact with each other [10]. Using vegetable oil as lubricant is not a new application. In recent decade, many kinds of vegetable oil such as palm oil, sunflower oil, soy bean oil and castor oil have been investigated and the results show that vegetable oils have potential to be used as an alternative source to replace mineral oil in large branches [11, 12]. Vegetable oils are not pure organic compounds with sharp melting point but mixtures, so that at any given temperature the sample may be wholly solid, wholly liquid, or frequently a mixture of solid and liquid [13].

Table 1
Typical properties of conventional transformer oil and vegetable oils [14]

Properties	**Conventional mineral transformer oil**	**Vegetable oil with saturated fatty acid ≥ 80%**	**Vegetable oil with unsaturated fatty acid ≥80%**
Viscosity (cSt) at 40°C	13	29	37.6
Density (kg/m^3) at 20°C	895	917	886
Pour point (°C)	-40	20	-22
Flash point (°C)	154	225	260
Oxidation onset temp (°C)	207	282	192
Conductivity (S/m) at 20(°C)	13^{-13}	10^{-11}	10^{-10}
Breakdown strength (kv)	45	60	56

Erhan and friends [15] have stated that the vegetable oils with high oleic content are considered to be potential candidates as substitutes for conventional mineral oil-based lubricating oils and synthetic esters. Vegetable oils are tri-esters of straight-chained, mostly unsaturated fatty acids with glycerol. Besides that Salimon and his co-worker found that vegetable oils have different unique properties compared to mineral oils, due to their unique chemical structure, vegetable oils are composed mostly of triacylglycerol (98%) and contain different fatty acids attached to a single molecule of glycerol. Recently, numerous types of vegetable oil being used in the industry such as palm oil, soybean, sunflower and rapeseed oil [16].

Vegetable oils are particularly effective as boundary lubricants as the high polarity of the entire base oil allows strong interactions with the lubricated surfaces. Boundary lubrication performance is affected by the attraction of the lubricant molecules to the surface and also by possible reaction with the surface [17].

2.2 Advantage of vegetable oils

According to Jabal and friends [18,19], the advantages of choosing vegetable oils rather than lubricants from other sources are the fact that they are biodegradable and less toxic when compared to petroleum-based oil and they are easy to produce and form a renewable source.

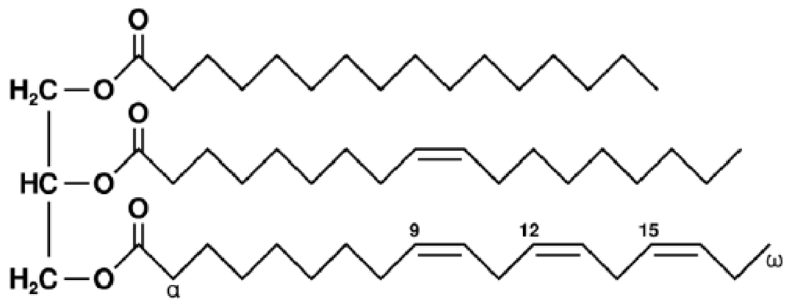

Fig. 1. 3-D representation of a triglyceride molecule [20].

Other advantages include very low volatility due to high molecular weight of the triglyceride molecule as shown in Figure 1. Their polar ester groups are able to adhere to metal surfaces, and therefore, possess good lubricity [7, 8]. A lot of lubricants are used in applications where fire or explosions are a possibility and vegetable oils can perform well in these environments because they have high flash and fire points [21]. Zulkifli and friends state that the vegetable oil has a high viscosity index, which should be high enough to maintain the lubricating film thickness, and low enough to make sure the oil can flow through all the engine parts. Superior anti-corrosion properties also are observed in vegetable oils and are induced by a greater affinity for metal surfaces [4].

2.3 Disadvantage of vegetable oils

Vegetable oil have low thermal oxidative stabilities primarily due to the presence of bisallylic protons. These active sites are highly susceptible to radical attack and subsequently the molecules undergo oxidative degradation and form polar oxy compounds. This phenomena eventually results in insoluble deposits and increases in oil acidity and viscosity [8, 15]. Besides that, a high degree of multiple C–C unsaturation in the fatty acid (FA) chain of many vegetable oils causes poor thermal and oxidative stability and confines their use as lubricants to a modest range of temperature [22]. Wahid and friend address that vegetable oil also have low pour point where at low temperatures there is formation of solid wax crystal nuclei. Wax constituents tend to separate from the liquid phase of the oil and start to crystalline when vegetable oil is below its wax appearance temperature [23, 24].

3. Challenge of using vegetable oil

Vegetable oils have displayed excellent lubrication properties in laboratory investigations. Composition and selected properties of vegetable oils commonly investigated properties as potential lubricants. Without additives vegetable oils outperformed mineral base oils in term of anti-wear and friction reducing properties, scuffing load capacity and fatigue resistance. Fully formulated vegetable oil lubricants, in comparison to mineral oil counterparts, display a lower coefficient of friction, equivalent scuffing load capacity and better pitting resistance, but also poorer thermal and oxidative stability. At extreme loads, vegetable oil-based lubricants become significantly less effective [25]. In summary, vegetable oils display many desirable characteristics, which make them very attractive lubricants for many practical applications. However, the main weakness is their relatively poor oxidation stability and low temperature behaviour.

3.1 Oxidation stability

Vegetable oils are sensitive to temperature and will undergo oxidation rapidly. This also results in releasing the fatty acids from the triglyceride structure by hydrolysis reaction which is primarily catalyzed by the oxidation process. The oxidation process results in deteriorating the quality of the oil which in turn will have great influence on the product quality and shelf life of the vegetable oil based lubricants. Thus, understanding oil oxidation process will be very essential while formulating biodegradable lubricants [20, 26, 27].

Oxidation stability of triglyceride-based vegetable oils is primarily limited by the degree of unsaturated double bonds. Unsaturated carbon–carbon bonds function as active sites for many reactions, including oxidation [28]. A majority of triglyceride-based vegetable oils contain unsaturated fatty acids and are susceptible to oxidation. The greater the level of unsaturation, the more double bonds, the more susceptible the oil becomes to oxidation. The mechanism for the autoxidation of vegetable oils is well studied and a classical representation of the oil autoxidation mechanism is shown in Table 2 [29, 30].

Table 2
Classical representation of the oil autoxidation mechanism

Initiation	$RH \rightarrow R^{\cdot}+H^{\cdot}$
Propagation	$R^{\cdot}+O_2 \rightarrow ROO^{\cdot}$ $ROO^{\cdot}+RH \quad ROOH+R^{\cdot}$
Branching	$ROOH \rightarrow RO^{\cdot}+{}^{\cdot}OH$ $RO^{\cdot}+RH+O_2 \quad ROH+ROO^{\cdot}$ ${}^{\cdot}OH+RH+O_2 \quad H_2O+ROO^{\cdot}$
Termination	$ROO^{\cdot}+ROO^{\cdot} \rightarrow ROOH+O_2$ $ROO^{\cdot}+R^{\cdot} \rightarrow ROOH$ $R^{\cdot}+R^{\cdot} \quad R-R$
Peroxide decomposition	$ROOH \rightarrow$ various lower molecular weight compounds
Polymerisation	$ROOH \rightarrow$ various higher molecular weight compounds

Vegetable oil oxidation is initiated by the formation of free radicals. Free radicals can easily formed from the removal of a hydrogen atom from the methylene group next to a double bond. Free radicals rapidly react with oxygen to form a peroxy radical. The peroxy radical can then attack another lipid molecule to remove a hydrogen atom to form a hydroperoxide and another free radical, propagating the oxidation process [25].

The abstraction of a hydrogen atom by the peroxyl radical to generate a hydroperoxide is the rate-limiting step of vegetable oil autoxidation [30]. The rate constant for the rate-limiting step depends primarily on the strength of the carbon–hydrogen bond being broken. The strength of a carbon–hydrogen bond next to a carbon–carbon double bond is lowered and the hydrogen can be removed easily, thus those oils containing double bonds are more susceptible to autoxidation. As the number of double bonds increases, there become more sites susceptible to the abstraction of a hydrogen atom and the autoxidation process can occur at a faster rate. Vegetable oils containing a high percentage of monounsaturated fatty acids will typically auto-oxidise only at high temperatures, whereas those oils containing polyunsaturates, such as linoleic and linoleic acid, readily auto-oxidise at room temperatures [31].

Hydroperoxides, once formed, can break down to produce more free radicals. This branching step leads to the proliferation of radicals that can go back and aid in the propagation of more hydroperoxides. Not all free radicals, however, will propagate the oxidation process; some may react with and terminate each other. Hydroperoxides continue to build up in the oil via the propagation and branching steps. At some point the collection of hydroperoxides no longer remain stable and decompose into a myriad of volatile and non-volatile secondary oxidation compounds. They can also be involved in polymerization reactions, leading to deposits [25, 31, 32].

3.1 Impact of oxidation on lubrication properties

The impact of free fatty acids on the lubrication performance of vegetable oils has been the main subject for a number of studies previously [8, 20, 33]. Each study suggests a method that can improve the boundary lubrication properties of vegetable oils.

Castro and friend has done the research on the oxidative and wear performance of oils to better understand how the chemical composition of the base stock affects these properties [33]. The oxidative stability of the base oils can be evaluated by different techniques. In that study, the Penn State micro-oxidation test (PSMO), a thin-film test used extensively to study the oxidative stability of mineral and synthetic oils, was selected. The wear performance of the test fluids was evaluated using a sequential four-ball wear test (SFBT). The result obtain show that differences in the wear characteristics of these fluids. High oleic soybean oil (HOSO) showed the best anti-wear performance, and epoxidized soybean oil (ESO), which had the best oxidative stability, showed the poorest wear characteristics of the three base stocks studied.

A four-ball machine was used by Mannekote and Kailas [20] to examine the effect of oxidation on the tribological performances of a few vegetable oils. It was found that fatty acids has improved wear resistance and the improvement was related to chain length. This paper conclude that the low coefficient of friction with four ball test for oxidized oil samples is due to the formation of soft iron soap having low resistance to shear.

Erhan and friends [8] also has study the effect of antioxidant-antiwear additive (zinc diamyl dithiocarbamate (ZDDC)) mixture has a good performances as antioxidant in vegetable oil. ZDDC has been reported to function both as radical scavenger and hydroperoxide decomposer. It converts the hydroperoxides formed during the oxidation process to non-radical products, thus preventing chain propagation.

Table 3
Summary of vegetable oil oxidation compounds, analytical techniques and lubrication impact [25]

Stage	Compound	Analytical techniques	Lubrication impact
Primary	Hydroperoxide	• Titration • Chemiluminescence [34, 35] • Electron spin-resonance spectroscopy [35] • Infra-red Spectroscopy [36-39] • Combined techniques [34]	• Prowear effect [40-42]
Secondary	Volatile	• Gas chromatography [25] • Gas chromatography/mass spectrometry[43-45]	• Likely negligible
	Non-Volatile	• High-performance liquid chromatography/mass spectrometry[46] • Atmospheric pressure chemical ionization/mass spectrometry [47]	• Epoxides—high viscosity, high-oxidation stability, similar boundary lubrication [28, 54] • Majority of compounds uncertain
	High molecular weight	• Gel permeation high-performance liquid chromatography [48] • High-performance size-exclusion chromatography [49, 50]	• Increased viscosity • Uncertain impact on lubrication
	Free Fatty Acid	• Titration • Capillary gas chromatography • High-performance liquid chromatography [51] • Supercritical fluid chromatography [52] • Nuclear magnetic resonance spectroscopy [53]	• Improve boundary lubrication properties [40] • Lower oxidation stability [55]

3.2 Pour point

Low-temperature performance is one of the main drawbacks of using vegetable oils as lubricants [56, 57]. Thus cloudiness and solidification become apparent at low temperature upon long-term exposure to low temperature, causing poor flow properties [15]. The lowest temperature at which a lubricant can flow or handled without freezing in a machine element is often specified by the pour point, measured according to the ASTM D97 standard [58].

After preliminary heating, the sample is cooled at a specified rate and examined at intervals of 3°C for flow characteristics. The lowest temperature at which movement of the specimen is observed is recorded as the pour point [59].

According to Nainwal and co-workers [24] pour point is when the temperature is decreased, the crystal nuclei aggrandizes and thus prevent free pouring of fluid. Low-temperature behavior of triacylglycerols relates first of all to their crystallization kinetics. Major crystalline forms have been established for saturated triacylglycerols [58].

3.2.1 Low temperature behaviour of vegetable oil

Low-temperature behavior of triacylglycerols relates first of all to their crystallization kinetics. Major crystalline forms have been established for saturated triacylglycerols [58]. Ribeiro et al. has listed over a hundred reports on melting temperatures of mainly monoacid triacylglycerols [60]. However, crystalline form of unsaturated triacylglycerols have been established only for triacylglycerols with symmetrical distribution of monounsaturated fatty acids [61].

Crystallization kinetics generally are very sensitive to temperature fluctuations and related factors such as cooling rate or thermal history. As can be expected from nucleation theory and crystallization thermodynamics, presence of contaminants, foreign bodies, or other nucleation centers and even shaking may affect crystallization [62].

Mineral oil also have their wax properties that is called paraffin. Paraffin are mixtures of hydrocarbons constituted of linear or normal chains, comprising mainly from 20 to 40 carbon atoms, in addition to alkanes with branched and cyclic chains. Paraffin crystals grow as temperature decreases, creating a crystalline net, which begins to trap the molecules of liquid hydrocarbon until the oil cannot flow [63].

Thus, chemical products known as flow improvers, crystal modifier and pour point reducers need to be used to reduce the apparent viscosity, the flow limit and the pour point of oils. During production, these additives minimize problems related to the deposition of waxes in the production units [62].

3.2.2 Modification of the phase change properties of vegetable oil

Various author have done extensive work on improving the cold flow properties caused by the crystallization of the vegetable oil. Deliberate modification on the chemical structure of vegetable oils is an alternative to allow their direct use as lubricant base stocks [7, 64]. Hageman & Rothfus stated that the situation in vegetable oils is far more complex [65]. This is primarily due to the presence of different fatty acid moieties, their chain length, abundance, structural difference and configuration in the triacylglycerol that makes vegetable oils significantly different from other pure molecules [66]. All the said factors individually and collectively are capable of influencing the physical properties of vegetable oils.

Numerous methods have been assessed for improving the CFP of biodiesel [67] including winterizing [68], ozonization [69], addition of cold flow improvers [70] and modification of the fatty ester composition [71]. According to Perez and friends, winterization is the crystallization fractionation by reducing its saturated component [68]. Crystallization fractionation involves the separation of the components of lipids (vegetable oils, fats, fatty acids, fatty acid esters, monodiglycerides and other derivatives) based on differences in crystallization temperatures. In their research, they studied the effect of saturated methyl ester content and type on the cold flow properties of biodiesel. The result showed the decrease in the total content of saturated compounds leads to improved cold flow properties as they go from palm to soybean, sunflower and rapeseed. However, the total content of saturated compounds of peanut methyl esters is similar to the soybean biodiesel, whereas peanut biodiesel presents similar cold behavior to palm biodiesel.

Another method to improve pour point is by ozonation as proposed by Soriano and his coworkers [69]. In that work, the used of ozonized vegetable oils as pour point depressant for neat biodiesel derived from different vegetable oils was evaluated. The effect of ozonized vegetable oils on other fuel properties of the biodiesel such as density, viscosity, cloud point and flash point was also analyzed statistically. The result obtain stated that ozonized vegetable oils could significantly improve the pour point of biodiesel prepared from sunflower oil, soybean oil and rapeseed oil. Because almost 50% of fatty acid methyl ester components in palm oil biodiesel were saturated, treatment with ozonized vegetable oil to improve its pour point was ineffective.

The influence of three cold flow improvers, namely, olefin-estercopolymers (OECP), ethylene vinyl acetate copolymer (EACP) and polymethylacrylate (PMA), on the low- temperature properties and viscosity-temperature characteristics of a soy bean biodiesel was evaluated on a low-temperature flow tester and a rotatory rheometer by Boshuid and friends [70]. The results indicated that the ability of the cold flow improvers differed in improving the cold flow properties of soybean biodiesel, of which OECP was the best candidate. OECP can significantly reduce pour point (PP) and cold filter plugging point (CFPP) of biodiesel and retard viscosity increase of biodiesel at low temperatures when incorporated into biodiesel at the additive contents of 0.03%. On the other hand, OECP function by inhibiting the wax crystals from growing to a larger size and provide a barrier to crystal agglomeration at low temperatures, thus improving the cold flow properties of soybean biodiesel.

3.2.3 Wax crystal modifier

The crystal modifier are substances capable of building into wax crystals and alter the growth and surface characteristics of the crystals. One effect utilized in oil production is the reduced tendency of the crystals to stick to metal surfaces such as pipe walls. Besides, the crystal modifiers will have the effect of reducing the tendency to form a three-dimensional network, thereby lowering the pour point as well as the viscosity [72].

In order to synthesize a polymer that can perform as an agent to reduce the pour point, the following characteristics should be considered such as sufficient number of pendant alkyl groups, alkyl groups with sufficiently long chains, a convenient distance between the hydrocarbon pendant chain, a medium molar mass. In the case of a copolymer, a suitable ratio must be met between the comonomer, and a high stability of the additive [13, 73-77].

3.2.4 Impact of low temperature with wax crystal modifier

There are various type of wax crystal modifier had been used by all researchers [58, 67, 72, 76, 78-80]. Asadauskas and Erhan has investigate depression of pour point of vegetable oils by blending with diluent used for biodegradable lubricant [58]. Effects of dilution with major biodegradable fluids, namely poly-alphaolefin (PAO 2), diisodecyl adipate (DIDA), and oleates, as well as impact of pour point depressant (PPD), were investigated. From the research they find that dilution with oleates appeared less effective than dilution with PAO 2 and DIDA. Addition of 1% PPD (w/w) depressed pour points down to −33°C for canola and −24°C for high-oleic sunflower oils. However, neither higher amounts of PPD nor incorporation of diluent produced further depression. Depression of pour points was not proportional to the amount of diluent and ceased with further dilution. Low-temperature performance of vegetable oils limits their prospect as biodegradable lubricants, but well-balanced usage of PPD and diluents can deliver some improvements.

Smith and his friend also has study the improving the low-temperature properties of biodiesel [67]. In their journal, they stated many type of vegetable oils and additives that can be study in term of their method and consequences of additive to vegetable pour point. Pour point depressants were developed to improve pump ability of crude oil and do not affect nucleation habit. They are typically composed of low molecular weight copolymers which similar in structure to aliphatic alkane molecules, the most widely applied group being copolymers of ethylene vinyl ester. Wax crystalline modifiers, as the name suggests, are copolymers that disrupt part of the crystallisation process to produce a larger number of smaller, more compact wax crystals [81].

The low-temperature behaviour of a variety of vegetable oil basestocks for lubricating applications, as well as their blends with some viscosity improvers and pour point additives, was studied by Quinchia and coworkers through pour point determinations, thermal analysis (DSC) and viscosity measurements at low temperature [15]. The concentration of polyunsaturated fatty acids (PUFAs) was found a predominant parameter influencing the low-temperature properties of vegetable oil-based lubricants. The pour point depressant (PPD) additives used had a positive influence by lowering the pour point and increasing the low-temperature performance of the vegetable oils studied, which was found dependent on vegetable oil fatty acid composition [82].

4. Palm oil as one of the potential lubricant

Oil palm (Elaeis guianensis) originates from Africa. It grows well in wet and humid places like Malaysia [83, 84]. According to Ming et al., Malaysia is presently the world's leading exporter of palm oil having a 60% market share and palm oil is second only to soybean as the major sources of vegetable oil worldwide [79]. Malaysian palm oil production has increased tremendously over the last 25 years, from 2.57 million metric tons in year 1980 to 14.96 million metric tons in year 2005, due to preference for palm oil at the expense of rubber and other crops [83].

Palm oil has been tested by several researchers for different engineering applications. Syahrullail and his colleagues investigated the characteristics of palm oil as a metal forming lubricant [12, 85]. Besides that, palm oil also was tested to be used as diesel engine and hydraulic fluid by Bari and Wan Nik respectively [86, 87]. There are four major groups of palm oil that were investigated by the researchers around the world namely 100% palm oil as a test lubricant [88, 89], palm oil as additives [90], palm oil with additive [91] and palm oil emulsion [92]. All the researchers found out and proved that palm oil shows satisfactory results and has a bright future to be used widely in engineering applications. It also been proven that palm oil has several good performances in term of lubrication and has potential to reduce the dependency on mineral based oil lubricants.

4.1 Refining Bleaching and Deodorizing (RBD) Palm oil

The palm oil comes from the seeds either through solvent extraction screw pressing processes or combinations of the two. The crude oil is either used as is or can be further refined (RBD) to produce higher value oils and products as shown in Figure 2 [21]. RBD is an abbreviation of refined, bleached and deodorized, which means that this oil has gone through a purifying process to vanish the unnecessary fatty acid and odour. Then, it has also gone through fractionation process to extract the palm olein. Palm olein is the liquid fraction obtained from the fractionation of palm oil after crystallization at a controlled temperature [93].

Chew et al., state that crude palm oil (CPO), used palm oil (UPO) and palm oil-based fatty acid mixture (FAM) are three potential feedstocks for biofuels production available in Malaysia [94]. The FAM is byproduct from oleochemical industry in Malaysia. All these three feedstocks contain palmitic acid, oleic acid and other typical fatty acids [95].

Crude palm oil is generally refined by the physical process, which includes a degumming pretreatment, a bleaching step, and a high-temperature (240°C –260°C), low-pressure (1 mmHg-3 mmHg) deodorization/deacidification step. Physical refining is preferred than the chemical process since the high acidity that is frequently observed in crude palm oil (up to 5%) can lead to excessive loss of neutral oil in the soapstock after alkali neutralization. Moreover, the high temperature reached during the deodorization/deacidification step should positively contribute to the bleaching of the oil (heat bleaching) [96].

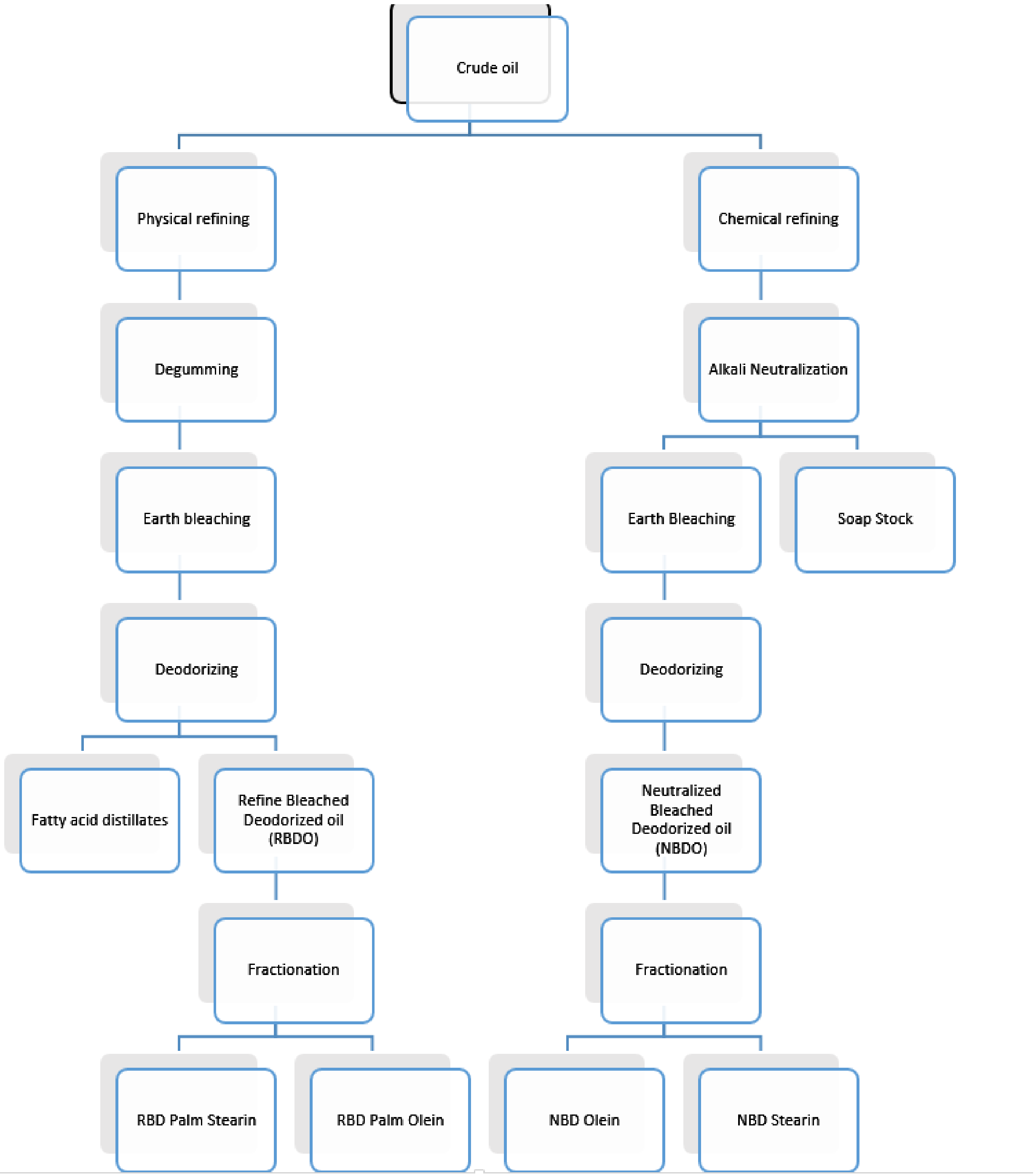

Fig. 2 Process of RBD

Deacidification is a process to remove free fatty acids from the oil. Deodorization is also function to remove the odor of the oil. Deodorization and deacidification normally are carried out by using steam under high vacuum. Palm fatty acid distillate is known as a highly odoriferous product. Palm fatty acid distillate also contains some glycerol esters along with minor components of the feedstocks [97].

RBD palm olein is the liquid form of palm oil at room temperature after the fraction process [98]. It exists in yellow in colour. RBD palm olein is used for manufacturing margarine and shortenings. It is also used as cooking oil as well as frying oil in food industries. Whilst RBD palm stearin is the solid form of palm oil at room temperature after the fractioning process [89, 99].

4.2 Palm oil composition

According to Abdelmalik, there are two major classes of vegetable oils; one has higher concentration of saturated fatty acids so it is more stable to oxidation but possesses a high melting point [14]. The other has a higher concentration of unsaturated fatty acids, which is highly unstable to oxidation but possesses a low melting point. Plant oils are composed mostly of triacylglycerol (98%) and contain of different fatty acids attached to a single molecule of glycerol. They also contain minor amounts of mono and diglycerols (0.5%), free fatty acids (0.1%), sterols (0.3%), and tocopherols [4].

Chemical properties, fatty acid compositions of crude palm oil (CPO) and its products are shown in Table 4, 5 and 6. RBD palm olein had a higher content of unsaturated fatty acid than CPO, while RBD palm stearin had a higher saturated fatty acid content [99].

Table 4
Composition of RBD palm olein.

Fatty acid	C-atoms	Saturation	Percentage (%)
Myristic acid	14	Saturated	1
Palmitic acid	16	Saturated	43
Stearic acid	18	Saturated	5
Oleic acid	18	Mono-unsaturated	39
Linoleic acid	18	Poly-unsaturated	11
Other	-	-	1

Table 5
Composition of RBD palm stearin.

Fatty acids	Saturation	Percentage (%)
Myristic acid	Saturated	1.21
Palmitic acid	Saturated	61.21
Stearic acid	Saturated	4
Oleic acid	Mono-unsaturated	27.54
Linoleic acid	Poly-unsaturated	6.05

Table 6
Composition of palm oil [89].

Fatty acids	C-atoms	Saturation	Palm oil
Caprylic acid	8	Saturated	0%
Capric acid	10	Saturated	0%
Lauric acid	12	Saturated	0%
Myristic acid	14	Saturated	1%
Palmitic acid	16	Saturated	43%
Stearic acid	18	Saturated	5%
Oleic acid	18	Mono-unsaturated	39%
Linoleic acid	18	Poly-unsaturated	11%
Linolenic acid	18	Poly-unsaturated	0%
			100%

4.3 Palm oil as Lubricant

Palm oil is good on the performance of palm oil as lubricant. It has been proven that palm oil has good performance in term of lubrication and has potential to reduce the dependency on mineral based oil lubricants. Palm olein is less efficient in reducing wear due to the rough edges shown in the wear scar but have better reliability than additives free mineral oil base stock because of the smaller wear scar diameter [100].

Many researcher has proven that the reliability of palm oil such as studied by [101]. According to them, palm oil has the potential to fulfil the demand for vegetable-based lubricants. They are trying to evaluate the viability of palm oil when used as a lubricant in cold work such as the forward plane strain extrusion process. The results obtained from the experimental work showed that palm oil has satisfactory lubrication performances, as compared to paraffinic mineral oil, and has advantages in reducing the extrusion load.

Razak et al., also agree that using palm oil has more significant compare to mineral oil [102]. In his experiment, the influence of lubricant on Acrylonitrile Butaiene Styrene (ABS) curve surface structure (CSS) sliding against ball bearing was investigated. The palm oil and commercial mineral oil (MO) were tested as the lubricant. The sliding friction was measured on a modified standard fourball tester with untested ball cup. It was found that the measured friction using palm oil lower than the mineral oil.

A comparative study of wear, friction, viscosity, lubricant degradation and exhaust emissions was carried out on a palm oil and a mineral oil-based commercial lubricating oil by (Masjuki, et al., 1999) [103]. Experimental results demonstrated that the palm oil based lubricating oil exhibited better performance in terms of wears, and that the mineral oil based lubricating oil exhibited better performance in terms of friction. However, the palm oil based lubricant was the more effective in reducing the emission levels of CO and hydrocarbon.

4. Conclusions

In summary, vegetable oil is an environmentally friendly lubricant which can be used in any industry that involve lubrication with a little modification. It is proved by the researchers that the properties of the vegetable oil that is rarely found in the mineral oil is very useful in industrial application. If the vegetable oil is develop efficiently for lubricant purpose, it would benefit the environment and the local people by creating job opportunity and provision of modern application carriers to rural people.

Vegetable oil is facing several issues and challenge like the oxidation stability and poor low temperature behaviour to be used in the industry, but there are many research that can been done in order to improve the quality of the vegetable oil.

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