INFLUENCE OF FEEDSTOCKS IN BIODIESEL PRODUCTION ON ITS PHYSICO-CHEMICAL PROPERTIES OF PRODUCT: A REVIEW

PENGARUH BAHAN BAKU DALAM PRODUKSI BIODIESEL TERHADAP SIFAT FISIKA-KIMIA PRODUKNYA: SUATU TINJAUAN

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SARI

Perhatian terhadap Biodiesel sedang meningkat secara mendunia sebagai suatu bahan bakar pengganti minyak solar atau sebagai komponen pencampur di sektor transportasi. Biodiesel juga menjadi lebih menarik karena keuntungan terhadap lingkungan dan kenyataannya dibuat dari sumber-sumber yang dapat diperbaharui. Bahan baku biodiesel dapat dibagi dalam empat kategori yaitu: (i) Minyak nabati yang dapat dimakan; (ii) Minyak nabati yang tidak dapat dimakan; (iii) Minyak goreng bekas; dan (iv) Lemak hewani. Ada dua faktor yang perlu dipertimbangkan bila menggunakan bahan baku untuk produksi biodiesel yaitu sumber dan komposisinya. Bahan baku biodiesel mempunyai tiga tipe asam lemak sebagai senyawa utama yang terdapat dalam trigliserida yaitu asam lemak jenuh (Cn:0), asam lemak mono-tidak jenuh (Cn:1) dan asam lemak poli-tidak jenuh (Cn:2,3). Sifat-sifat fisika-kimia biodiesel secara keseluruhan sangat dipengaruhi oleh sifat individu ester-ester asam lemak dalam biodiesel. Komposisi asam lemak bervariasi untuk seluruh bahan baku biodiesel yang mempengaruhi mutu produk. Sifat-sifat penting dari bahan bakar biodiesel yang dipengaruhi oleh komposisi asam lemak adalah viskositas, angka setana, nilai pemanasan/kalori, titik kabut, dan stabilitas oksidasi. Stabilitas oksidasi adalah salah satu issu besar yang mempengaruhi penggunaan biodiesel atau EMAL (ester metil asam lemak) karena sifat alamiah biodiesel, yang membuat biodiesel lebih rentan terhadap oksidasi atau auto-oksidasi selama penyimpanan jangka panjang daripada bahan bakar diesel petroleum. Nilai stabilitas oksidasi biodiesel berkisar dari 0,4 jam (untuk biodiesel yang paling tidak jenuh, linseed) sampai 35,5 jam (untuk biodiesel yang paling jenuh, minyak kelapa).

Kata kunci: biodiesel, komposisi asam lemak, bahan baku, stabilitas oksidasi, sifat fisika-kimia, jenuh (saturasi), tidak jenuh (tidak tersaturasi)

ABSTRACT

Biodiesel is attracting increasing attention worldwide as a substituted petroleum diesel fuel or a blending component in transport sector. Biodiesel also become more attractive because of its environmental benefits and the fact that it is made from renewable resources. Biodiesel feedstock can be divided into four main categories: (i). Edible vegetable oi; (ii). Non-edible vegetable oil, (iii); Waste or used cooking oil; and (iv). Animal fats. There are two major factors to take into consideration when dealing with feedstock for biodiesel production i.e the source and composition. Biodiesel feedstocks have three main types of fatty acids as the main compounds that are present in a triglyceride: saturated (Cn:0), monounsaturated (Cn:1) and polyunsaturated (Cn:2,3). The overall biodiesel physicochemical properties are strongly influenced by the properties of individual fatty acid esters in biodiesel. Fatty acid composition varies for all biodiesel feedstocks that affected the product quality. Important fuel properties of biodiesel that are influenced by the fatty acid composition are viscosity, cetane number, heating/ calorific value, cloud point,and oxidation stability. Oxidation stability *is one of the major issues influencing the use of biodiesel or FAME (fatty acid methyl ester), due to the nature of biodiesel, makes it more susceptible to oxidation or auto-oxidation during long-term storage than petroleum diesel fuel. The oxidation stability values of the biodiesel range from 0.4 hr (for the most unsaturated biodiesel, linseed) to 35.5 hr (for the most saturated one, coconut).*

***Keywords**: biodiesel, fatty acid composition, feedstock, oxidation stability, physico-chemical properties, saturation, unsaturation*

I. INTRODUCTION

Nowadays, biodiesel is becoming popular as a renewable fuel and a more environment friendly fuel. Biodiesel is attracting increasing attention worldwide as a blending component or a direct replacement of petroleum diesel fuel in transport sector. Biodiesel has a similar characteristic to petroleum diesel fuel and is therefore biodiesel rated as a strong potential alternative to diesel fuel. The increasing interests on biodiesel is fueled by the need to find a sustainable diesel fuel alternative. Moreover, the world is confronted with the twin crises of fossil fuel depletion and environmental degradation. Global demand for energy, particularly petroleum, is predicted to increase 30% by 2035[1, 2].

The term of Biodiesel was introduced in the United States during 1992 by the National Soy diesel Develoment Board (presently National Biodiesel Board). Meanwhile, Biodiesel was introduced in Indonesia during 1995 by LEMIGAS and PERTAMINA based on their research cooperation.

According to the World Customs Organization (WCO) definition, biodiesel is a mixture of mono-alkyl esters of long-chain (C16-18) fatty acids derived from vegetable oils or animal fats, which is a domestic renewable fuel for diesel engines and which meets the specifications of ASTM D 6751[3].

The utilization of biodiesel as substitute fuel to petroleum diesel is becoming worldwide acceptability because it is a clean burning fuel, high cetane numbers, biodegradable, also has low toxicity and is environment friendly. Moreover, it has a low smoke and particulates and does not contribute to green house gases (GHG) as they have closed carbon dioxide cycle[4,5]. Biodiesel can be used in its pure form (B100) or as a blend (BXX) with conventional petroleum diesel fuels as it has very similar characteristics. The blend is designated using B followed by the percentage of biodiesel in the finished product.

Some important properties of biodiesel depend on the fatty acid composition of its feedstock. Different types of oil feedstock have different types of fatty acids[6]. The fatty acid composition of oil feedstock plays a significant role in the performance of biodiesel in diesel engines.

In this review article, the composition of different biodiesel feedstocks are examined into their physico-chemical properties of biodiesel products, and also discussing the main critical properties of biodiesel especially the oxidation stability.

II. OBJECTIVE

The objective of this paper is to describe the influence of biodiesel feedstocks compositions to their physico-chemical of biodiesel produced from these feedstocks.

III. METHODOLOGY

In order to find out the influence of the feedstocks compositions the physical and chemical properties of biodiesel from various feedstocks, then an amount of data was carefully collected from literatures or papers published international Journals, Conferences and reports issued by well-known research centers.

IV. BIODIESEL FEEDSTOCK

In global, there are more than hundred oil-bearing crops identified as potential sources for biodiesel production to substitute the petroleum diesel fuel[7,8]. However, nowadays the most common feedstocks for biodiesel are only palm, jatropha, rapeseed, soybean, sunflower, cottonseed, safflower, and peanut oils are considered as potential feedstocks for commercial production[9].

Generally, biodiesel feedstock can be divided into four main categories i.e[10-16] : (i). Edible vegetable oil: rapeseed, soybean, peanut, sunflower, palm and coconut oil. (ii). Non-edible vegetable oil: jatropha, karanja, cotton seed, algae and halophytes. (iii). Waste or used cooking oil. (iv). Animal fats: tallow, yellow grease, chicken fat and by-products from fish oil. Biodiesel has been in use in many countries such as United States of America, Indonesia, Malaysia, Brazil, Germany, France, Italy and other European countries. Primary biodiesel feedstock for some selected countries around the world is shown in Table 1[10,17-22].

There are two major factors to take into consideration when dealing with feedstock for biodiesel production. Firstly, is the source, and secondly is composition. In the first case it is important to know if the oil is derived from food or non-food crops; the second consideration is to know the composition of the oil and how appropriate it is as a feedstock. The availability of feedstock, in large amount, for biodiesel production represents one of the most significant factors of producing biodiesel[18,23,24] Another factor of biodiesel production that the feedstock should fulfill two main requirements: low production costs and large production scale. The availability of feedstock for producing biodiesel depends on the regional climate, geographical locations, local soil conditions and agricultural practices of any country. In consideration of any feedstock as a biodiesel source, the oil percentage and the yield per hectare are important parameters. Table 2 shows the list of oil percentage and its yield for some biodiesel feedstocks[10,17,19,22,23,25-31]. Meanwhile, in Indonesia has an amount of abundant resources for biodiesel feedstock, instead of palm oil, such as kemiri sunan (*Reutalis trisperma*), kranji (*Pongamia pinnata*), kepuh (*Sterculia foetida L.*), kosambi (*Schleichera oleasa*), bintaro (*Carbera manghas*), etc.

The major components of vegetable oils and animal fats are mixtures of triglycerides from various fatty acids. Chemically the vegetable oils and animal fats consist of 90-98% triglycerides and small amount of mono and diglycerides. Triglycerides are esters of glycerol (an alcohol with a hydroxy group on each of its three carbon atoms) with long-chain acids, commonly called fatty acids. Fatty acids contain an even number of carbon atoms, from 8 to 26, bonded in unbranched chains. There are three main types of fatty acids that are present in a triglyceride: saturated ($C_{n:0}$), mono-unsaturated ($C_{n:1}$) and poly-unsaturated ($C_{n:2,3}$). The percentage of these compounds differs for each vegetable oil. Table 3 shows the percentage of saturated, mono-unsaturated and polyunsaturated for various biodiesel feedstocks[15,32,33].

Table 1
Current potential feedstocks for biodiesel worldwide[10,17-22]

No	Country	Feedstock
1	Argentina	Soybeans
2	Brazil	Soybeans/palm oil/castor/cotton oil
3	Canada	Rapeseed/fat/soybeans/yellow grease and tallow/mustard/flax
4	China	Jatropha/waste cooking oil/rapeseed
5	France	Rapeseed/sunflower
6	Germany	Rapeseed Italy Rapeseed/sunflower
7	Greece	Cottonseed
8	India	Jatropha/Pongamia pinnata (karanja)/soybean/rapeseed/ sunflower/peanut
9	Indonesia	Palm oil/jatropha/coconut
10	Japan	Waste cooking oil
11	Malaysia	Palm oil
12	Mexico	Animal fat/waste oil
13	New Zealand	Waste cooking oil/tallow
14	Philippines	Coconut/jatropha
15	Singapore	Palm oil
16	Spain	Linseed oil/sunflower
17	Sweden	Rapeseed Ireland Frying oil/animal fats
18	Thailand	Palm/jatropha/coconut
19	UK	Rapeseed/waste cooking oil
20	USA	Soybeans/waste oil/peanut/sunflower

Table 2
Estimated oil content and yields of different biodiesel feedstocks[10,17,19,22,23,25-31]

No	Feedstocks	Oil Content (%)	Oil Yield (L/Ha/Year)
1	*Calophylum inophyllum L*	65	4680
2	Castor	53	1413
3	Coconut	63-65	2689
4	Corn (Germ)	48	172
5	Cotton seed	18-25	325
6	*Euphorbia lathyris L*	48	1500-2500a)
7	Jatropha:	- seed : 35-40 - kernel : 50-60	1892
8	Jojoba	45-50	1818
9	Linseed	40-44	-
10	Microalgae (Low oil content)	30	58700
11	Microalgae (Medium oil content)	50	97800
12	Microalgae (High oil content)	70	136900
13	Moringa oleifera	40	-
14	Olive oil	45-70	1212
15	Palm oil	30-60	5950
16	Peanut oil	45-55	1059
17	Pongamia pinnata (Karanja)	27-39	225-2250a)
18	Rapeseed	38-46	1190
19	Rice bran	15-23	828
20	Rubber seed	40-50	80-120a)
21	Soybean	15-20	446
22	Sunflower	25-35	952
23	Tung	16-18	940

Note: a) = (kg oil/ha)

Most common biodiesel feedstocks such as vegetable oils possess fatty acid profiles consisting of six common fatty acids i.e. palmitic acid (C16:0), stearic acid (C18:0), palmitoleic acid (C16:1), oleic acid (C18:1), linoleic acid (C18:2) and linolenic acid (C18:3). Moreover, biodiesel feedstocks from different or even from the same source may have different chemical structures and consequently different properties. The fatty acids found in the biodiesel feedstocks are summarized in Table 4[15,32,33]. The physico-chemicals of some biodiesel feedstocks is shown in Table 5[34-36]. These properties do not meet the requirement of specification as petroleum diesel fuel, particularly cetane number and viscosity. Low cetane number implies long ignition delay, high auto ignition temperature and diesel knock. Meanwhile, high viscosity interference with injection process, poor fuel atomization, high viscosity and low volatility causes poor cold engine start-up and ignition delay.

V. PRODUCTION PROCESS OF BIODIESEL

There are the crucial factors for the production process and biodiesel use, based on the kind and quality of feedstock, according the technical design of processing plant that correspond to material and energy flows as indicator of technical and economic efficiency of biodiesel production. The most pertinent feedstock parameters, as the crucial factors, and their relevance for the production process and biodiesel use is shown in Table 6[37].

Biodiesel feedstocks (vegetable oils) have an extreme problems, if used as substituted diesel fuel, due to their chracteristics, i.e. high viscosity, low volatility and polyunsaturated. The high viscosity and poor volatility are the major limitations of vegetable oils for their utilization as fuel in diesel engines. Therefore the problems can be overcome by certain process. There are several processes to produce biodiesel such as pyrolysis, dilution with hydrocarbons blending, microemulsion, and transesterification[19,20,38]. Pyrolysis (thermal cracking) is the thermal decomposition of the organic matters that generally occurs under temperatures that vary from 400°C up to 650°C in the absence of oxygen and in the presence of a catalyst. In dilution process, vegetable oils are diluted with petroleum diesel fuel to reduce the viscosity and improve the engine performance. Micro-emulsion process is defined as a collodial equilibrium dispersion of optically isotropic fluid microstructure, formed spontaneously from two normally immiscible liquids and one and more ionic

Table 3
Percentage of saturated and unsaturated in various biodiesel feedstocks[15,32,33]

No	Feedstock	Saturated	Monounsaturated	Polyunsaturated
1	Butter	63%	26%	4%
2	Chicken Fat	30%	45%	21%
3	Camelina Oil	10%	33%	54%
4	Coconut oil	90%	6%	2%
5	Corn Oil	13%	24%	59%
6	Cottonseed Oil	26%	18%	52%
7	Jatropha	26%	42%	30%
8	Lard	39%	45%	11%
9	Olive oil	14%	73%	11%
10	Palm Kernel Oil	81%	11%	2%
11	Palm Oil	49%	37%	9%
12	Peanut oil	17%	46%	32%
13	Rapeseed oil	7%	62%	31%
14	Safflower Oil	7%	14%	79%
15	Soybean oil	16%	23%	58%
16	Sunflower oil	10%	20%	66%
17	Waste cooking oil	16%	22%	62%

Table 4
Fatty acid composition of various feedstock oils[15,32,33]

No	Feedstock	Fatty Acid Composition (wt-%)*													
		C12:0	C14:0	C14:1	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C22:0	C24:0	C6,8,10 and Other
1	Almond kernel	-	-	-	6.5	0.5	1.4	70.7	20.0	-	-	-	-	-	-
2	Beef tallow	-	2.73	0.50	22.99	2.86	19.44	41.60	3.91	0.49	0.14	0.33	-	-	-
3	Camelina oil	-	-	-	5.4	-	2.6	14.3	2.9	38.4	0.25	16.8	1.4	-	-
4	Castor	-	-	-	1.1	-	3.1	4.9	1.3	-	-	-	-	-	Ricinoic acid = 89.6
5	Coconut	48.8	19.9	-	10.08	0.1	4.31	7.4	0.8	-	-	-	-	-	C8:0 = 6.38 C10:0 = 5.56
6	Corn	-	-	-	12	-	2	25	6	trace	trace	-	-	-	-
7	Cottonseed	-	-	-	28	-	1	13	58	-	-	-	-	-	-
8	Jatropha	-	0.1	-	15.6	-	10.5	42.1	30.9	0.2	0.6	-	-	-	-
9	Karanja	-	-	1.7-7.9	-	-	2.4-8.9	44.5-71.3	10.8-18.3	-	-	-	-	1.1-1.5	-
10	Linseed	-	-	-	5.1	0.3	2.5	18.9	18.1	55.1	-	-	-	-	-
11	Olive kernel	-	-	-	5.0	0.3	1.6	74.7	17.6	-	-	-	-	-	-
12	Palm	-	-	-	42.6	0.3	4.4	40.5	10.1	0.2	-	-	-	-	-
13	Peanut	-	-	-	11	-	2	48	32	1	1	-	2	1	-
14	Poultry fat	-	0.57	0.26	22.76	8.37	5.36	42.07	17.14	1.07	0	0.45	-	-	-
15	Rapeseed	-	-	-	3.5	-	0.9	64.1	22.3	8.2	-	-	-	-	-
16	Rice-bran	-	0.4-0.6	-	11.7-16.5	-	1.7-2.5	39.2-43.7	26.4-35.1	-	0.4-0.6	-	-	-	-
17	Safflower	-	-	-	8	-	2	12	78	-	-	-	-	-	-
18	Sesame	-	-	-	8.9	0.2	4.8	39.3	41.3	0.3	-	0.2	-	-	-
19	Soyabean	-	-	-	12	-	3	23	55	6	-	-	-	-	-
20	Sunflower	-	-	-	6.4	0.1	2.9	17.7	72.9	-	-	-	-	-	-
21	Tallow	-	-	-	23.3	0.1	42.4	2.9	0.9	-	-	-	-	-	-
22	Waste cooking oil (Palm)	0.1	0.1	-	11.8	0.4	4.4	25.3	49.5	7.1	0.3	-	0.4	0.1	-
23	Waste cooking oil (Soybean)	-	<0.10	-	10.29	<0.10	4.28	21.55	53.68	8.16	0.34	0.19	0.37	-	-

Note *: C6:0 = Caproic acid; C8:0 = Caprylic acid; C10:0 = Capric acid; C12:0 = Lauric acid; C14:0 = Myristic acid; C14:1 = ; C16:0 = Palmitic acid; C16:1 = Palmitoleic acid; C18:0 = Stearic acid; C18:1 = Oleic acid; C18:2 = Linoleic acid ; C18:3 = Linolenic acid ; C20:0 = Arachidic acid; C20:1 = Gadoleic acid; C22:0 = Behenic acid; C22:1 = Erucic acid; C24:0 = Lignoceric acid

Table 5
Physical and chemical properties of vegetable oils (biodiesel feedstocks)[34-36]

No	Oil Feedstock	Kinematic Viscosity, cSt	Carbon Residue, wt-%	Cetane Number	Heating Value, MJ/kg	Ash Content, wt-%	Sulfur Content, wt-%	Iodine Value	Flash Point, °C	Pour Point, °C	Cloud Point, °C
1	Almond kernel	34.2	0.22	34.5	39.8	0.01	0.01	102.35	-	-	-
2	Castor	29.7	0.21	42.3	37.4	0.01	0.01	88.72	-	-	-
3	Corn marrow	35.1	0.22	37.5	39.6	0.01	0.01	119.41	277	-40.0	-1.1
4	Cottonseed	33.7	0.25	33.7	39.4	0.02	0.01	113.20	234	-15.0	1.7
5	Jatropha	46.6	0.3	24	39.6	-	-	111.03	309	-6	2
6	Linseed	28.0	0.24	27.6	39.3	0.01	0.01	156.74	241	-15.0	1.7
7	Olive kernel	29.4	0.23	49.3	39.7	0.008	0.02	100.16	-	-	-
8	Palm	39.6	0.23	42.0	39.5	-	0.01	48-58	267	-	31.0
9	Peanut kernel	40.0	0.22	34.6	39.5	0.02	0.01	119.55	271	-6.7	12.8
10	Rapeseed	37.3	0.31	37.5	39.7	0.006	0.01	108.05	246	-32	-3.9
11	Safflower seed	31.6	0.26	42.0	39.5	0.007	0.01	139.83	260	-6.7	18.3
12	Sesame seed	36.0	0.25	40.4	39.4	0.002	0.01	91.76	260	-9.4	-3.9
13	Soybean	33.1	0.24	38.1	39.6	0.006	0.01	69.82	254	-12.2	-3.9
14	Sunflower seed	34.4	0.28	36.7	39.6	0.01	0.01	132.32	274	-15.0	-1.2
15	Tallow	51.2	-	40.2	-	-	-	-	201	-	-
16	Walnut kernel	36.8	0.24	33.6	39.6	0.02	0.02	135.24	-	-	-

Table 6
Feedstock parameters and their relevance for biodiesel production and use[37]

No	Parameter	Characterization	Relevance for the Biodiesel Production and Use
1	Free fatty acids (FFA)	Significant measure of feedstock quality, indicator for the level of hydrolysis; FFA of native unrefined oils and fats can be above 20.0, refined oils/fats have FFA up to 1.0	Influence degree of required processing (e.g. catalyst demand) and biodiesel quality (primarily cold flow properties)
2	Kinematic viscosity	Physical-mechanical characteristic, depending of specific melting point	Influenced by the temperature, fatty acid profile and oil-aging degrees, whereas the kind of the oil production procedure does not affect viscosity
3	Cold flow properties	Strongly affected by temperature; saturated fatty compounds with a significantly higher melting points than unsaturated fatty compounds	Cloud point (CP) and the cold filter plugging point (CFPP) or pour point (PP) for fuels not suitable to describe cold flow properties of oils/fats, since the transition of the liquid to the solid phase can not be definite
4	Water content	Mainly affected by the moisture of the seeds and refined oils/fats; with all oils/fats the water content can rise through storage and transport	At high temperatures water can hydrolyze the triglycerides to diglycerides and form free fatty acids; relevant for disturbing the transesterification by catalysts loss and unwanted soap production
5	Iodine number	Indicator for double bindings in the molecular structure of oils/fats. the higher the iodine value, the more unsaturation acids are present in the oils/fats	High iodine number in oils/fats for less age resisting than oils/fats with high degree of saturation; informs about the tendency of deposits in the combustion chamber and at injection nozzles
6	Phosphorus content	Present in vegetable oils in the form of phospholipids; depends on refining grad of oils/fats (influenced by oil production process)	Decreasing oxidation stability with rising portion of phospholipids; high amounts of phospholipids leading to disturbances with technical processes (e.g. blockages of filters and injection nozzles); avoidance of phosphorous compounds in waste water
7	Oxidation stability	Value, which describes the aging Condition and the shelf-life of oils/fats	Oxidation and polymerization procedures During fuel storage, which can lead to formation of insoluble compounds and thus cause e.g. filter blockage
8	Total contamination	Proportion of unresolved impurities (particles) in the oils/fats; mainly affected by the oil production procedure	Relevant to glycerin quality and unwanted glycerin caking within the process; High total contaminations lead to clogging the fuel filters and injection pump and to injection nozzles as well as of deposits in the combustion chamber

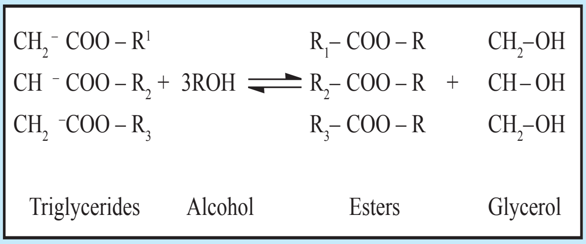
Table 7
Comparisons between chemically catalytic processes and supercritical methanol method for biodiesel production from vegetable oils by transesterification[9,37,40]

No	Parameter/ Operating Condition	Transesterification Method			
		Alkali Catalysis	**Acid Catalysis**	**Lipase Catalysis**	**Supercritical**
1	Reaction Temperature (^oC)	60-70	55-80	30-40	231-385
2	Reaction Pressure (Mpa)	0.1	0.1	0.1	10-25
3	Reaction Time (min)	60-360	4140	600-1800	7-15
4	Catalyst	NaOH, KOH	H_2SO_4, HCl	Enzyme Lipase	None
5	Methyl Ester Yield (Wt-%)	96	90	99	98
6	Removal of	Catalyst, Methanol	Catalyst, Methanol	None	Methanol
7	Purification	Glycerol	Soaps	Glycerol	Glycerol
8	Free Fatty Acids	Saponified products	Methyl esters, Water	Methyl esters	Methyl esters, Water
9	Process	Complicated	Complicated	Simple	Simple
10	Yield	Normal	Normal	High	High
11	Production cost of Catalyst	Cheap	Cheap	Relatively expensive	Medium

or more ionic amphiphiles. The most common one to produce biodiesel fuel is by transesterification, in which various oils (triglycerides) are converted into methyl ester through a chemical reaction with methanol in the presence of a catalyst such as an acid or alkaline catalyst. The by-products of this chemical reaction are glycerols and water. Transesterification is regarded as the best method among other approaches due to its low cost and simplicity[6,39,41]. Generally, the choice of a particular technology is dependent on catalyst and the source, type and quality of feedstock.

The process of production of biodiesel can be divided into two ways based on catalytic processing i.e. by chemical catalyst and non-catalytic production. Alkaline catalyzation is preferred, because the reaction is rapid and complete. This process occurs at a relatively low temperature and pressure when compared to those of other processes. Since transesterification is an equilibrium-controlled reaction, an excess of alcohol is used to shift the equilibrium forward as shown in Figure 1.

Methanol is the most often preferred alcohol because of its low cost compared to other alcohols. As a result, the operating cost as well as the capital cost of this process is reduced.



$$\begin{array}{llll} CH_2-COO-R^1 & & R_1-COO-R & CH_2-OH \\ CH-COO-R_2 + 3ROH & \rightleftharpoons & R_2-COO-R \; + & CH-OH \\ CH_2-COO-R_3 & & R_3-COO-R & CH_2-OH \end{array}$$

Figure 1
Transesterification of triglycerides

Several factors, including the type of catalyst, alcohol/vegetable oil molar ratio, temperature, water content and free fatty acid content have an influence on the process of transesterification.. If FFA (free fatty acid) concentration of the feedstock is higher, the alkali catalyst should not be used in the transesterification reaction due to the soap formation[38]. The acidic catalyst is much more tolerant to FFAs and is not strongly affected by the presence of the free fatty acids in the feedstock[39]. Comparison between chemically catalyzed processes and a non-catalytic supercritical methanol method, for biodiesel production from vegetable oils, is shown in Table 7[9,37,40].

VI. BIODIESEL PROPERTIES

One of the major issues when using biodiesel is fuel properties. The main criterion of biodiesel quality is the integration of its physical and chemical properties into the requirements of the adequate standard. Quality standards for biodiesel are continuously updated, due to the evolution of compression ignition engines, everstricter emission standards, reevaluation of the eligibility of feedstocks used for the production of biodiesel, dependence of the climate in each region, etc.

Generally, these properties vary from biodiesel fuel to biodiesel fuel because of the fact that the feedstocks contain different fatty acid profiles. Fuel properties are very essential for the use of biodiesel, in some cases even precluding use of a specific fuel under certain circumstances, for example, a fuel with high cloud point will exhibit significant operability problems at low temperatures.

Physical and chemical properties of biodiesel are affected by their esters (fatty acid methyl ester, FAME) compositional profiles include chain length, degree of unsaturation and branching of the chain[42]. The properties of greatest interest are those defined by standard specifications that have been established for biodiesel such as kinematic viscosity, cetane number, flash point, sulfur content, iodine value, heating value, and low temperature operability metrics (cloud point, pour point, and cold filter plugging point). Additional biodiesel properties are of importance with respect to in-use fuel quality, but are dictated primarily by biodiesel manufacturing, purification, and storage processes, rather than by the fatty acid compositional profiles of the fatty esters (FAME). These properties include oxidation stability, water and sediment content, methanol content, ash, metals, acid number, glycerine content, and cold soak filterability.

The physical and chemical properties of the methyl esters (biodiesel) were determined by methods specified in standard specification that have been established for biodiesel – especially ASTM D6751 in the U.S. and EN 14214 in Europe. Many countries have now adopted standard specifications for biodiesel fuel (B100) include Indonesia with SNI (Standard National Indonesia) 7182:2012. Table 8 shows the comparison of standard specification for ASTM D6751, EN 14214 and SNI 7182:2012. Many studies have shown that the properties of biodiesel are very close to petroleum diesel fuel. Therefore, biodiesel fuel can be used in diesel engines with little or no modification. The physical and chemical fuel properties of biodiesel basically depend on the type of feedstock and their fatty acids composition[20,21,24,43-48]. A summary of physicochemical properties of diesel and biodiesel produced from different feedstocks are shown in Table 9[31-33].

A. Kinematic Viscosity

Kinematic viscosity is an important parameter required by biodiesel and diesel fuel standards because of being key fuel property for diesel engines. The viscosity of an engine fuel is one of the most critical fuel features. It plays a dominant role in the fuel spray, mixture formation and combustion process. The high viscosity interferes with the injection process and leads to insuffcient fuel atomization. Moreover, the mean diameter of the fuel droplets from the injector and their penetration increases with increasing fuel viscosity. The ineffcient mixing of fuel with air contributes to incomplete combustion in the engine. Viscosity of any fuel is related to its chemical structure. Viscosity of biodiesel increases with the increase in the chain length (number of carbon atoms) and decreases with the increase in the number of double bonds (unsaturation level)[7, 47, 49, 50]. As seen in Table 9, the highest viscosity of biodiesels is from castor (14.52 cSt) and the lowest is from coconut (2.72 cSt) that compared to other vegetable oils.

B. Cetane number

Cetane number (CN) is a dimensionless indicator that characterizes ignition quality of fuels for compression ignition engines (CIE). Since in the CIE burning of the fuel-air mixture is initiated by compression ignition of the fuel, the cetane number is a primary indicator of fuel quality as it describes the ease of its self-ignition. It can be defined as the measure of knock tendency of a diesel fuel. The cetane number is releated to the ignition delay time that is the time between the start of injection and start of combustion. As the cetane number increases, the ignition delay decreases and the main combustion phase (diffusion controlled combustion) increases.

The cetane number of a substance depends on its molecular structure and on the concentration of the esters it is made up of. The cetane number decreases

Table 8
Properties and qualities of biodiesel in comparison with diesel by standard specification (USA, Europe and Indonesia)

No	Fuel Properties	Diesel Fuel	Biodiesel			Test Method		
		ASTM D975	ASTM D6751	DIN 14214	SNI 7182:2012	ASTM	DIN	SNI 7182:2012
1	Density 15 °C (kg/m3)	850	880	860-900	850-890	D1298	EN ISO 3675/12185	D1298 or D4052
2	Viscosity at 40 °C (cSt)	2.6	1.9–6.0	3.5–5.0	2.3-6.0	D445	EN ISO 3104	D445
3	Cetane number	40–55	Min. 47	Min. 51	Min. 51	D613	EN ISO 5165	D613 or D6890
4	Calorific value (MJ/kg)	42–46	-	35	-	-	EN 14214	-
5	Acid (neutralization) value (mg KOH/g)	0.062	Max.0.50	Max.0.5	Max. 0.6	D664	EN 14104	D664
6	Pour point (°C)	−35	−15 to −16	-	-	D97	-	-
7	Flash point (°C)	60–80	Min. 100–170	>120	Min. 100	D93	ISO DIS 3679	D93
8	Cloud point (°C)	−20	−3 to −12	-	Max. 18	D2500	-	D2500
9	Cold filter plugging point (°C)	−25	19	Max. +5	-	D6371	EN 14214	-
10	Copper strip corrosion (3 h at 50°C)	1	Max. 3	Min.1	1	D130	EN ISO 2160	D130
11	Distillation temperature (%)	-	Max. 360 °C	-	Max. 360 °C	D1160	-	D1160
12	Carbon (wt%)	84–87	77	-	-	-	-	-
13	Hydrogen (wt%)	12–16	12	-	-	-	-	-
14	Oxygen (wt%)	0–0.31	11	-	-	-	-	-
15	Methanol content % (m/m)	-	-	Max. 0.20	-	-	EN 14110	-
16	Water and sediment content (vol%)	0.05	Max. 0.05	Max. 500 (mg/Kg)	Max. 0.05	D2709	EN ISO 12937	D2709
17	Ash content % (w/w)	0.01	0.02	0.02	Max. 0.05	-	EN 14214	D4530 (as MCR)
18	Sulfur % (m/m)	0.05	Max. 0.05	10 (mg/Kg)	Max. 100 (mg/Kg)	D5453	EN ISO 20846	D5453 or D1266
19	Sulfated ash % (m/m)	-	Max. 0.02	Max. 0.02		D874	EN ISO 3987	D874
20	Phosphorus content	-	Max. 0.001	10 (mg/Kg)	Max. 10 (mg/Kg)	D4951	EN 14107	AOCS Ca 12-55
21	Free glycerin % (m/m)	-	Max. 0.02	Max. 0.02	Max. 0.02	D6584	EN 14105/14106	D6584 or AOCS Ca 14-56
22	Total glycerin % (m/m)	-	Max. 0.24	0.025	Max. 0.24	D6584	EN 14105	D6584 or AOCS Ca 14-56
23	Monoglyceride % (m/m)	-	0.52	0.8	-	-	EN 14105	-
24	Diglyceride % (m/m)	-	-	0.2	-	-	EN 14105	-
25	Triglyceride % (m/m)	-	-	0.2	-	-	EN 14105	-
26	Iodine number	-	-	Max. 120	Max. 115	-	EN 14111	AOCS Cd 1-25
27	Oxidation stability (h, 110°C)	-	Min.3	Min. 6	Min. 6	D675	EN 14112	EN 15751 or D7545

with the number of double bonds in fatty acid ester molecules (degree of unsaturation, characterized by the iodine number) and increases with the number of carbon atoms[51]. The more saturated the molecules, the higher the CN[52].The cetane number of biodiesels is higher (the value ranges from 37.9 to 62) than that of its feedstock (the value range from 24 to 42), as can be seen by comparing Table 5 and Table 9.

C. Iodine value

The iodine number (IN, or iodine value IV) is a parameter used to determine the degree of unsaturation in a vegetable oil or animal fat. This number indicates the mass of iodine (I2) in grams that is necessary to completely saturate, by means of a stoichiometric reaction, the molecules of 100g of a vegetable oil. As seen in Table 9, the iodine values of the biodiesel range from 7.8 (for the most saturated ME, coconut) to 184.5 (for the most unsaturated one, linseed), with an overall average value of 98.4. However, the the iodine value of the biodiesel lower than that of its feedstock (as comparing of Table 5 and Table 8). The degree of unsaturation (number of double bonds) was found to correlate excellently with the iodine number.

Table 8 lists that there is no specification in the US for the IN, but European specifications require that biodiesels used in compression ignition engines have a (rather low) maximum value of IN of the order of 120. Meanwhile Indonesia specifications require the maximum value of IN is 115.

The idea behind this specification is that high fuel iodine values indicate tendency for polymerization resulting in deposit formation[53]. This means that many of the investigated FAMEs have to be excluded from use in pure form in Europe, namely linseed and safflower, whereas corn, soybean and sunflower are only marginally accepted. Moreover, the most popular in Europe rapeseed ME, having an average IV of 112, is actually quite close to the specification limit. High iodine numbers (IN) have been also linked with storage stability problems[54],

D. Flash Point

The flash point (FP) is a measure of the temperature to which a fuel must be heated such that the mixture of vapor and air above the fuel can be ignited; FP varies inversely with the volatility of fuel. As flash point values presented in Table 9 then storage of neat biodiesel is thus much safer than diesel in this regard. Specifically, the values of flash point for all biodiesel in Table 9 range from 114.6°C (for the most saturated FAME, coconut) to 174.5°C (peanut ME), with the mean value from all feedstocks being 163.3°C. European specifications require biodiesel fuels to have at least 120°C flash point, whereas in the US and Indonesia the minimum required level is lower (100°C); both are meant to determine a lower limit of purity in the final FAME. Although flash point depends, in general, on the originating oil, it is not directly linked to the fatty acid composition[55].

E. Mono-, Di-, and Triglycerides, Total and Free Glycerin

Biodiesel or ester that produced from transesterification reaction can contain unreacted starting material (vegetable oil) such as triglyceride, residual alcohol, and residual catalyst. Moreover, traces of glycerol which is separated from biodiesel in the production process can also be found in the final biodiesel product. Monoglyceride and diglyceride formed as intermediates can also be found in biodiesel and be as indicator that transesterification reaction is not completely[56]. The total glycerin is defined as the sum of free and bound glycerol, and the bound glycerol is equal to the glycerol portion of the residual monoglyceride, diglyceride and triglycerides. Free glycerol in biodiesel results from not quantitative separation during the production process or from formation by hydrolysis of remaining glycerides during longer storage[57]. The total and free glycerin amounts of biodiesel are two of the most important parameters to determine if the product is ready for commercial applications. Free glycerin results show that it is not directly affected by reaction parameters. This means that free glycerin amount of the final product depends on purification step rather than reaction parameters.

F. Copper Strip Corrosion

The copper strip corrosion is used for the detection of the corrosiveness to copper of biodiesel fuels. This test indicates the presence of acid in the fuel, particularly the sulfur compounds. High levels of FFAs or residual levels of acids may results in unwanted values for this test[58,59]. It is also stated in the ASTM D130 standard test method that the sulfur compounds in the product can have a corroding

Table 9
Summarization of various biodiesel physical and chemical properties for the main feedstocks[31-33]

No	Fuel Properties	Diesel Fuel	Biodiesel						
		ASTM D975	ASTM D6751	Castor	Coconut	Corn	Cotton seed	Jatropha	Linseed
1	Density 15 °C (kg/m3)	850	880	917.6	807.3	882	875	879.5	891
2	Viscosity at 40 °C (cSt)	2.6	1.9–6.0	14.52	2.726	4.382	4.07	4.72	4.06
3	Cetane number	40–55	Min. 47	42.1	61	52.5	54.13	55.7	52
4	Calorific value (MJ/kg)	42–46	-	39.90	38.98	40.19	40.43	39.23	40.41
5	Acid (neutralization) value (mg KOH/g)	0.062	Max.0.50	0.39	0.106	0.283	0.16	0.34	0.29
6	Pour point (°C)	−35	−15 to −16	-23.4	-3.8	-5.1	6	-0.9	-8
7	Flash point (°C)	60–80	Min. 100–170	160.9	114.6	165.7	150	158.5	170.3
8	Cloud point (°C)	−20	−3 to −12	-15.1	-1.2	-2.8	7	2.7	-1.7
9	Cold filter plugging point (°C)	−25	19	5.9	-4	-7	1	-1.2	-8
10	Copper strip corrosion (3 h at 50 °C)	1	Max. 3	1a	1b	1a	1a	1a	1a
11	Distillation temperature (%)	-	Max. 360 °C	381.6	-	345.8	349.5	341.2	361
12	Carbon (wt%)	84–87	77	-	72.75	-	77	76.57	77.75
13	Hydrogen (wt%)	12–16	12	-	11.65	-	12.5	12.21	-
14	Oxygen (wt%)	0–0.31	11	-	-	-	10.49	11.32	11.29
15	Methanol content % (m/m)	-	-	-	-	-	0.175	-	-
16	Water and sediment content (vol%)	0.05	Max. 0.05	-	<0.005	<0.005	-	<0.005	<0.005
17	Ash content % (w/w)	0.01	0.02	-	-	-	0.019	0.012	-
18	Sulfur % (m/m)	0.05	Max. 0.05	0.5 (ppm)	3.2 (ppm)	4.6 (ppm)	3 (ppm)	1.2 (ppm)	8.2 (ppm)
19	Sulfated ash % (m/m)	-	Max. 0.02	-	0.006	<0.005	-	0.009	<0.005
20	Phosphorus content	-	Max. 0.001	-	<0.1	<0.1	-	<0.1	<0.1
21	Free glycerin % (m/m)	-	Max. 0.02	-	0.025	0.001	0.015	0.006	0.001
22	Total glycerin % (m/m)	-	Max. 0.24	-	0.065	0.66	0.229	0.1	0.12
23	Monoglyceride % (m/m)	-	0.52	-	0.13	0.197	-	0.291	0.392
24	Diglyceride % (m/m)	-	-	-	0.04	0.080	-	0.104	0.112
25	Triglyceride % (m/m)	-	-	-	0	0.02	-	0.022	0
26	Iodine number	38.3	-	85.2	7.8	-	120	104	184.5
27	Oxidation stability (h, 110 °C)	-	Min.3	12.9	35.5	2.2	3.0	5	0.4

Table 9
Summarization of various biodiesel physical and chemical properties for the main feedstocks[31-33].(cont'd)

No	Fuel Properties	Biodiesel						
		Microalgae	**Olive Oil**	**Palm**	**Palm Kernel**	**Peanut**	***Pongamia*** **(Kranja)**	**Poultry Fat**
1	Density 15°C (kg/m3)	-	881	864	-	883	882	876
2	Viscosity at 40°C (cSt)	4.519	5.05	4.5	4.85	4.77	5.04	4.81
3	Cetane number	-	58.9	61.2	62	54.9	55	57
4	Calorific value (MJ/kg)	-	40.28	39.98	34.75	39.93	40.27	39.89
5	Acid (neutralization) value (mg KOH/g)	0.022	0.37	0.27	-	0.19	0.44	0.32
6	Pour point (°C)	-	-5.0	15	10	-2.7	2.5	4.4
7	Flash point (°C)	>160	171	161.9	167	174.5	163.6	162.2
8	Cloud point (°C)	-5.2	-2	16	13	4.3	7.6	7.5
9	Cold filter plugging point (°C)	-7	-5.3	12	-	16.3	-7	2.7
10	Copper strip corrosion (3 h at 50°C)	1a	-	1a	-	-	-	1a
11	Distillation temperature (%)		-	339.3			345.4	-
12	Carbon (wt%)	-	-	76.09	-	62.1	76.35	-
13	Hydrogen (wt%)	-	-	12.44	-	-	11.95	-
14	Oxygen (wt%)	-	-	11.27	-	-	11.51	-
15	Methanol content % (m/m)	-	-	-	-	-	-	-
16	Water and sediment content (vol%)	<0.005	-	-	-	-	-	<0.005
17	Ash content % (w/w)	-	-	-	-	-	0.001	-
18	Sulfur % (m/m)	5.1 (ppm)	7.8 (ppm)	0.003	-	5.9 (ppm)	13.5 (ppm)	21.1 (ppm)
19	Sulfated ash % (m/m)	<0.005	-	0.012	-	-	-	<0.005
20	Phosphorus content	<0.1 (ppm)	-	<0.001	-	-	-	<0.1
21	Free glycerin % (m/m)	0.009	-	0.01	-	-	0.015	0.002
22	Total glycerin % (m/m)	0.091	-	0.01	-	-	0.0797	0.079
23	Monoglyceride % (m/m)	0.265	-	-	-	-	-	0.244
24	Diglyceride % (m/m)	0.078	-	-	-	-	-	0.079
25	Triglyceride % (m/m)	0.02	-	-	-	-	-	0.02
26	Iodine number	-	80.3	54	-	67.45	85.5	78.7
27	Oxidation stability (h, 110 °C)	8.5	1.7	10.3	-	-	4.1	8.7

Table 9
Summarization of various biodiesel physical and chemical properties for the main feedstocks[31-33].(cont'd)

No	Fuel Properties	Biodiesel						
		Rapeseed	Rice bran	Safflower	Soybean	Sunflower	Tallow (Beef)	Waste Cooking Oil
1	Density 15 ^{o}C (kg/m3)	882	872	888.5	913.8	880	-	870
2	Viscosity at 40 ^{o}C (cSt)	4.439	4.81	5.8	4.039	4.439	4.824	4.70
3	Cetane number	54.4	51.6	56	37.9	49	-	48-56
4	Calorific value (MJ/kg)	37	41.38	38.122	39.76	-	-	39.80
5	Acid (neutralization) value (mg KOH/g)	0.24	0.48	0.32	0.266	0.027	0.147	0.41
6	Pour point (^{o}C)	-12	269 (^{o}K)	-	-	-	-	-0.3
7	Flash point (^{o}C)	170	430 (^{o}K)	148	254	>160	>160	161.7
8	Cloud point (^{o}C)	-3.3	-	-5	0.9	3.4	16	5.3
9	Cold filter plugging point (^{o}C)	-13	-	-	-4	-3	14	-2.8
10	Copper strip corrosion (3 h at 50 ^{o}C)	-	-	-	1a	1a	1a	
11	Distillation temperature (%)	344.3	346		345.0	356.5		350.1
12	Carbon (wt%)	81	76.22	59.5	77.03	76.90	-	76.90
13	Hydrogen (wt%)	12	12.38	-	11.90	11.84	-	12.02
14	Oxygen (wt%)	7	11.26	-	10.95	10.98	-	10.77
15	Methanol content % (m/m)	-	-	-			-	
16	Water and sediment content (vol%)	-	-	-	<0.005	<0.005	<0.005	
17	Ash content % (w/w)	-	-	-	-	-	-	
18	Sulfur % (m/m)	4.6 (ppm)	11(ppm)	-	0.8	0.2 (ppm)	7 (ppm)	8.6 (ppm)
19	Sulfated ash % (m/m)	-	-	-	<0.005	<0.005	<0.005	
20	Phosphorus content	-	-	-	<0.1 (ppm)	<0.1 (ppm)	<0.1 (ppm)	
21	Free glycerin % (m/m)	-	-	-	0.012	0.007	0.008	
22	Total glycerin % (m/m)	-	-	-	0.149	0.121	0.076	
23	Monoglyceride % (m/m)	-	-	-	0.473	0.387	0.273	
24	Diglyceride % (m/m)	-	-	-	0.088	0.092	0.063	
25	Triglyceride % (m/m)	-	0	-	0.019	0.0	0.0	
26	Iodine number	111.7	91.8	136.7	128.6	126	-	85.1
27	Oxidation stability (h, 110 ^{o}C)	7.6	-	-	2-5	1.3	1.6	5.0

effect on the various metals. Most the biodiesel in Table 9 have a copper strip corrosion results with the lowest level of corrosiveness (No 1a). This means that corrosion would not be a problem for those biodiesels.

G. Cold-Flow Properties

One of the major problems related with the use of biodiesel is poor low temperature flow properties, which indicated by relatively high cloud points (CP) and pour points (PP)[47]. The CP, which usually occurs at a higher temperature than the PP, is the temperature at which a liquid fatty material becomes cloudy due to formation of crystals and solidification of saturates. These formed crystals can cause operation problems because they can plug the fuel lines and filters and causing major operability problems. The pour point is the lowest temperature at which the fuel will still flow and can be pumped. Saturated fatty compounds have significantly higher cold flow properties than unsaturated fatty compounds (Table 9) and in a mixture they crystallize at higher temperature than the unsaturates. The biodiesel from feedstocks with large amounts of saturated fatty acids have higher cloud points and pour points. Unsaturated compounds have better low temperature properties but fail in oxidation stability. All biodiesel fuels regardless of its source have higher cloud and pour points than that of petroleum diesel fuel, and this poor cold flow property is one of the most critical obstacles against the widespread biodiesel usage. The fatty acid composition of biodiesel greatly influences its cold-flow properties.

H. Oxidation Stability

Oxidation stability is one of the major issues influencing the use of biodiesel or FAME, due to the nature of biodiesel, makes it more susceptible to oxidation or auto-oxidation during long-term storage than petroleum diesel fuel. Because of their chemical composition, fatty acid methyl esters are more sensitive to oxidation degradation than petroleum diesel fuel especially those esters containing a high content of twice and morefold unsaturated esters, as the ethylene groups adjacent to double bonds have turned out to be particularly liable to radical attack as the first step of fuel oxidation[56]. In general, unsaturated fatty compounds are more susceptible to oxidation than saturated compounds. Oxidation is caused from the presence of double bonds in the chains, that is, feedstocks rich in polyunsaturated fatty acids are much more susceptible to oxidation than the feedstocks rich in saturated or monounsaturated fatty acids[53]. The autoxidation of unsaturated fatty compounds proceeds at different rates depending upon the number and position of the double bonds. For instance, relative rates of oxidation are 1 for oleates (C18:1), 41 for linoleates (C18:2) and 98 for linolenates (C18:3[47,60]. Oxidation eventually deteriorates the fuel properties because of gum formation. This formed gum does not combust completely, resulting in carbon deposits in the combustion chamber and lubrication oil thickening[4].

As seen in Table 9, the oxidation stability values of the biodiesel range from 0.4 hr (for the most unsaturated biodiesel, linseed) to 35.5 hr (for the most saturated one, coconut). It means that biodiesel from coconut the more stable (35.5 hr) and linseed the more sensitive to oxidation degradation (0.4 hr). The oxidation stability of biodiesel is influenced by environmental and chemical factors. Environmental factors include temperature, exposure to light and air, and storage tank material of construction. Chemical factors include the fatty acid methyl ester (FAME) composition, natural antioxidant content, and the presence of minor components. Leung *et al*. reported that temperature and air exposure are two important factors affecting the degradation of biodiesel[61]. Table 8 lists that the specification in the US for the oxidation stability has a minimum value of the order 3 hours, but European specification and Indonesia specification have a minimum value of oxidation stability of the order of 6 hours. Obviously, in US using soybean and sunflower as feedstocks that its oxidation stability around 2-5 hours and 1.3 hours, respectively. Soybean and sunflower have unsaturated fatty compounds especially polyunsaturated 58% and 66%, respectively. Meanwhile in Europe using rapeseed with its oxidation stability 7.6 hours and Indonesia using palm oil with its oxidation stability 10.3 hours. The oxidation stability of biodiesel can be improved by addition of an antioxidant (an appropriate additive).

From several researchs reported that higher composition of saturated fatty acid in feedstock increases the oxidation stability but lowers the cloud point and pour point of biodiesel, whereas, higher composition of unsaturated fatty acids enhances cloud point but possess a poor oxidative stability. Therefore, a balance has to be maintained between the ratio of saturates and unsaturates for an oil to be used as a feedstock for biodiesel production[62].

I. Distillation temperature

Distillation is a method of separating mixtures based on differences in volatilities of components in a boiling liquid mixture. In general, most biodiesels contain a few numbers of major fatty acid compounds and boil at roughly the same temperature (approximately 330-357°C at atmospheric pressure). Therefore, the distillation temperature specification can be used as indicator for residual methanol and/or glycerol content. For example, in cases where unusually low distillation temperatures were reported, these were actually combined with low CN and flash point, indicative of high residual amounts of methanol and/or glycerol content. As seen in Table 8 that there are no European specifications for biodiesel distillation, whereas in the US and Indonesia have a maximum limit of 360^{o}C for T90. Table 9 lists the high values for T90 is biodiesel from castor (381^{o}C) and the low values is palm (339^{o}C).

J. Heating atau Calorific value

The heat of combustion or calorific value is a measure of the energy available from the fuel. Biodiesel contains approximately 8–12% less energy than that of petroleum diesel fuel, due to the content of oxygen in fatty acid methyl ester (FAME, Biodiesel), which leads to proportionally lower energy density and heating or calarific value, thus more fuel needs to be injected in order to achieve the same engine power output. The calorific value or heat of combustion increases with increasing chain length and decreases with increasing unsaturation. The energy content of fatty acid methyl esters (biodiesel) is directly proportional to chain length.

K. What is the Best Feedstock for Biodiesel Production?

Since the composition of the biodiesel feedstock was found to affect the final ester's or biodiesel properties decisively, a question arises as to which is the biodiesel feedstock with the best properties, or whether it is more preferable to use saturated or unsaturated oils for the production of methyl esters. Although production cost, apart from the chemical properties, plays a important role here, it is not easy to answer this question in a single and irrevocable manner. Saturated feedstocks (such as those derived from coconut, palm and tallow) excel in cetane number and oxidation stability, while exhibiting poor cold flow properties, higher kinematic viscosity, lower (but still high enough) flash point and lower heating/calorific value. In contrast, increasing the unsaturation decreases the kinematic viscosity, improves the cold flow properties (additives are most probably still required) and increases moderately the heating/calorific value, but also lowers the cetane number and deteriorates the oxidation stability. Interestingly, it is the most unsaturated feedstocks that are susceptible to rejection based on the existing specification limits.

There are two feedstocks that differentiate by a lot from the others, i.e. coconut and castor. Coconut methyl ester is the most saturated biodiesel, and is characterized by low viscosity and high cetane number (CN). Castor, on the other hand, although exhibiting excellent oxidation stability and at the same time has very good cold flow properties, fails to fulfill three major fuel specifications namely, cetane number, viscosity and density. Interestingly, the most popular biodiesel (methyl ester) worldwide, soybean methyl ester, should be rejected in pure form in Europe and Indonesia since it does not meet the (rather strict) iodine number (IN), the oxidation stability and usually the CN specification. Other feedstocks that do not (or only marginally) fulfill at least two specifications in the US or the EU or the Indonesia are the most unsaturated ones, namely linseed, safflower, and sunflower.

VII. CONCLUSION

Biodiesel has recently become more attractive because of its environmental benefits and the fact that it is made from renewable resources.

From this overview, it can be concluded that biodiesel feedstock can be divided into four main categories: (i). Edible vegetable oil: rapeseed, soybean, peanut, sunflower, palm and coconut oil. (ii). Non-edible vegetable oil: jatropha, karanja, cotton seed, algae and halophytes. (iii). Waste or used cooking oil. (iv). Animal fats: tallow, yellow grease, chicken fat and by-products from fish oil. Biodiesel feedstocks have three main types of fatty acids as the main compounds that are present in a triglyceride: saturated (Cn:0), monounsaturated (Cn:1) and polyunsaturated (Cn:2,3). The percentage of these compounds differs for each vegetable oil. Biodiesel feedstocks from different or even from the same source may have different chemical structures and consequently different properties. Important fuel properties of biodiesel that are influenced by the fatty acid composition are viscosity, cetane number, heat of combustion, cloud point, oxidation stability, and lubricity.

The overall biodiesel properties are strongly influenced by the properties of individual fatty acid esters in biodiesel.Viscosity of biodiesel increases with the increase in the chain length (number of carbon atoms) and decreases with the increase in the number of double bonds (unsaturation level). Unsaturation in the fatty acid chain is a significant factor causing lower cetane number. The degree of unsaturation (average number of double bonds) was found to correlate excellently with the iodine number. The feed stock with relatively low concentration of saturated fatty acids shows lower cloud point. Oxidation stability is one of the major issues influencing the use of biodiesel or FAME, due to the nature of biodiesel, makes it more sensitive to oxidation or auto-oxidation during long-term storage than petroleum diesel fuel.The oxidation stability values of the biodiesel range from 0.4 hr (for the most unsaturated biodiesel, linseed) to 35.5 hr (for the most saturated one, coconut). The more unsaturation is present in the biodiesel feedstock, the higher the iodine value and higher is the tendency of the oil to polymerize. The density of biodiesel varies depending on its feedstock. Longer and straighter chains (saturated fats) tend to have higher density than shorter and unsaturated molecules.

It is difficult to determine, which is the biodiesel feedstock with the best properties, or whether it is more preferable to use saturated or unsaturated oils for the production of methyl esters (biodiesel).

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