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Chapter 3

A Comprehensive Review on the Physical and Chemical Properties of the Three Generations of Biofuels

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Abstract

The shortage of fossil fuel resources and the dramatic increase in population have raised many concerns about fuel supply in the years ahead. Researchers are now focusing on renewable fuels, and biodiesel is one of those renewables. Four generations of biodiesel have been reported today and many studies have been done to optimize and enhance their performance. The present review article examines the physical and chemical properties of three generations of biodiesel. It was observed that the physical and chemical properties of the biodiesel vary based on the feed stocks and have a significant effect on the dynamic characteristics of emission level and performance of engine. All properties have the highest and lowest ranges for each feed. All the oils that have been studied for three generations to date have been fully reported, and these properties have been studied and compared for each of the three generations.

Keywords: Biodiesel; First Generation; Second Generation; Third Generation; Physical and Chemical Properties

1. Introduction

policies and dramatic fuel price changes in fuel-producing countries have caused many crises in the world. Lack of adequate resources and fossil fuel contamination in the world are other causes of global energy issues. (**Figure 1**) shows the increase of the demanding for the crude oil and the price changes in the world. These reasons have made the need for alternative fuel in the world completely necessary. Nowadays, biofuels have attracted a lot of attention as an alternative to fossil fuels [1-5]. Biofuels are included several advantages and the most important of them are related to the environmental benefits. Biodiesel can diminish emissions that cause environmental difficulties such as acid rain and global warming. Also, health issues as a consequence of emissions exposure are significantly declined by the cleaner emissions of biodiesel [5, 6]. Biodiesel is the non-petroleum based diesel fuel. It is contained of the mono-alkyl esters of the long-chain fatty acids derived from the renewable lipid sources [7-9]. Quality of biofuels is always dependent on many factors. Some of them are included the feedstock, fatty acid composition, production process, handling and storage, and postproduction parameters [10].

The close similarities between the properties of biodiesel and diesel fuels make that biodiesel is a good alternative to diesel fuels. The viscosity of biodiesel is so close to the diesel fuel. The conversion of triglycerides into ethyl or methyl esters via the transesterification procedure diminishes the molecular weight and viscosity and rises the volatility gradually. The cetane number is around 50-60 for biodiesel and it's higher than diesel fuels, however, the heating value of the diesel fuel is greater than biodiesel. The flashpoint and density of biodiesel are much higher than diesel fuels, while the cloud point for diesel fuels normally is better than biodiesel fuel. The sulfur compounds in petrodiesel provide much of the lubricity, however, Biodiesel comprises virtually no sulfur and this is frequently applied as the additive to ultra-low-sulfur diesel (ULSD) fuel to help with lubrication [11-13].

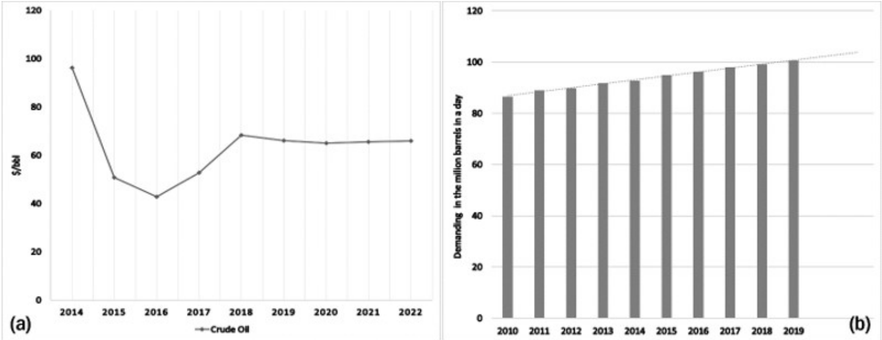

Figure 1: World Bank: average crude oil prices (a) and daily demand for crude oil worldwide (b)

1.1. Biodiesel feedstocks

The different types of feedstocks are used for the production of biodiesel. The choice of feedstocks relies on the economic aspects and availability of the concerned country. The major biodiesel feedstocks for different regions of the world are shown in (**Figure 2**). Four generations of biodiesel fuels are applied worldwide.

Figure 2: Main biofuel producers by region

The first generation of biodiesel is edible oils such as palm, soybeans, rapeseed, and sunflower oil. Some of the main advantages of the first generation of biodiesel are shown in Fig 3. However, the use of edible oil sources as biodiesel fuel has caused great concern in the world. These concerns include the possibility of food shortages in the world and rising food prices. This generation has also required arable land for the production and it creates serious ecological imbalances due to that countries start cutting down forests for plantation purposes. Therefore, the demand for biodiesel increases, it will cause severe damage to the environment and wildlife, due to the greater need for arable land and larger scale deforestation [3, 5].

The second generation of biodiesel is non-edible oils. The mahua, jatropha, tobacco seed, jojoba oil are examples of second-generation biodiesel. This generation of biodiesel has many advantages, as shown in Fig 3. This generation also has some limitations for worldwide using. They may not be abundant enough to substitute transportation fuels. The performance of this generation has some restriction in cold temperatures [14].

The third generation of biodiesel are included microalgae, animal fats, and waste cooking oils. Some advantages of this generation are shown in (Figure 3) [3]. While, this generation requires huge amount of money for producing. According to research, the production of algae biofuel still requires a lot of work, mainly in the process of the oil extraction and low yields as well as it emits captured carbon dioxide.

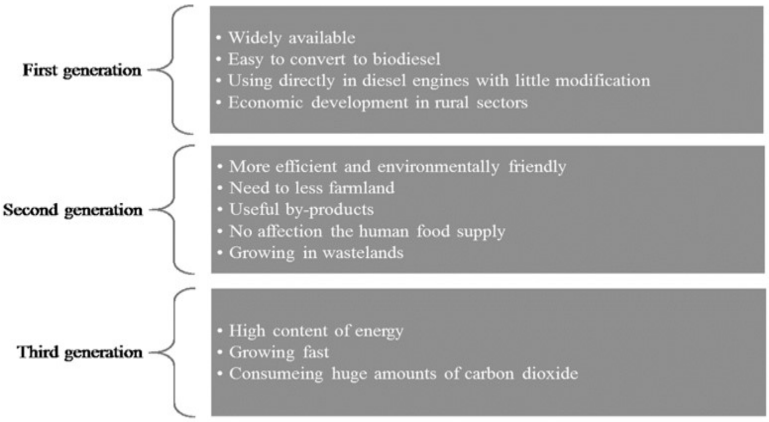

Figure 3: The advantages of the first, second, and third generation

Limited information is available on fourth generation biodiesel. This has led to a complete lack of scrutiny in this area. The Synthetic Genomics Company is applied genetic engineering in production of biofuel. The genetically modified microorganisms is used to generate fuel directly from the carbon dioxide on the industrial scale. Furthermore, the fourth generation biofuels are gained from genetically modified crops in which they spend more carbon dioxide from the atmosphere than they release over combustion which makes it a carbon negative fuel.

1.2. The standards of biodiesel in the worldwide

Several studies indicated that the physical properties of biodiesel have a huge effect on emission and combustion. The physical and chemical properties of the produced biodiesel must reach the standard value defined in the different regions for using. Some of the standards are included EN 14213/EN 14214, SANS 1935, JASO M360, ASTM D 6751, ANP 42, and IS 15607 which used in EU, South Africa, Japan, U.S, Brazil, and India, respectively [10]. Some of the most important physical characteristics of biodiesel are included density, cetane number, kinematic viscosity, flash point, pour point and cloud point, calorific value, acid value, copper strip corrosion, ash content, sulfur content, glycerine, and oxidation stability [12, 15]. Standards set guidelines for testing the biodiesel fuels and propose the proper ranges for different physical and chemical properties of the fuel.

There have been limited studies of the physical properties of biodiesel, but no reports to date have examined the physical properties of all three generations of biodiesel and comparing them to one another. A recent study has surveyed all the physical properties of three-generations of biodiesel from all oil sources which effect on the engine performance and emission features and also shown comparisons between them. The report also mentioned the lowest highest values of properties and shows the range for all biodiesels.

1.3. Characteristics and properties of three generations of biodiesel

The important physical properties of three-generation biodiesels are summarized in Table 1, 2, and 3. The Physicochemical property ranges are illustrated for pure biodiesels. All tables show the most important properties of biodiesels such as Density (kg/m^3), Kinematic Viscosity 40°C (mm^2/s), Calorific Value (Mj/Kg), Higher (gross) Heating Value (Mj/Kg), Lower (net) Heating Value (Mj/Kg), Acid Value (Neutralization number) (mg KOH/g), Flash Point (°C), Cetane Number, Oxidation Stability (h), Cloud Point (°C), and Pour Point (°C).

There have been numerous reports on the types of vegetable oils and different amounts have been reported. About 69 first generation oils that have been the most researched are shown in (**Table 1**).

Taramira (Eruca sativa)	at 15°C: 881.1 [183] at 40°C: 871±0.15 [184]	5.71±0.21, 5.9 [184] [183]	…	…	…	0.40 [183]	197.3±2.1 [184]	48, 59.08±1.34 [183] [184]	6 [183]	1.5±0.7 [184]	-2.97±0.17 [184]
Tea seed (Camellia)	at 20°C: 884 [185]	4.95 [185]	37.512 [185]	…	…	…	120 [185]	52 [185]	…	…	…
Thistle (Silybum marianum)	at 20°C: 863 [186] at 15.6°C: 0.8788 ± 0.0012 [187] at 40°C: 899 [188]	4.46, 6.32 [186] [188]	16.984 [188]	…	…	0.10 ± 0.01, 0.44 [187] [186]	115.0 ± 0.50, 153 [187] [186]	44, 51 [188] [186]	2.1 [186]	-1, 7 [186] [188]	-6, 10 ± 1.0 [188] [187]
Tobacco seed (Nicotiana tabacum)	at 15°C: 886.8, 888.5 [189] [137] at 25°C: 870 [190] at 20°C: 882 [191]	3.5, 5.2 [189] [191]	38, 39.811 [190] [189]	…	…	0.3 ,0.66 [137] [191]	165.4 [137]	51, 52 [189] [190]	0.8 [137]	…	…
Tomato seed	at 40°C: 915.1 [192]	28 [192]	…	35.9 [192]	…	…	189 [192]	54.71 [192]	…	…	…
Castor	at 20°C: 917 [90]	13.5, 14.4 [43] [90]	…	…	…	0.42, 3.9 [43] [90]	165 to 186.5 [193]	…	…	…	…
Colza (Brassica rapa)	at 20°C: 882±25 [30]	4.02±0.12 [30]	…	…	…	0.22±0.03 [30]	185±3 [30]	…	11.2±0.1 [30]	...	…
Radish	…	4.6 [37]	…	…	…	…	…	53 [37]	…	…	…
Tigernut (Nut-sedge , Cyperus esculentus)	at 30°C: 866 [194]	2.34 [194]	…	…	…	…	186 [194]	…	…	…	…

Niger seed (Asteraceae , Guizotia abyssinica)	at 15°C: 890 [163]	4.10, 4.30 [163] [164]	…	…	…	…	128, 157 [163] [164]	57 [164]	1.02 [164]	3, 4 [163] [164]	2.5 [163]
Okra seed (Abelmoschus esculentus)	at 15°C: 870 [104]	4.1 [104]	…	…	…	0.22 [104]	126 [104]	…	1.6 [104]	6 [104]	6 [104]
Papaya seed	at 40°C: 840, 900 [165] [166] at 15°C: 895 [134]	3.53, 6 [165] [167]	42.085 [41]	38.49, 38.97319 [165] [134]	…	0.35, 0.72 [167] [166]	112, 147 [165] [134]	77.3, 48.29 [168] [165]	…	1, 2 [167] [168]	-1, 1 [167] [168]
Pequi (Caryocar brasiliense)	at 20°C: 69.69 ± 0.07, 866.3 [169] [170]	4.27 ± 0.03, 5.64 [169] [170]	…	…	…	0.7909 [170]	…	…	4.5±0.3, 5.85 [169] [170]	…	…
Pomegranate seed (Punica granatum)	at 40°C: 892 [171] at 20°C: 895.2 [135]	3.31, 5.65 [135] [171]	39.49, 40.048 [135] [171]	…	…	…	130 [171]	26.1, 45.02 [135] [171]	…	…	…
Poppyseed	893 [41]	3.5, 4.63 [49] [41]	42.085 [41]	…	…	…	…	…	…	…	…
Pracaxi (Pentaclethra macroloba)	at 20°C: 869±6 [172]	5.8 ±0.03 [172]	…	…	…	…	…	…	3.2±0.2 [172]	…	…
Rice bran	at 40°C: 868.1 [26] at 15°C: 876±15.7, 892 [173] [174]	4.14, 5.37 [175] [114]	39.957, 42.2 [26] [176]	39.5, 43.10±0.98 [114] [173]	…	0.09, 0.586 [175] [26]	174.5, 183 [26] [176]	73.6, 51 [26] [114]	1.61, 1.63±0.12 [86] [173]	-10, 9 [174] [176]	-11, -2.00±0.14 [174] [173]
Sacha inchi	…	4.66 [177]	…	…	…	0.39 [177]	…	…	…	…	…
Sapote	at 40°C: 864 [178]	4.5, 5.43 [179] [178]	37.12 [178]	37.12 [179]	…	0.16 [179]	174 [178]	52 [178]	…	…	-6 [179]
Shea butter	At 5°C: 877, 883 [180] [181]	4.42, 5.93 [180] [181]	…	37.93, 37.98 [180] [182]	38.9 [182]	0.16, 0.28 [181] [180]	130, 171 [181] [180]	47, 58 [181] [180]	…	3,12 [182] [181]	3, 10 [180] [181]

Cocklebur (Xanthium)	at 15°C: 896.89 [148]	6.877 [148]	38.527 [148]	…	…	…	166 [148]	42.3 [148]	…	-1 [148]	-19 [148]
Coriander seed	…	4.21 [92]	…	40.1 [92]	37.5 [92]	0.1 [92]	…	…	14.6 [92]	…	-19 [92]
Date seed	at 15°C: 870 to 890 [149]	3.7 to 4.2 [149]	…	…	…	…	122 to 131 [149]	53.56 [149]	…	3 to 7 [149]	…
Dika (Irvingia gabonensis)	…	3.2 [150]	39 [150]	…	39 [151]	0.01 [150]	140 [150]	…	…	-14 [151]	-6 [151]
False flax (Camelina sativa)	…	2.9 to 3.15, 4.37 [152] [51]	45.05 to 46.15 [152]	…	…	0.04 [51]	179 [51]	41.26 to 51.17 [152]	…	4.1 [51]	-11 to -8, 0 [152] [51]
Grape seed	at 20°C: 882 [135] at 32°C: 890 [126]	4.04, 4.1 [135] [38]	39.73 [135]	…	…	0.27, 0.31 [38] [126]	175 [38]	48, 48.6 [38] [135]	0.5 [38]	…	-22 [126]
Hemp	at 15°C: 884, 891.5 [153] [154] at 40°C: 858, 872 [155] [156]	3.48, 4.23 [155] [156]	39.81 [155]	…	…	0.01, 0.67 [156] [153]	120, 175 [154] [157]	…	…	-5, -2.5 [153] [154]	-17, -4 [155] [154]
Kapok seed (Ceiba pentandra)	at 15°C: 876.9, 890 [158] [104] at 40°C: 875 [159]	4.2, 5.4 [104] [159]	40.493 [158]	36.292 [159]	…	0.24, 0.38 [104] [158]	156, 167 [159] [104]	57.2 [158]	0.8, 4.42 [104] [158]	2, 3 [104] [158]	1, 2.8 [104] [158]
Kenaf seed (Hibiscus cannabinus)	at 15°C: 879.5 [160]	4.8 [160]	…	…	…	0 [160]	…	54 [160]	0.35 [160]	3.8 [160]	1.7 [160]
Marula (Sclerocarya birrea)	at 25°C: 877 [161]	4.12 [161]	…	…	…	…	171 [161]	…	…	6 [161]	3 [161]
Meadowfoam seed	…	6.18, 6.22 [162] [51]	…	40.591 [162]	38.499 [162]	0.02, 0.06 [162] [51]	205 [51]	…	…	-6.6, -6 [51] [162]	-10 [162]
Mustard	at 40°C: 866 [36]	4.1 [36]	…	41.3 [36]	…	…	169 [36]	…	…	…	…

Açaí (Euterpe oleracea)	…	4.5 [138]	…	…	…	…	200 [138]	…	1.5 [138]	…	…
Black seed (Nigella sativa)	at 15°C: 886.1 [139] at 40°C: 867.7 [139]	4.5026 [139]	39.967 [139]	…	…	0.26 [139]	172.5 [139]	…	1.32 [139]	-1 [139]	-1 [139]
Blackcurrant seed (Ribes nigrum)	at 15°C: 892.6 [140]	3.84 [140]	…	…	…	0 [140]	…	40.5 [140]	1.67 [140]	-2.2 [140]	-12 [140]
Borage seed (Borago officinalis)	at 15°C: 887.09 [140]	4 [140]	…	…	…	0 [140]	…	45.6 [140]	1.67 [140]	4.5 [140]	-2 [140]
Evening promise (Oenothera biennis)	at 15°C: 878 [141]	5.68 [141]	…	…	…	0.37 [141]	196 [141]	51 [141]	…	7 [141]	4 [141]
Flaxseed (linseed , Linum usitatissimum)	at 40°C:870, 888.2 [32] [142]	2.8, 4.07 [32] [25]	…	40.84, 41.82 [32] [142]	37.267 [25]	…	142, 184 [36] [138]	41, 55 [37] [142]	2.2 [138]	…	…
Apricot	at 15°C: 884.3 [143]	4.92 [143]	39.95 [143]	…	…	…	111 [143]	…	…	…	…
Apple seed	at 20°C: 881 [135] at 40°C: 865 [144]	4.12,5.9 [135] [144]	37.51, 40.48 [145] [144]	…	…	0.34 [144]	150, 161 [145] [144]	50.4 [135]	…	2 [145]	5 [145]
Avocado	at 15°C: 877.68 [146]	4.9581 [146]	41.33 [146]	…	…	…	184 [146]	…	…	…	-7 [146]
Babassu (Attalea speciousa)	…	3.18 [147]	…	…	…	0.0778 [147]	112 [147]	…	…	…	…
Ben (Moringa oleifera)	at 40°C: 859.6, 869.6 [22] [63] at 15°C: 869.6, 885.8 [56] [86]	4.1264, 5.0735 [86] [27]	40.05 [22]	39.888, 40.115 [86] [27]	…	0.05, 0.185 [56] [26]	150.5, 180.5 [63] [56]	56, 67.07 [56] [26]	4.45, 26.2 [56] [63]	0, 19 [86] [56]	19 [27]

Macadamia	at 15°C: 859.2, 868 [114] [115]	4.4, 4.57 [37] [115]	39.88 [115]	39.9 [114]	…	0.08 & 0.055, 0.15 [116] [115]	135, 178.5 [115] [114]	55, 59.5 & 57.5 [37] [116]	1.97 & 2.06, 3.35 [116] [114]	-1, 8 [117] [114]	-3, 5 & 1 [115] [116]
Mongongo nut (Manketti , Schinziophyton rautaneuii)	at 15°C: 876, 878 [118] [119] at 25°C: 869 [120]	3.72, 4.43 [120] [118]	36.97, 37.82 [118] [119]	41.2 [120]	…	0.08, 0.35 [118] [120]	150, 165 [119] [120]	49.1, 51 [118] [120]	4.75 [119]	-3.8, 1.2 [119] [118]	-6.2, -4.1 [119] [118]
Pistachio	at 15°C: 860, 880 [121] [122]	3.44, 4.71 [121] [122]	…	…	…	0.16, 0.187 [122] [121]	148, 168 [122] [121]	52, 53.94 [122] [121]	8.3 [122]	-2 [122]	-1 [122]
Walnut	at 40°C: 864 [36] at 15°C: 864 [89]	3.88, 4.11 [68] [89]	39.47, 41.18 [68] [89]	41.32 [36]	…	0.03 [68]	170 [36]	…	2.9 [68]	-6.1 [68]	-10 [68]
Lemon	at 40°C: 853 [123]	1.06 [123]	41.510 [123]	…	…	…	…	…	…	…	…
Orange	at 40°C: 812, 876 [124] [125] at 32°C: 892 [126] at 15°C: 852 [127]	1.04, 5.6 [127] [126]	38.158, 42.8 [125] [124]	…	…	0.25 [126]	29, 78.5 [127] [125]	37, 49 [125] [124]	…	…	-25, -10 [126] [125]
Bitter ground (Momordica charantia)	at 15°C: 889 ± 10.50 [128]	4.48 ± 1.02 [128]	…	…	…	0.40 ± 0.39 [128]	162 ± 11.20 [128]	64.0 ± 4.80 [128]	1.99 ± 0.85 [128]	9.00 ± 2.12 [128]	15.00 ± 1.82 [128]
Egusi seed (Cucumeropsis mannii naudin)	at 15°C: 883, 884±8.75 [129] [99]	3.83, 3.91±0.014 [129] [99]	…	39.97, 42±1.2 [129] [99]	…	0.11±0.01, 0.19 [99] [129]	142±2.82 [99]	53.66, 55 [99] [108]	1.32±0.1, 1.41 [99] [129]	0.5±0.1 [99]	…
Pumpkin seed	at 15°C: 883.7 [130]	4.1, 4.41 [37] [130]	40.21 [131]	38.08, 40.84 [130] [132]	…	0.48 [130]	120, 175 [130] [131]	47, 60.01 [37] [132]	7.2 [131]	-18 [131]	-32 [131]
Watermelon seed (Citrullus vulgaris)	at 15°C: 800, 893 [133] [134] at 20°C: 880.6 [135]	1.05, 5.33 [133] [134]	39.74, 39.85 [135] [136]	39.36195 [134]	…	1.387, 3.66 [136] [137]	107, 143 [133] [134]	44.47, 54.682 [133] [136]	…	-1 [133]	-3 [133]

Soybean	at 40°C: 855, 877 [33] [32] at 20°C: 871±20, 885 [30] [90] at 15°C: 881.1, 887 [53] [41]	3.5, 5.75 [32] [91]	39.72 to 40.08, 40.297 [44] [41]	39.85, 45.07 [92] [53]	37.38, 37.75 [92] [33]	0.04±0.01, 0.45 [44] [91]	152, 202.5 [41] [27]	58.1, 46 [93] [37]	1.3, 6±0.3 [38] [30]	-2, 4 [33] [93]	-6, 1 [33] [27]
Sunflower	at 40°C: 863, 874 [36] [32] at 20°C: 832±4 [30] at 15°C: 880, 888.4, [41] [94]	3.2, 5.241 [49] [95]	38.1 to 38.472, 42.02 [44] [96]	41.03, 41.33 [32] [36]	37.532 [25]	0.04±0.01, 1.3 [44] [95]	125, 192±2 [41] [30]	47, 54 to 58 [37] [44]	0.5, 1.73 [95] [93]	-14, 5±1 [96] [44]	-16, -2±1 [44] [96]
Almond	at 25°C: 881 [58] at 15°C: 882±0.011, 887 [97] [98]	4.2, 4.726 [38] [58]	41.761 [58]	…	…	0.10±0.02, 0.44 [97] [98]	145, 173 [58] [98]	44.6, 58 [98] [99]	3, 3.1 [38] [99]	-3,11 [99] [88]	-9±0.5, -2 [97] [88]
Beech nut (Fagus sylvatica)	at 15°C: 876 [100]	3.8 to 4 [100]	…	…	…	…	173 [100]	49 [100]	…	…	…
Brazilnut (Bertholletia excelsa)	…	4.3, 4.56 [37] [101]	…	…	…	0.15 [101]	170.3 [101]	53 [37]	…	…	…
Cashew	at 40°C: 863.6, 909.3 [102] [103] at 15°C: 880, 884 [104] [105] at 18°C: 882, 883.5 [106] [107] at 20°C: 890 [19]	3.85, 10.3 [107] [103]	37.51, 39.52 [105] [54]	34.3 [103]	…	0.25, 3.69 [104] [103]	113, 170 [104] [103]	51, 63 [37] [108]	5.6 [104]	-5, 10 [103] [107]	-1, 7.9 [103] [107]
Hazelnut	at 40°C: 875 [36] at 15°C: 863, 884.8 [109] [110]	3.097, 5.48 [109] [110]	37.23, 41.172 [111] [110]	39.889, 41.12 [112] [36]	39.75 [109]	0.05, 0.23 [68] [96]	152, 183 [36] [89]	52.6, 55 [109] [111]	7.6 [68]	-14.7±0.5, -9.3 [113] [68]	-17, -13 [96] [68]

Olive	at 40°C: 860 [36]	4.18, 6.18 [36] [54]	39.92 [54]	41.35 [36]	…	0.13 [38]	178, 204 [38] [36]	57, 61.72 [38] [27]	3.3 [38]	…	…
Palm	at 40°C: 858.9, 875 [22] [55] at 15°C: 858.9, 879.7 [56] [57] at 25°C: 884 [58]	2.8, 5.64 [23] [25]	36.5, 40.322 [23] [58]	38.3, 41.3 [59] [60]	37.13, 37.92 [61] [57]	0.01±0.01, 0.4 [44] [21]	125, 214.5 [23] [27]	44, 72.09 [59] [25]	2.41, 23.56 [22] [27]	3, 17±1 [62] [44]	3, 15±1 [63] [44]
Peanut (Arachis hypogea, Ground nut)	at 40°C: 861.1, 992 [39] [64] at 15°C: 848.5, 884 [65] [41] at 20°C: 877.1±2, 877.3 [66] [67]	4.29, 5.908 [39] [64]	39.98, 40.297 [68] [41]	…	…	0.08, 0.28 [68] [65]	156, 192 [67] [64]	53, 58.9±4.1 [38] [66]	2, 21.1 [38] [68]	0, 17.8 [65] [68]	-8, 15 [65] [68]
Rapeseed	at 40°C: 857, 872 [36] [32] at 20°C: 879.35 [29] at 15°C: 884, 880 [69] [70]	3.3, 5.51 [49] [71]	37.23, 38.7 [69] [72]	41.31, 41.55 [32] [36]	38.177, 39 [71] [73]	0.03, 0.33 [69] [74]	130, 180 [74] [36]	51, 55 [71] [38]	2, 8.1 [38] [74]	-5 [70]	-13, -10 [70] [69]
Safflower	at 40°C: 866 [36] at 15°C: 860, 890.73 [75] [76] at 20°C: 888, 891 [77] [78]	2.9, 5.8 [49] [79]	38.122, 40.71 [80] [41]	40.604, 45.21±1.58 [81] [82]	38.122, 39.322 [77] [79]	0.06, 0.39 [83] [75]	129, 187 [84] [85]	42.07, 53.16 [76] [75]	0.9, 2.66 [70] [81]	-5, -2±0.05 [76] [82]	-24, -7 [85] [81]
Sesame	at 40°C: 866.9, 884.8 [86] [26] at15°C: 867.2, 884.8 [87] [88]	3.04, 4.3998 [36] [26]	39.996, 40.7 [26] [89]	39.996, 40.9 [86] [32]	…	0.3 [87]	145, 208.5 [36] [26]	50.48 [87]	1.135, 1.14 [86] [26]	-6 to 1 [26]	-14 to 1 [26]

Table 1: Properties of the first generations of biodiesel.

Biodiesels	Physicochemical property ranges										
	Density (kg/m^3)	Kin. Viscosity 40°C (mm^2/s)	Calorific Value (Mj/Kg)	Higher (gross) Heating Value (Mj/ Kg)	Lower (net) Heating Value (Mj/Kg)	Acid Value (Neutralization number) (mg KOH/g)	Flash Point (°C)	Cetane Number	Oxidation Stability (h)	Cloud Point (°C)	Pour Point (°C)
Coconut (Coconut pulm , Copra)	at 40°C: 800 , 869.5 [16] [17] at 15°C: 873.3 [18] at 20°C: 870 [19]	2.61, 4.0927 [20] [21]	38, 41.9 [22] [23]	37.26, 39.95 [24] [16]	57.743 [25]	0.106, 0.35 [26] [21]	108, 120.5 [25] [22]	37, 63.73 [24] [19]	5.12, 9.2 [22] [18]	-3, 1 [18] [27]	-12, -4 [18] [22]
Corn (Maize)	at 15°C: 864.2, 879.65 [28] [29] at 20°C: 865±12, 890 [30] [31] at 40°C: 868, 880 [32] [33]	2.45 to 2.56, 4.89 [34] [29]	39.12, 44.92 to 45.06 [31] [34]	39.93, 41.14 [35] [32]	37.679, 38.48 [25] [33]	0.03±0.002, 0.3 [30] [28]	154, 188±4 [36] [30]	46, 58.37 to 59 [37] [34]	1.2, 6.5±0.3 [38] [30]	-15, -3 [28] [33]	-5 to -2 [34]
Canola	at 40°C: 853.6, 875±0.6 [39, 40] at 15°C: 883, 883.2 [41] [42]	2.56 to 2.84, 4.6 [34] [43]	44.65 to 44.93, 37.3 to 39.87 [34] [44]	25.11±0.29, 40.195 [40] [27]	…	0.01±0.01, 0.35 [44] [43]	105, 186.5 [41] [27]	48 to 56 [44]	7.08, 12 [27] [42]	-3, 1 to 2 [27] [40]	-4 to -1, -8 to -10 [34] [40]
Cotton seed	at 40°C: 871 [36] at 20°C: 878±9, 882±1 [30] [45] at 15°C: 850, 887 [46] [47] at 25°C: 875±15.7 [48]	3.1, 6 [49] [46]	39.19, 39.524 [47] [41]	41.68, 48.18 [46] [36]	36.896 [50]	0.02, 0.58 [51] [47]	150±3, 200 [48] [50]	48, 57.1 [52] [53]	1.83±0.12, 4.9±0.8 [48] [45]	-5, 7±0.11 [52] [48]	-4, 6±0.15 [46] [48]

Nerium oleander(Thevetia peruviana)	at 15°C: 875,880 [240] [241]	4.3, 4.33 [241] [240]	42.4, 44.986 [241] [240]	42.279 [240]	…	0.057, 0.66 [240] [241]	75, 178 [240] [241]	61.5, 71.5 [240] [241]	6.5 [241]	-3, 15 [241] [240]	-7, 3 [241] [240]
cebera odollam(sea mango)	at 15°C: 880 [242]	4.5 [242]	39.095 [242]	…	…	…	138 [242]	…	…	…	…
nagchampa	at 40°C: 876.8,877 [243] [244]	2.64, 4.72 [244] [243]	39.882 [243]	…	…	0.41, 0.76 [244] [243]	151, 159 [243] [244]	51.9 [243]	…	13 [243]	10 [243]
Croton megalocarpus	at 40°C: 867.2, 870.4 [22] [27] at 15°C: 883 [245]	4.05, 4.78 [22] [245]	37.24, 39.53 [245] [22]	39.786 [27]	…	0.16 & 0.2 [26]	164, 192 [27] [245]	46.6, 47.52 [26] [245]	0.71, 2.88 [27] [245]	-6, -3 [245] [27]	-3, -2 [22] [27]
Patchouli (Pogostemon cablin)	at 40°C: 922.1 [27]	6.0567 [27]	…	44.18 [27]	…	…	118.5 [27]	…	0.022 [27]	-33 [27]	-33 [27]
Sterculia foetida	at 40°C: 877.6 [27]	6.3717 [27]	…	40.001 [27]	…	…	130.5 [27]	…	1.46 [27]	1 [27]	2 [27]
greenseed	at 40°C: 877±1 [40]	…	…	20.95±0.2 [40]	…	0.162±0.021 [40]	…	…	…	1 to 3 [40]	-12 to -10 [40]
Aphanamixis polystachya	at 40°C: 873.5 [26]	4.7177 [26]	39.960 [26]	…	…	0.448 [26]	188.5 [26]	…	0.16 [26]	8 [26]	8 [26]

Honesty (Lunaria annua)	at 15°C: 877±2 [223]	6.815±0.034 [223]	…	…	…	0,42±0.02 [223]	…	78.9±0.8 [223]	…	…	…
Mango	at 40°C: 873, 882 [224] [225]	4.3, 4.73 [224] [225]	40.453 [225]	…	…	0.78 [224]	135, 178 [225] [224]	54 [225]	…	…	…
Neem (Azadirachta indica)	at 40°C: 868,895.2±0.59 [26] [226]	3.58, 5.53 [227] [228]	39.810 [26]	…	…	0.42, 0.649 [227] [26]	76 to 120, 175 [26] [227]	48 to 53, 57 [26] [229]	7.1 [26]	9 to 14.4, 6 [26] [228]	2,10 [26] [227]
Passion fruit (Passiflora edulis)	…	4.1 [138]	…	…	…	…	172 [138]	…	3.1 [138]	…	…
Rubber seed (Hevea brasiliensis)	at 15°C: 877.3 [230]	5.77 [230]	…	40.3 [230]	37.15 [230]	0.448 [230]	141 [230]	52.56 [230]	8 [230]	9 [230]	7 [230]
Sea buckthorn (Hippophae rhamnoides	at 20°C:886.5 [135]	3.79,[135]	39.64 [135]	…	…	…	…	40.9 [135]	…	…	…
Tall	at 15°C: 878 to 885, 922 [231] [232]	4.1 to 5.3, 7.1 [231] [232]	40.023 [232]	…	…	…	89 [232]	54 [232]	…	1 [232]	…
Tamanu (Polanga , Foraha, Calophyllum tacamahaca)	at 40°C: 869, 894 & 892 & 893 [197] [233] at 15°C: 868.7, 873 [56] [234] at 32°C: 905 [235]	5.74, 3.99 [22] [197]	38.33, 41.397 [234] [197]	39.38, 41.5 [56] [235]	…	0.3, 0.88 & 1 & 0.76 [120] [233]	93.5, 162.5 [22] [27]	56.53 & 58.42 & 58.39, 50 [233] [235]	3.58, 9.42 [56] [22]	7, 13.2 [56] [234]	4.3, 13 [234] [27]
Tucumã butter (Astrocaryum vulgare)	at 40°C: 877 [236]	3.7, 4.54 [237] [236]	…	…	…	0.23 [237]	124 [237]	…	…	…	…
sapindus mukorossi (soapnut)	at 15°C: 875, 876 [238] [239] at 20°C: 870 [238]	4.63 [239]	40.02 [239]	…	…	0.14 [239]	140 [239]	56 [239]	…	-1 [239]	-4 [239]

Stillingia (Chinese vegetable tallow, Sapium sebiferum)	at 15°C: 892, 900 [209] [210]	3.698, 4.81 [209] [210]	…	…	…	0.007, 0.15 [211] [209]	137, 180 [211] [209],	40.2, 50 [209] [210]	0.6, 0.8 [211] [209]	-13 [211]	…
Artichoke	at 25°C: 880 [212] at 15°C: 889 [213]	3.56, 5.101 [212] [213]	…	39.8 [212]	…	…	175, 182 [212] [213]	59 [213]	…	-4, -1 [213] [212]	…
Astrocaryum murumuru butter	at 20°C: 877.9 ± 1.6 [172]	3.1 ± 0.03 [214]	…	…	…	0.6±0.1 [214]	…	…	40 [172]	…	…
Balanos (Balanites aegyptiaca)	at 40°C: 860, 874.8 [215] [216]	3.98, 4.46 [215] [216]	42.5 [216]	39.65 [215]	…	0.34, 1.26 [215] [216]	75, 160 [215] [216]	42 [216]	…	…	-2.5, 0 [215] [216]
Brucea javanica	at 40°C: 871 [217]	3.556 [217]	…	…	…	0.027 [217]	164 [217]	…	3 [217]	2 [217]	1 [217]
Buriti (Mauritia flexuosa)	at 40°C: 877.3 ± 6 [172]	5.22 [218]	…	…	…	…	190 [218]	…	16.5 [218]	…	…
Candlenut (Kukui nut)	at 40°C: 886.9 [219] at 20°C: 885.7 [220]	4.8, 4.819 [220] [219]	40.33 [220]	…	…	0.4 [220]	160, 161 [219] [220]	…	5.9 [220]	6 [220]	6.667, 6.84 [219] [220]
Chaulmoogra (Hydnocarpus wightiana)	at 40°C: 893 [221]	5.4 [221]	40.7 [221]	…	…	…	163 [221]	…	…	…	2 [221]
Crambe (Crambe abyssinica)	at 40°C: 848 [32]	5.1, 5.12 [32] [36]	…	41.98, 42.26 [36] [32]	…	…	190 [36]	…	…	…	…
Croton (tiglium , Croton tiglium)	at 40°C: 865 [16]	4.78 [16]	…	39.95 [16]	…	…	…	46.6 [16]	…	…	…
Cuphea	…	2.38 & 2.4 [222]	…	…	…	…	…	56.07 & 55.06 [222]	3.09 & 3.57 [222]	-9.1 & -10.1 [222]	-21.5 & -22.5 [222]
Cupuaçu butter	…	4.8 [138]	…	…	…	…	176 [138]	…	72.7 [138]	…	…

A wide range of second-generation oils, all of which are non-edible, are reported in the table. Table 2 shows the second generation oils that have been the most researched. The limitations of second generation oils compared to first generation oils are quite evident and 39 oils have been studied to date.

Table 2: Properties of the second generations of biodiesel.

Biodiesels	Physicochemical property ranges										
	Density (kg/m^3)	Kin. Viscosity 40°C (mm^2/s)	Calorific Value (Mj/Kg)	Higher (gross) Heating Value (Mj/Kg)	Lower (net) Heating Value (Mj/Kg)	Acid Value (Neutralization number) (mg KOH/g)	Flash Point (°C)	Cetane Number	Oxidation Stability (h)	Cloud Point (°C)	Pour Point (°C)
Tung	at 15°C: 883, 903 [195] [196]	4.64, 7.84 [195] [196]	38.8 [195]	…	…	0.124 [196]	197 [195]	39 [196]	0.3 [196]	…	…
Jatropha	at 40°C: 864.2, 873 [27] [197] at 20°C: 784, 875.9 [198] [199] at 15°C: 865.7, 880 [56] [104]	2.35 to 2.47, 6.1 to 6.7 [34] [200]	39.56, 42.673 [200] [152]	39.738, 39.84 [27] [16]	…	0.05, 1.05 [56] [104]	108, 194 [199] [124]	49, 60.74 to 63.27 [26] [34]	3.02, 13.51 [56] [199]	1, 10.2 [104] [197]	-6 to 2, 10 [34] [27]
Jojoba (Simmondsia chinensis)	at 40°C: 830 [201]	2.2, 5.86 [201] [202]	35.66 [202]	…	…	0.22 to 0.45 [202]	100, 150 [201] [202]	…	…	7 [201]	5 [201]
Nahor (Mesua ferrea)	at 40°C: 873 [203]	4.1, 5.525 [204] [203]	35 [203]	…	…	1.8 [203]	113, 142 [203] [204]	…	…	6.1 [204]	-1.2 [204]
Paradise (Simarouba glauca)	at 40°C: 875.2 [205] at 15°C: 865 [206]	4.68, 5.4 [206] [205]	…	…	…	0.1, 0.7 [205] [207]	141.2, 165 [205] [206]	64 [205]	…	19 [206]	14.5 [206]
Pongamia (Karanja , Honge, Millettia pinnata)	at 15°C: 880, 890 [208] [104] at 40°C: 883 [197]	3.99, 5.52 to 5.79 [208] [34]	37.8 to 39.69, 42.133 [34] [197]	…	…	0.1, 0.72 to 0.76 [93] [34]	141, 163 [93] [197]	55.1, 59.68 to 60.9 [93] [34]	2.35, 4.5 [93] [104]	-1, 14.6 [104] [197]	-3, 5.1 [104] [197]

Mutton fat	at 40°C: 856 [270]	…	…	…	…	0.65 [270]	…	59 [270]	…	-4 [270]	-5 [270]
Poultry fat	…	4.32, 4.71 [271] [278]	…	…	…	0.298 [279]	…	…	0.52 [271]	7 [278]	1, 3 [278] [280]
Waste cooking oil	at 15°C: 874.9, 880 [281] [282] at 40°C: 863.7, 890 [283] [284]	2.72, 6.1 [284] [285]	37.2, 37.9 [286] [285]	35.401, 41.2 [284] [282]	…	0.6, 0.71 [286] [283]	134, 186 [281] [284]	51.48, 64.2 [286] [281]	15.9 [281]	10.5 [286]	-1, 1 [282] [286]
Waste fat oil	…	…	…	…	…	10.91 [287]	…	…	…	…	…
Waste fried oil	at 25°C: 855 [288] at 15°C: 888 [289]	4.318, 4.57 [289] [288]	…	…	39.55, 40.5 [289] [288]	1.31±0.06 [287]	126, 156 [288] [289]	52 [289]	…	-8.3, 3 [288] [289]	-2.5 [289]
Waste frying palm oil	at 15°C: 875 [290]	4.401 [290]	38.73 [290]	…	…	0.15 [290]	70.6 [290]	60.4 [290]	…	…	…
Waste mixed vegetable oil	at 15°C: 878.9 [280]	4.83 [280]	…	…	…	…	…	59.7 [280]	14.12 [280]	…	…
Waste sunflower oil	at 15°C: 887.5 [280]	4.42 [280]	…	…	…	…	…	51.5 [280]	0.43 [280]	…	…
Trout oil	at 15°C: 885 [291]	4.25 [291]	37.8 [291]	…	…	…	…	51.3 [291]	…	…	…
Larvae grease (housefly)	at 15°C: 881 [292]	5.64 [292]	…	…	…	0.63 [292]	145 [292]	52 [292]	…	…	…
Plastic pyrolysis oil	at 15°C: 981 [293]	1.918 [293]	…	…	38.3 [293]	41 [293]	13 [293]	…	…	…	…
Sludge pyrolysis oil	at 22°C: 890 [294]	8.2 [294]	…	39.29 [294]	36.49 [294]	0.489 [294]	170 [294]	…	…	…	…
Neem seed pyrolysis oil	at 40°C: 982 [295]	9.38 [295]	…	20.8 [295]	…	…	…	…	…	…	…

Schizochytrium mangrovei	…	5.22 [259]	…	…	…	7.59 [259]	186.53 [259]	68.80 [259]	0.05 [259]	19.12 [259]	…
Spirulina	at 40°C: 860 [258]	5.66 [258]	41.36 [258]	…	…	0.45 [258]	130 [258]	…	…	…	-18 [258]
Spirulina platensis	at 15°C: 863.7 [260]	12.4 [260]	45.63 [260]	…	…	0.75 [260]	189 [260]	70 [260]	…	-3 [260]	-9 [260]
Animal fat	at 15°C: 871, 877 [261] [262]	4.03, 4.42 [261, 262]	…	36.73 [263]	36.83, 89.49 [261] [262]	0.38 [263]	161.5 [261]	57.49, 65.6 [261] [262]	13.03 [263]	…	…
Animal fat traps	at 15°C: 870 [264]	4.7 [264]	…	…	37 [264]	0.3 [264]	128 [264]	53 [264]	…	…	…
Beef tallow	at 17°C: 877 [265] at 20°C: 832 266] at 40°C: 0.890 [267]	4.89, 5.47±0.005 [266] [268]	39.858 [265]	39.931 [267]	…	0.495±0.007 [268]	152, 210 [266] [268]	58.8, 64.8 [267] [267]	1.99 [268]	…	0 [265]
Camelus dromedaries fat (Camel fat)	at 15°C: 871 [269]	3.39 [269]	…	39.52 [269]	…	…	158 [269]	58.7 [269]	…	12.7 [269]	15.5 [269]
Chicken fat	at 40°C: 867, 881.6 [270] [267] at 15°C: 869, 889.7 [271] [272]	5.3 [272]	…	39.911 [267]	…	0.25, 0.43 [270] [272]	169 [272]	57, 61 [267] [270]	…	-5 [270]	-6 [270]
Fish oil	at 40°C: 880,885 [273] [274]	4, 4.96 [273] [275]	37.8, 42.241 [275] [273]	…	…	…	114, 176 [274] [273]	51, 52.4 [275] [276]	…	-5 [275]	-14, 4 [275, 276]
Fleshing oil	at 15°C: 876.7 [272]	4.7 [272]	…	…	…	0.28 [272]	168 [272]	58.8 [272]	…	…	…
inedible animal tallow	at 17°C: 877 [265]	5.072 [265]	39.858 [265]	…	…	…	…	…	…	…	…
Lard	at 40°C: 879.5 [267]	4.64 to 7.73 [277]	…	39.932 [267]	…	1.13 [277]	…	57.8 [267]	…	…	…

The third generation of biofuels, which has done less to date than the previous two generations. The values are reported in Table 3. 33 oils in the third generation have been studied to date and the incidence rate is lower than the previous two generations due to the novelty.

Table 3: Properties of the third generations of biodiesel.

Biodiesels obtained from	Physicochemical property ranges										
	Density (kg/m^3)	Kin. Viscosity 40°C (mm^2/s)	Calorific Value (Mj/Kg)	Higher (gross) Heating Value (Mj/Kg)	Lower (net) Heating Value (Mj/Kg)	Acid Value (Neutralization number) (mg KOH/g)	Flash Point (°C)	Cetane Number	Oxidation Stability (h)	Cloud Point (°C)	Pour Point (°C)
Ankistrodesmus braunii and Nannochloropsis	at 40°C: 869 [246]	4.19 [246]	40.72 [246]	…	…	…	144 [246]	…	…	7 [246]	-6 [246]
Auxenochorella protothecoides	at 15°C: 876.9 [247]	4.354 [247]	…	…	…	0.2 [247]	…	52.6 [247]	1.2 [247]	…	…
Chlorella protothecoides	at 15°C: 882 [248] at 40°C: 864 [249]	4.41, 5.2 [249] [250]	39.01, 41 [249, 250]	…	…	0.29, 0.374 [248] [249]	115 [249]	…	4.52 [248]	…	…
Chlorella variabilis	at 15°C: 867 [251]	4.85 [251]	38.78 [251]	…	…	…	157 [251]	58.6 [251]	…	…	…
Chlorella vulgaris	at 40°C: 860, 895 [252] [253]	4.1, 5.2 [253] [252]	42.7 [253]	…	…	0.51 [253]	115 [252]	…	…	…	-7 [253]
Euglena sanguinea	at 15°C: 861, 868 [254] [255]	4.483, 4.545 [254, 255]	…	…	…	0.29, 0.32 [255] [254]	169, 172 [254] [255]	65 [255]	6.20 [255]	15 [255]	13 [255]
Heterotrophic microalgae (Sugar plant)	at 15°C: 778 [256]	2.748 [256]	…	…	44 [256]	…	…	75 [256]	…	…	…
Melanothamnus afaqhusainii	at 40°C: 870 [257]	3.67 [257]	…	…	…	0.75 [257]	…	…	…	-1 [257]	-2 [257]
Pond water algae	at 40°C: 872 [258]	5.82 [258]	40.80 [258]	…	…	0.40 [258]	…	…	…	…	-16 [258]

2. Density

Density is one of the most important factors in biodiesels. Most studies have reported temperatures of density between 15 and 40 ˚C for all three generations because the temperature has a direct effect on density. Also, the free fatty acid content, molar mass, temperature, the water content can effect on the density of esters. The cetane number, viscosity, heating value, fuel performance, and the quality of combustion and atomization are strongly connected to the density. The density of diesel fuel is lower than biodiesels. The unit quantity of all reports is converted to kg/m^3.

The maximum density of the first generation of biodiesel is reported for Castor biodiesel (at 20°C: around 917). Peanut sample also showed the highest density of about 992 and 884 at 40 and 15°C. The minimum density of the biodiesel was stated for the Watermelon seed around 800 and 880.6 at 15 and 20°C.

Patchouli and Tall biodiesels (second generation of biodiesel) could show the highest amount of density at 15 and 40°C around 922 and 922.1. The minimum of this generation was shown by the jojoba and jatropha at 40, 20 and 15°C (830, 865.7, and 874).

Plastic pyrolysis and neem seed pyrolysis were shown the highest amount of density at 15 and 40°C around 981 and 982. The majority of reports were done at 15 and 40°C, however, some reports were performed at 22, 17, and 25°C (Table 3). The lowest of the density for the third generation of biodiesels were shown by the heterotrophic microalgae at 15°C (778).

Comparison between three generations of biodiesel shows that the highest of density was reported by Peanut biodiesel (first generation) and it was higher than second and third generation of biodiesel around 8 and 2 % and heterotrophic microalgae (third-generation) had the lowest density compared to other generation to approximately 3 and 8%.

2.1. Viscosity

The viscosity plays a leading role in the engine performance of biodiesels. It can affect the size of the particles, spray quality, starting the engine, the quality of the fuel-air mixture combustion, and penetration of the injected jet. Also, the viscosity can affect the lubricity. The amount viscosity has a limitation due to several reasons. The high viscosity makes the formation of too big drops, the increase of combustion chamber deposits, the increase of needed fuel pumping energy and wear of the pump and the injector elements. Also, the high viscosity causes operational issues at the low temperatures due to that the viscosity enhances with reducing the temperature. The low viscosity makes the inadequate penetration and the formation of the black smoke specific to combustion (during the absence of oxygen). Biodiesel is more polar compared to the diesel fuel, so, the viscosity of biodiesel is greater than diesel fuel. Table 1, 2, and 3 show the viscosity of different feedstocks. The viscosity was measured at 40°C for three generations of biodiesel.

The unit quantity of all reports is converted to mm^2/s.

The maximum viscosity was reported for castor biodiesel around 14.4 for the first generation of biodiesel. Orange and watermelon seed biodiesels also showed the lowest amount of viscosity to roughly 1.04 and 1.05.

The highest amount of viscosity for the second generation of biodiesel was shown by tung. It could show the viscosity around 7.84. The minimum of the viscosity was displayed by the jatropha and jojoba biodiesel. It was only around 2.35 and 2.2.

Spirulina platensis and neem seed pyrolysis were shown the highest amount of viscosity for the third generation of biodiesel. They were around 12.4 and 9.38. On the other hand, the lowest amount of viscosity was reported for plastic pyrolysis and it was about 1.91.

The comparison between all generations could show that the maximum viscosity was shown by the castor and it was higher than the second and third generation of biodiesels to approximately 46 and 14%. The minimum of viscosity also reported by the first generation of biodiesels and it was 52 and 45% lower than the second and third generation of biodiesels.

2.2. Calorific Value

The heating value or calorific value of the fuel is defined as the amount of energy released through the combustion of the unit value of the fuel. The unit quantity of all reports is converted to Mj/Kg. The upper heating value is gained while all products of the combustion are cooled down to the temperature before the water vapor combustion formed over combustion is condensed. The lower heating value is achieved by subtracting the latent heat of vaporization of the water vapor formed with the combustion from the upper heating value. Some of the reports indicated only to the calorific value and others referred to higher and lower heating values.

The highest calorific value for the first generation was gained by the false flax biodiesel. It was from 45.05 to 46.15. The maximum higher heating value was shown by the cottonseed and it was about 48.18. Also, the greatest amount of the lower heating values reported by the coconut biodiesel (57.74). On the other hand, the minimum of calorific value was displayed by the thistle biodiesel (36.5). The lowest amount of the higher and lower heating values were gained by the canola and cottonseed biodiesels (25.11±0.29 and 36.89).

Nerium oleander had the highest amount of calorific value between all second generations of the biodiesel (44.98) and the lowest heating value was shown by the nahor biodiesel [35].

The higher heating value of the patchouli was greater than other second generations (44.18). The lowest higher heating value was shown by the green seed biodiesel and it was only around 20.95±0.2.

Spirulina platensis showed the maximum of calorific value between all third generations of biodiesel (45.63). The lowest calorific value was gained by waste cooking and it was around 37.2. Lard biodiesel showed the highest higher heating values around 39.93 and neem seed pyrolysis was gained 20.8. The greatest lower heating value of the third generation of biodiesels was gained by the heterotrophic microalgae. It was around 44. The minimum lower heating value was reported sludge pyrolysis biodiesel (36.49).

Comparison between all biodiesel generations could display that the spirulina platensis could achieve the maximum of calorific value and it was higher than nerium oleander and false flax to approximately 3 and 2%. Also, the highest higher heating value of the first generation of biodiesel (cottonseed) was higher than the second and third generation of biodiesel around 9 and 18%.

2.3. Acid Value

The acidic value (acid number or neutralization number) in chemistry is the amount of mg of potassium hydroxide needed to neutralize one gram of a substance. An acidic number is a measure of the number of carboxylic acid groups in a compound, such as a fatty acid or a mixture of compounds. The upper amount of free fatty acid contributes to the elevated acid value which in turn causes severe corrosion in fuel supply lines of the engine. Besides, the acid value can be observed as the indication of the level of lubrication in fuel lines. The unit quantity of all reports is mg KOH/g.

The castor biodiesel showed the highest acid value between all biodiesels of the first generation (3.9). The lowest acid value was displayed by the dika biodiesel and it was merely around 0.01.

The maximum of acid value for the second generation of biodiesel was gained by the nahor (1.8) and the minimum of the acid value was shown by the stillingia (0.007).

Plastic pyrolysis biodiesel from the third generation could display the highest amount of the acid value (41) and the lowest of acid value was gained by the waste frying palm (0.15).

The third generation of the biodiesel could show the much higher acid value compared to other generations and the second generation of biodiesel could gain the minimum of the acid value compared to others.

2.4. Flash Point

Flashpoint is the smallest temperature at which the fuel will ignite on the application of the ignition source under particular situations. Every liquid has a vapor pressure which is a function of its temperature. As the temperature rises, the vapor pressure increases. As the vapor pressure increases, the density of flammable liquid vapor increases. Therefore, temperature determines the amount of combustible liquid vapor in the air. Flashpoint measurement is done in two main ways: open cup and closed cup. The diesel fuel has a flashpoint around 50-65°C. Mostly, the flashpoint of the biodiesel is much higher than diesel fuel. The high flash point of biodiesel increases the security of fuel storage and transportation. The unit quantity of all reports is Celsius (centigrade).

The palm biodiesel had the maximum of the flashpoint between all first generation of biodiesel (214.5°C). On the other hand, the minimum of the flashpoint was gained by the orange biodiesel (29°C) and it was lower than diesel fuel.

Tung biodiesel (second generation of biodiesel) had the highest amount of the flashpoint around 197°C. However, the flashpoint of the nerium oleander was merely about 73°C.

In the third generation of biodiesel, the beef tallow had the greatest flashpoint between all samples (around 210°C) while the plastic pyrolysis biodiesel was only around 13°C.

The flashpoint of palm biodiesel was higher than tung and beef tallow around 8 and 3% and the plastic pyrolysis biodiesel was lower than the nerium oleander and orange biodiesel around 82 and 55%

2.5. Cetane Number

The cetane number represents the delay between the start of the injection into the combustion chamber and the start of the fuel combustion. During this delay, the fuel accumulates and then ignites and the combustion explodes to produce a powerful effect. Reducing the delay time makes the combustion more uniform. The increase of the cetane number causes the quick ignition of the fuel and it makes less non-ignited fuels building up in the combustion chamber and also further complete fuel combustion. The low cetane number affect the incomplete combustion and it causes the enhancement of the exhaust emissions and extreme deposits in the engine. Normally, biodiesels have a higher cetane number due to greater oxygen content compared to the diesel fuel.

Papaya seed biodiesel (first generation) showed the highest amount of the cetane number compared to other biodiesels. The value of the cetane number was around 77.3. On the contrary, pomegranate seed biodiesel had the lowest cetane number around (26.1).

Honesty biodiesel (second generation) displayed the highest amount of cetane number around 78.9±0.8 compared to other biodiesels in this generation, while tung biodiesel could reach only around 39.

Heterotrophic microalgae were shown the maximum of the cetane number in the third generation of biodiesel (almost 75). However, the cetane number of the fish biodiesel was around 51.

The highest cetane number between all generations was shown by the honesty biodiesel and it was 3 and 6 % higher than the maximum of the other generations. Pomegranate seed biodiesel was shown the lowest amount of cetane number compared to other generations and it was 33 and 48% than the minimum of the other generations.

2.6. Oxidation Stability

The oxidation can affect the quality of the biodiesel over storage in contact with air. The storage stability is extremely important for the biodiesel and it indicates the ability of the fuel to stand chemical changes over the long term storage due to the connection with the oxygen from the air. The oxidation stability of biodiesel is subject to the number of bis-allylic sites in unsaturated compounds. The primitive oxidation is started by the radical formation at bis-allylic sites and it forms peroxides. Then, the secondary oxidation generates the aldehydes, volatile organic compounds, and ketones with ruing the methyl ester which polymerizes to form waste sludge that can detriment the engine fuel injection system.

This feature is not mentioned in all reports but Ben biodiesel had the highest in first-generation biodiesel (26.2 h). On the contrary, the kenaf seed biodiesel had the lowest oxidation stability and it was around 0.35 h.

The honesty biodiesel showed the maximum of the oxidation stability between all second generations of biodiesel (72 h). Sterculia foetida biodiesel displayed the minimum of the oxidation stability around 0.022 h.

The waste mixed vegetable biodiesel presented the greatest amount of oxidation stability in the third generation of biodiesel about 14.12 h. However, the lowest of the oxidation stability was shown by the waste sunflower biodiesel (around 0.43 h).

Comparing between all generations, the honesty biodiesel was higher than the maximum of the first and third generation of biodiesel around 63 and 80%. Also, Sterculia foetida biodiesel (second generation of biodiesel) was lower than the minimum of the first and third generation of biodiesel to approximately 93 and 94%.

2.7. Cloud and Pour Point

The minimum temperature at which a cloud of paraffin crystals appears inside the oil product is called the cloud point. At this temperature, the sample does not lose its fluidity and is usable. The pour point of a hydrocarbon material is when it cools under certain conditions and is defined as the lowest temperature at which the hydrocarbon flows. This temperature is somewhat higher than the solidification point temperature. It is difficult to define precisely the pour or solidification point since the transition from the liquid phase to the solid phase is gradual. The unit quantity of all reports is Celsius (centigrade).

Ben biodiesel showed the highest could and pour point between all first generations of biodiesel (19°C). However, pumpkin seed had the minimum of could point around -18°C. Also, it had the lowest pour point between all biodiesel samples around -32°C.

The maximum of could and pour point was shown by the paradise biodiesel between the second generation of biodiesel (19 and 14.5°C). On the other hand, the minimum of could and pour point was reported by the patchouli biodiesel (-33°C).

Euglena sanguinea biodiesel had the greatest could and pour point between all third generations of biodiesel and it was around 15 and 13°C. Waste fried oil and Spirulina showed the lowest cloud and pour point to roughly -8.3 and -18°C.

Paradise and ben biodiesel had the highest cloud point and it was 21% higher than Euglena sanguinea biodiesel. However, the ben biodiesel had the maximum pour point compared to the all second and third generation of biodiesel. It was 23 and 31% higher than the maximum of other generations. The patchouli biodiesel indicated the minimum of the cloud and pour point between all generations and it was lower than the lowest cloud and pour point of other generations between 4-74%.

3. Conclusion and Future Trend

This review article attempts to provide comprehensive information on the physical properties of the majority of biodiesel used in all three generations and propose the best biodiesel concerning their physical properties. Biodiesel has many advantages over fossil fuels. One of the most important reasons for choosing biodiesel is its impact on the economy, environment and energy security in the world. Some of the most important benefits of biodiesel on the economy can be sustainability, job opportunities in the rural area, fuel diversity, more income taxes, development of agriculture, International competitiveness, decreasing the dependency on the imported petroleum, and improving investments in equipment and plant. Reducing air contamination, Biodegradability, Greenhouse gas reductions, better combustion efficiency, and carbon sequestration are some of the environmental impacts of biodiesel. One of the most important impacts of biodiesel on energy security can also be addressed renewability, ready availability, domestic distribution, supply reliability, domestic targets, and decreasing use of fossil fuels [296].

Although biodiesel has superior properties over fossil fuels, choosing the right biodiesel has many difficulties. Choosing the right biodiesel depends on various factors including standards set in different countries, raw material production policies, weather conditions, engine biodiesel performance, initial production costs, and physical properties of biodiesel available in that region and so on. Therefore, choosing the best option among all the studied biofuels is almost impossible, and choosing the best feedstock has to take into account all the physical, chemical and product conditions, and so on.

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5. Conflict Of Interest Statement

The authors have confirmed that there is no conflict of interest.

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