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A Review on Biodiesel: From Feedstock to Utilization in Internal Combustion Engines

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ABSTRACT

Transportation and energy sector depend highly on conventional fossil fuels. Biodiesel has been very attractive fuel nowadays since fossil fuels faced with extinction dangerous. It has a huge potential as an alternative energy source to fulfill the energy requirement of the world with parallel to rise in population and growing industrialization. Renewable, sustainable, environment friendly and biodegradable nature are the featured properties of biodiesel. Similar physicochemical properties of biodiesel with diesel fuel allow to be used with little or no engine modification in diesel engines. There are lots of raw materials from vegetable oils to animal fats for their production. Although it has lower energy content compared to diesel fuel which cause to deterioration on engine performance as reduced torque and increased fuel consumption, biodiesel is very effective environmentally. It causes to decrease on emissions such as unburned hydrocarbon, carbon monoxide, carbon dioxide and particulate matter. The fundamental objective of this paper is to provide a literature survey related with biodiesel utilization in internal combustion engines.

Biyodizel Üzerine Bir Derleme: Hammaddesinden, İçten Yanmalı Motorlarda Kullanımına

Derleme

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ÖZ

Ulaşım ve enerji sektörü büyük oranda geleneksel fosil yakıtlara bağımlıdır. Biyodizel fosil yakıtların tükenme tehlikesiyle karşı karşıya kalmasıyla günümüzde oldukça cazip bir yakıt haline gelmiştir. Biyodizel, artan nüfusa ve gelişen endüstrileşmeye paralel olarak dünyanın enerji ihtiyacını karşılayabilmek için alternatif bir enerji kaynağı olarak yüksek bir potansiyele sahiptir. Yenilenebilir, sürdürülebilir, çevre dostu ve biyolojik olarak bozunabilir doğası biyodizelin öne çıkan özelliklerindendir. Dizel yakıtıyla benzer fizikokimyasal özellikler göstermesi dizel motorlarda çok küçük ya da herhangi bir modifikasyon olmadan kullanılmalarına izin verir. Bitkisel yağlardan, hayvansal yağlara kadar üretilmeleri için birçok hammadde vardır. Torkta azalma ve yakıt tüketiminde artma gibi motor performansında kötüleşmelere sebep olan düşük enerji içeriğine rağmen çevresel olarak oldukça etkilidir. Yanmamış hidrokarbon, karbon monoksit, karbon dioksit ve partikül madde emisyonlarında düşüşe sebep olurlar. Bu makalenin temel amacı, içten yanmalı motorlarda biyodizel kullanımı ile ilgili bir literatür taraması yapmaktır.

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Introduction

Compression ignition (diesel) engines have series of advantages compared to spark ignition (gasoline) engines such as higher thermal efficiency and fuel economy. However, diesel engines are notorious with being one of the major environmental pollution contributors when operated by conventional diesel fuel (Krishnasamy and Bukkarapu, 2021). On the other hand, fossil based fuels have faced with scarcity threat since late 1970s and early 1980s (Tüccar et al., 2014). Energy demand of the world has increased due to population increment and growing industrialization. Besides that, environmental concerns have forced researchers to explore renewable, sustainable and cleaner fuels.

Biofuel such as biodiesel and bioethanol can be described as a fuel that is produced by biomass. Biodiesel are one of the probable alternative energy source candidates for diesel engines. Similar properties with diesel fuel and cleaner combustion characteristics make biodiesel attractive among others (Singh et al., 2021). It requires little or no engine modification for use. Sulfur free structure, oxygenated nature, high flash point, reduced emission levels can be sequenced as significant advantages. Vegetable and algal oils, animal fats, waste oils can be used for production of biodiesel (Tosun and Özcanlı, 2021).

Feedstocks of Biodiesel

Biofuel can be produced by various raw materials. Generally, feedstocks of biofuel can be evaluated in four different generations. First and second generation biofuels are derived from edible and non-edible biomasses, respectively. Algal biomasses are used in third generation whereas genetically modified microalgae are used in the fourth generation (Sikarwar et al., 2017; Aron et al., 2020). Fourth generation can be thought as extension of third generation. Table 1 gave examples to each generation biofuels (Dutta et al., 2014; Aro, 2016; Sikarwar et al., 2017; Aron et al., 2020; Ishola et al., 2020; Vignesh et al., 2021).

Table 1. Biofuel generations and raw materials

Raw Materials			
1st generation	**2nd generation**	**3rd generation**	**4th generation**
Corn, sugar beet, wheat, rice bran, sugar, starch, potato, barley, animal fats, soybean, palm, sunflower	Waste cooking oil straw, grass, wood, forest residues, jatropha, mahua, jojoba, salmon, solid municipal wastes	Micro algae, macro algae, cyanobacteria	Solar fuels, electrobiofuels, oxygenic photosynthetic microbes, genetically engineered plants
Examples of Biofuels by Generation			
Biodiesel, bioethanol, biobutanol	Biodiesel, bioethanol, biobutanol, syngas	Biodiesel, bioethanol, biobutanol, syngas, biohydrogen, methane	Biodiesel, bioethanol, biobutanol, syngas, biohydrogen, methane

Methods for Reducing Viscosity of Vegetable Oils

Viscosities of the vegetable oils mostly are not suitable for direct usage of them in engines and they can cause some problems as injection system problems (Razzaq et al., 2020). Therefore, some methods must be applied to oils in order to enhance fuel properties. Figure 1 demonstrated the summary of improvement processes of oils.

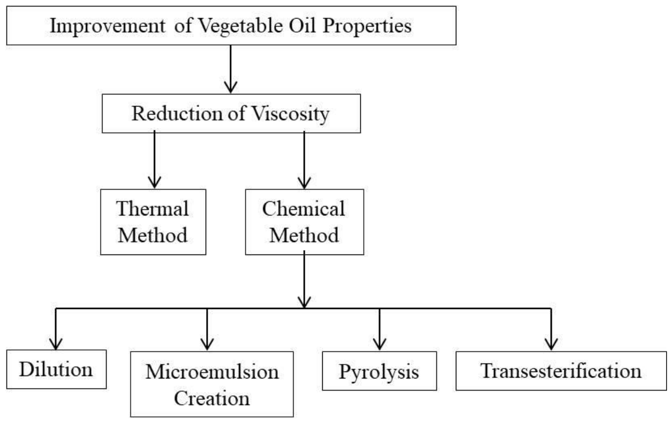

Figure 1. Improvement methods of vegetable oils fuel properties (Alptekin and Çanakçı, 2006)

Dilution Method

It is a technique that used for thinning oils by blending them with diesel fuel or various solvents in specific proportions. Dilution process may also be achieved with pure ethanol (Demirbas, 2009; Aktaş et al., 2020).

Microemulsion Method

Preparing microemulsion is another way of reducing viscosity. Microemulsions are created by two immiscible liquids with the presence of a suitable surface active agent (surfactants). Generally short-chain alcohols (methanol or ethanol) were selected for preparing microemulsion with oil. Surfactant cause to obtain reduced interfacial tension between immiscible liquids (Demirbas, 2009; Kumar et al., 2020).

Pyrolysis (Thermal Cracking)

Pyrolysis can be defined as transformation of a one substance to another by heat or by heat with the help of a catalyst. Heating is achieved in absence of oxygen and large molecules break down into smaller molecules at high temperature. Vegetable oils and animals fats may be pyrolyzed materials (Ma and Hanna, 1999).

Table 2. Thermally cracked soybean oil fuel properties (Ma and Hanna, 1999)

	Soybean oil	Cracked soybean oil	Diesel fuel
Cetane number	38.0	43.0	51.0
Higher heating value (MJ/kg)	39.3	40.6	45.6
Pour point (^{o}C)	-12.2	4.4	-6.7 max
Viscosity (cSt at 37.8 ^{o}C)	32.6	7.74	2.82

As seen from the Table 2, viscosity of soybean oil was reduced considerably by thermal cracking method.

Transesterification

Transesterification is the mostly preferred method for biodiesel production. A chemical reaction between a triglyceride and alcohol in the existence of a suitable catalyst is called as transesterification. Figure 2 illustrated the transesterification reaction.

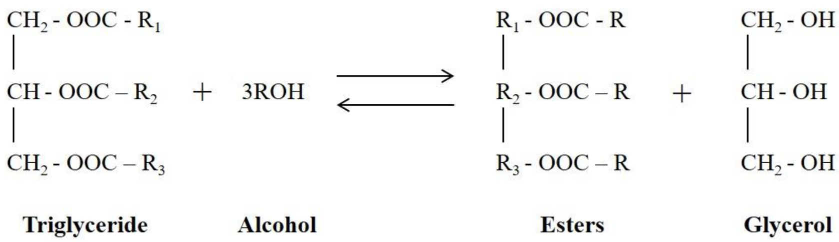

Figure 2. Transesterification reaction (Demirbas, 2009)

Alcohols such as methanol, ethanol, propanol and butanol are commonly used in reaction. Among all, methanol and ethanol are mostly preferred since they have benefits as low cost and some physical and chemical advantages. This method improves the properties of oils and causes to obtain enhanced engine performance (Fukuda et al., 2001).

Table 3. Fuel properties of oil and biodiesel (Şahin and Aydın, 2018)

	Canola oil	Canola oil biodiesel	Diesel fuel
Density @ 15 ^{o}C (g/cm^{3})	0.915	0.883	0.834
Kinematic viscosity @ 40 ^{o}C (mm^{2}/s)	31.388	4.453	3.071
Flash point (^{o}C)	150	125	61
Calorific value (cal/gr)	-	9585	10319

Şahin and Aydın (2018) gave the fuel property analyses as shown above in Table 3. Improvement of fuel properties of the canola oil biodiesel which was produced by transesterification method compared to canola oil can easily be seen.

Fuel Properties of Biodiesel

Biodiesel exhibits similar fuel properties as diesel fuel. There are lots of studies which evaluated the fuel properties of biodiesel produced by different raw materials. Table 4 showed a comparative summary of fuel properties of biodiesel by taking diesel fuel as reference.

In summary, biodiesel generally cause to obtain higher density and viscosity values than diesel fuel. The high values of these properties will trigger poorer atomization of fuel which will result with lowered engine performance and increased nitrogen oxides (NO_x) emissions (Razzaq et al., 2020). Energy content of biodiesel is lower than diesel fuel. It means compared to diesel fuel that much more biodiesel fuel will be consumed in order to obtain same power (Oliveria and Da Silva, 2013). Cetane number of biodiesel is generally higher than diesel fuel although there are some which have lower. Cetane number is a property that which affects the period of ignition delay. Higher cetane number means that lowered ignition delay period and improved ignition quality (Tosun and Özcanlı, 2021). In case of flash point, biodiesel presents increased levels of flash point. Flash point is very important for safe storage of fuel (Ahmad et al., 2011).

Utilization in Engines: Performance and Emission Characteristics

Depending on its fuel properties, biodiesel affects engine combustion, performance and emission characteristics. Table 5 summarizes how biodiesel affects these characteristics.

Table 5 showed decrement/increment (with reference to diesel fuel) on combustion, performance and emission characteristics of biodiesel operated diesel engines.

As seen from the Table 5 that, engine torque and power showed reduced trends when engine was operated with biodiesel compared to diesel fuel. According to literature, low calorific value of biodiesel may be the potential reason of this situation. Brake specific fuel consumption was increased by use of biodiesel. Lower calorific value of biodiesel compared to diesel fuel may be the main reason which causes to inject more fuel in order to obtain same power values.

Table 4. Fuel properties of various biodiesels from literature

Fuel	Density	Viscosity	Calorific Value	Cetane Number	Flash Point	Reference
	(kg/m³)	*(mm²/s)*	*(kJ/kg)*	-	*(°C)*	(Tayari et al., 2020)
Eruca Sativa Biodiesel	870	4.192	43760	47.5	185	
Diesel	830	3.1	46800	46.2	88	
	(kg/m³)	*(mm²/s) @40 °C*	*(kJ/kg)*	-	*(°C)*	(Nedayali and Shirneshan, 2016)
Waste Cooking Oil Biodiesel	880	4.15	37700	55.1	176	
Diesel	840	4.03	42900	50.33	61	
	(kg/m³)	*(mm²/s)*	*(kJ/kg)*	-	*(°C)*	(Akar, 2016)
False Flax Biodiesel	886	4.38	39048	51	>140	
Diesel	837	2.76	45856	59.47	71.5	
	(kg/m³)	*(mm²/s)*	-	-	*(°C)*	(Bora, 2009)
Karabi Seed Biodiesel	860	4.2	-	50	110	
Diesel	834	2.6	-	48	66	
	-	*(mm²/s) @40 °C*	*(kJ/kg)*	-	-	(Canakci and Van Gerpen, 2003)
Soybean Oil Biodiesel	-	4.2691	37388	51.5	-	
Yellow Grease Biodiesel	-	5.1643	37144	62.6	-	
Diesel	-	2.8271	42640	42.6	-	
	(kg/m³)	*(mm²/s)*	*(kJ/kg)*	-	*(°C)*	(Özcanlı et al., 2011)
Terebinth Oil Biodiesel	870	5.72	38516	59.68	106.5	
Diesel	831	2.65	44861	54.791	67	
	(kg/m³)	*(mm²/s) @40 °C*	*(kJ/kg)*	-	*(°C)*	(Romola et al., 2021)
Palm Oil Biodiesel	835	3.23	24686.06	-	128	
Diesel	829	2.91	44642.1	-	70	
	(kg/m³)	*(mm²/s)*	*(kJ/kg)*	-	*(°C)*	(Sathyamurthy et al., 2021)
Corn Oil Biodiesel	910	6.38	36598	-	139	
Diesel	824	2.73	42125	-	57	
	(kg/m³) @15 °C	*(mm²/s) @40 °C*	*(kJ/kg)*	-	*(°C)*	(Uyumaz et al., 2020)
Opium Poppy Biodiesel	890	4.682	40187	-	151	
Diesel	830	2.89	42600	-	67	
	(kg/m³) @15 °C	*(mm²/s) @40 °C*	*(kJ/kg)*	-	*(°C)*	(Yesilyurt, 2020)
Peanut Oil Biodiesel	878	4.389	39860	52.5	173	
Diesel	835	2.597	43090	55.1	58	

Table 5. Performance and emission changes (compared to diesel) of biodiesel operated diesel engines from literature

Fuel	Torque	Power	Specific Fuel Consumption	Carbon Dioxide (CO_2)	Carbon Monoxide (CO)	Unburned Hydrocarbon (UHC)	Nitrogen Oxides (NO_x)	Particulate Matter (PM) / Smoke	Reference
Vegetable Oil Biodiesel	↓	↓	↑	-	↓	↓	↑	↓	(Khan et al., 2020)
Castor Biodiesel	-	↓	↑	-	↓	↓	↑	↓	(Islam et al., 2014)
Waste Cooking Oil Biodiesel	↓	-	↑	-	↓	-	↑	-	(Altun, 2011)
Inedible Animal Tallow Biodiesel	↓	-	↑	-	↓	-	↓	-	
Rice Bran Oil Biodiesel	-	-	-	-	↓	↓	↑	↓	(Devarajan and Madhavan, 2017)
Microalgae Biodiesel	-	-	↑	-	-	↓	↑	↓	(Yasar and Altun, 2018)
Victoria Oil Biodiesel	-	-	-	-	↓	↑	↑	↓	(Pesic and Davinic, 2019)
Neem Biodiesel	-	-	↑	-	↓	↓	↓	↑	(Nair et al., 2017)
Watermelon Seed Oil Biodiesel	-	-	↑	-	↓	↓	↑	↓	(Asokan et al., 2021)
Coconut Biodiesel	↓	↓	↑	↑	↓	↓	↑	-	(Liaquat et al., 2013)
Macadamia Biodiesel	-	-	↑	↑	↓	↓	↑	↓	(Azad et al., 2017)
Cotton Seed Oil Biodiesel	-	-	↑	-	↓	-	↑	↓	(Nabi et al., 2009)
Juliflora Biodiesel	-	-	↑	-	↓	↓	↑	↓	(Asokan et al., 2019)
Karanja Biodiesel	-	-	↑	↓	↓	↓	↑	-	(Sivaramakrishnan, 2018)
Hazelnut Biodiesel	-	-	↑	-	↓	↓	↑	↓	(Krishnaiah et al., 2016)
Prunus Armeniaca L. (Wild Apricot) Biodiesel	-	-	↑	-	↓	↓	↑	↓	(Yadav et al., 2018)
Canola Oil Biodiesel	↓	-	↑	-	-	-	↓	↓	(Şen, 2019)
Rapeseed Oil Biodiesel	↓	↓	↑	-	↓	↓	↑	↓	(Buyukkaya, 2010)
Fish Oil Biodiesel	-	↓	↑	-	↓	↓	↑	↓	(Nguyen et al., 2020)
Pomegranate Seed Oil Biodiesel	-	↓	↑	-	↓	-	↑	-	(Tüccar and Uludamar, 2018)

CO and UHC emissions are generated due to the incomplete combustion and insufficient temperature levels in cylinder (Nair et al., 2017). Oxidization capability of biodiesel since it has extra oxygen in its structure induced to obtain less amount of UHC and CO emissions according to literature. When CO molecules are oxidized, much more CO_2 molecules are generated. Therefore, biodiesel generally will cause to increase CO_2 emission. But, in total carbon cycle, CO_2 is reduced since plants consume it for photosynthesis (Tosun and Özcanlı, 2021). Oxygenated nature of biodiesel will trigger to obtain more NO_x emissions. A huge part of literature had a consensus on that increased level of in cylinder temperature due to enhanced combustion generated by extra oxygen in chemical structure of biodiesel caused to obtain higher NO_x. Incomplete combustion and combustion of lubrication oil may be the potential reasons of PM and smoke (Nabi et al., 2009). Biodiesel with extra oxygen may improve the combustion and may reduce the PM formation.

Conclusions

The scarcity threat of traditional fuels has led researchers to search for alternative fuels. Biodiesel is one of the most reasonable alternatives in order to replace conventional fuels with its superior advantages. It has lots of feedstocks to be produced. Fuel properties of biodiesel are very much alike with diesel fuel.

This study has offered a review on biodiesel from raw materials to utilization in engines. Fuel properties of various biodiesels compared to standard diesel fuel were supplied from the literature. Furthermore, performance, emission and combustion characteristics of diesel engines powered by miscellaneous biodiesels were evaluated.

Totally, biodiesel may be suggested as a renewable, sustainable and alternative fuel for internal combustion engines with its notable properties.

Conflict of Interest

The author declares that there is no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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