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The Physical Properties of Biodiesel-Diesel Fuel Produced *via* Transesterification Process from Different Oil Sources

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Biodiesel is one of the sources of renewable fuel. Due to increasing environmental pollution, global warming caused by fossil fuels and limited fossil fuel resources, its production has significantly increased during the last decades. In addition, low price renewable sources have been wisely used to produce biodiesel. Herein, biodiesel is produced from edible oil wastes, such as goat fat, chicken fat and palm kernel-derived oil using the transesterification process. The produced biodiesel is mixed with different ratios of petroleum diesel to improve the physical properties of the produced biodiesel, such as flash point, kinematic viscosity, density, cloud point and pour point. The physical properties were measured according to the ASTM D6751 standard. The obtained results show that some of the properties of final biodiesel, such as density, viscosity and flash point are improved with the addition of biodiesel to the diesel fuel. Among oil resources, the oil produced from goat fat had a better flash point where B100, B80, B60 and B50 had a flash point in the standard range. The other properties, such as pour point and cloud point were increased with the higher proportion of the biodiesel in the mixture. This causes a bad effect on the consumption of fuel which cannot be used in cold weather. Generally, adding biodiesel to diesel enhances the fuel properties.

Keywords: Biodiesel production, Transesterification, Alkaline catalyst, Biodiesel-diesel mixture

INTRODUCTION

Nowadays, a considerable attention has been paid to different kinds of fossil energy resources such as oil, coal and natural gas. By developing the societies, the demand for fossil fuels has enormously increased and reached to the limit of energy resources depletion [1-2]. Biodiesel is an alternative fuel for common energy sources that can be prepared from different renewable sources [1-2]. This fuel is biodegradable, non-toxic, renewable and produce fewer pollutants compared to the petroleum-derived fuels [2-3]. Biodiesels produced from vegetable oils and animal fats have shown to have a higher viscosity than diesel and can be used as a fuel in diesel engines without any significant breakdown in performance [4-6]. Its usage in diesel engines produces fewer amounts of smoke, noise, carbon monoxide, sulfur-containing compounds and polyaromatic hydrocarbons compared to the fossil fuels [4,7-8].

There are various production procedures for development of biodiesel, namely microemulsion, pyrolysis, and transesterification. Transesterification process is mostly used in the industrial production of biodiesel due to its cost affordability. Among the mentioned procedures, transesterification is the most common, economic, high conversion yield and appropriate method for biodiesel

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production [9-10]. Transesterification process in the presence of homogeneous catalysts, such as sodium hydroxide or potassium hydroxide, is generally used for biodiesel production [11].

In transesterification, a chemical reaction occurs between free fatty acids and alcohol chains; methanol is often used as the alcohol because of the low commercial price [12-13]. The reaction requires alkaline, acidic or enzymatic catalysts to occur [14-16].

In biodiesel production, the cost of raw materials used for the production of final product contributes more than 70% of the total cost required [17-18]. Crude vegetable oils, often used as the raw material, have a relatively high cost [19] that can increase the operational costs and the price of the final product. Hence, to minimize the total cost, the use of waste oils from animal fats and food waste have been recently taken into consideration [20].

The main aim of the present study is to produce biodiesel through transesterification process using low-value triglyceride resources such as waste edible oils, palm kernel oil, and animal fats such as goat and chicken fats in the presence of KOH as the alkali catalyst and methanol as the alcohol reagent. Due to the rapid increase in the usage of fossil fuels, these efficient biodiesels can be efficient alternatives for common diesel sources, leading to decrease the overall amount of pollution created by the petroleum fuels used in the car engine. After the preparation and purification of the biodiesel, the biodiesel is mixed with petroleum diesel produced in Iran in different ratios. The physical properties of the mixtures, such as density, kinematic viscosity, cloud point, flash point, and pour point are measured according to international standards and these properties compared to standard conditions. Finally, the best ratio of biodiesel/diesel is obtained.

MATERIALS AND METHODS

Materials

Chicken and goat fats were collected from industrial slaughterhouses in Bushehr city (Iran). The pieces of meat were separated, washed and then stored into a plastic bag and kept at a temperature of about -4 °C. Food waste oil was collected from local restaurants in Bushehr. The oil was filtered, separated from the food residues and subsequently kept in closed bottles at room temperature. Palm kernel for oil extraction was purchased from farmers at Bushehr. The palm kernel was washed, dried, powdered and then stored in moisture-resistant plastic bags at a temperature of 4 °C. Methanol (> 99%), sodium sulfate (> 99%), sulfuric acid (> 99%), and potassium hydroxide (KOH) were supplied by Merck & CO. Additionally, He and N_2 gases were used as gas sources for chromatography.

Instruments

Gas chromatography machine model Varian cp-3800 equipped with FID detector and a capillary column with a length of 30 m was used to evaluate the fatty acids. Magnetic stirrer machine (model yellow MAG HS 7) was used to provide heat and stirring for the solution.

Oil Extraction Technique from Chicken and Goat Fat

For extraction of chicken and goat fats from collected wastes, first 500 g of goat fat was poured into a 1000 ml beaker glass and then 100 ml of distilled water was added to the resulting mixture. Thereafter, the obtained suspension was heated at 110 °C for 2 h until the fat being fully melted and the residual water evaporated completely from the suspension. The produced oil was then placed under a hood for 2 h at room temperature until it was completely cooled. The excessive oil-inconvertible fat material was then removed by cloth filtering. The resulting oil was stored in plastic bottles made of polyethylene at room temperature. A similar procedure was employed for extraction of oil from chicken fat.

Extraction of Palm Kernel Oil

The oil content from palm kernel was obtained through Soxhlet apparatus according to the American Oil and Chemical Society Official Method. For doing so, the oil was extracted from palm kernel samples using an *n*-hexane solvent extractor for both percolation and immersion under the test conditions [21].

Determination and Analysis of Fatty Acids Compositions

The fatty acid compositions of oil obtained from different oil resources (edible oil wastes, goat fat, chicken

Table 1. The Fatty Acid Composition of Oils and Fats Used to Produce Biodiesel

Fatty acid compositions (%)	Chicken fat	Goat fat	Edible waste oil	Palm kernel oil
Palmitic acid C16:0	28.65	25.75	31.88	37.71
Stearic acid C18:0	6.93	5.58	6.45	4.3
Oleic acid C18:1	43.13	43.158	41.04	42.44
Linoleic acid C18:2	12.51	12.98	17.98	13.71
Linolenic acid C18:3	0.01	0.714	0.43	0.23
Myristic acid C14:0	7.9	0.7	0.77	0.95

fat and oil derived from palm kernel) were determined directly using gas chromatography (GC). Helium gas was used as a carrier gas. Nitrogen (as a makeup), hydrogen and air gas flows were adjusted at 30, 30 and 300 ml min^{-1}.

After reaching equilibration for 60 s, the temperature of the column was increased from 150 to 220 °C at a rate of 10 °C min^{-1} and then kept for 2 min. The temperature was then increased to 235 °C at a rate of 7 °C min^{-1} and kept for 2 min. The temperature was increased again to 255 °C at the same rate and kept for 1 min. Finally, the temperature was increased with a rate of about 10 °C min^{-1} until the temperature reached 268°C and kept for 30 min. The fatty acid compositions from the oil sources are tabulated in Table 1.

Production and Purification of the Biodiesel

For production of biodiesel from palm kernel, the optimum conditions were considered to produce the product. In this case, the ratio of methanol to oil was set on 6:1, the reaction temperature was set on 60 °C, and reaction time was considered to be 60 min. Furthermore, the biodiesel produced from edible oil waste and chicken fat were obtained at the methanol to oil ratio of 6:1, the catalyst content of 1 wt.%, reaction temperature of 60 °C, and reaction time of 90 min. Additionally, for fabrication of biodiesel from goat fat, the ratio of methanol to oil, weight percentage of catalyst, reaction temperature and reaction time were set on 12:1, 1 wt%, 70 °C and 60 min, respectively. Moreover, all reactions were carried out at atmospheric pressure.

The produced biodiesels from the resulting transesterification reaction were poured into a separating funnel for 24 h until the biodiesel and the glycerol phase were separated. After the glycerol phase got separated from the solution, the methyl ester phase was firstly washed with 5% sulfuric acid solution to dissolve the soap phase. After being washed for several times with the solution containing 5 wt% acid, the desired phase was washed with distilled water for several times at the temperature of 65 °C until all of the residual acids were completely removed (neutralized). The product was then poured into the beaker glass and about 10 g of sodium sulfate was added to the mixture and thence stirred for further 40 min to absorb the water in the product. The resulting product was filtered through the filter paper and vacuum pump to separate the sodium sulfate from the solution. After filtration process, the biodiesel was poured into the plastic bottles made of polyethylene terephthalate and stored at room temperature.

Preparation and Characterization of Biodiesel-diesel Fuel Mixtures

The biodiesel was mixed with various amounts of diesel to investigate and improve the physical properties of the biodiesel. The mixing between biodiesel and diesel was carried out at room temperature using a magnetic stirrer to obtain a uniform mixture. The fuel properties such as

Table 2. The Physical Properties of the Biodiesel-diesel Mixture

Biodiesel source	Property	Biodiesel composition (%)						ASTM D6751
		100	80	60	50	20	10	Limit
Edible waste oil	Flash point (°C)	171	102	83	78	68	62	93
	Kinematic viscosity ($mm^2\ s^{-1}$)	4.5	4.1	3.8	3.5	3	2.7	1.9-6
	Cloud point (°C)	13	9	5	3	-5	-10	
	Density ($kg\ m^{-3}$)	872	866	860	840	828	820	Report
	Pour point (°C)	6	3	-1	-16	-19	-35	
Chicken fat	Flash point (°C)	174	110	85	74	69	64	93
	Kinematic viscosity ($mm^2\ s^{-1}$)	5	4.5	4.2	4.1	3.8	3.6	1.9-6
	Cloud point (°C)	10	8	3	-1	-7	-11	
	Density ($kg\ m^{-3}$)	886	878	867	850	842	830	Report
	Pour point (°C)	3	-3	-5	-8	-21	-25	
Palm kernel oil	Flash point (°C)	176	120	104	92	81	69	93
	Kinematic viscosity ($mm^2\ s^{-1}$)	5.7	4.7	4.2	4	3.6	3.4	1.9-6
	Cloud point (°C)	15	11	9	6	1	-2	
	Density ($kg\ m^{-3}$)	879	868	860	845	828	820	Report
	Pour point (°C)	15	12	7	2	-8	-13	
Goat fat	Flash point (°C)	180	140	122	115	84	72	93
	Kinematic viscosity ($mm^2\ s^{-1}$)	5.5	5.1	4.8	4.5	3.7	3	1.9-6
	Cloud point (°C)	8	4.2	3	1	-1	-4	
	Density ($kg\ m^{-3}$)	890	879	870	854	830	825	Report
	Pour point (°C)	2	-1	-6	-9	-16	-28	

viscosity, density, flash point, cloud point and pour point were analyzed according to the international standard of ASTM D 6751.

RESULTS AND DISCUSSION

Kinematic Viscosity

The physical properties and characteristics of the produced biodiesel are tabulated in Table 2. Kinematic viscosity is a critical feature for motor fuel. It plays an important role in the fuel injection, mixing and combustion [22]. The viscosity of the fuel is crucial to soften the system. In this regard, if the fuel viscosity is low, it cannot supply effective softening properties to provide a fuel injection system, which thereby leading to increase in the erosion and leak of the fuel system. On the other hand, if the fuel

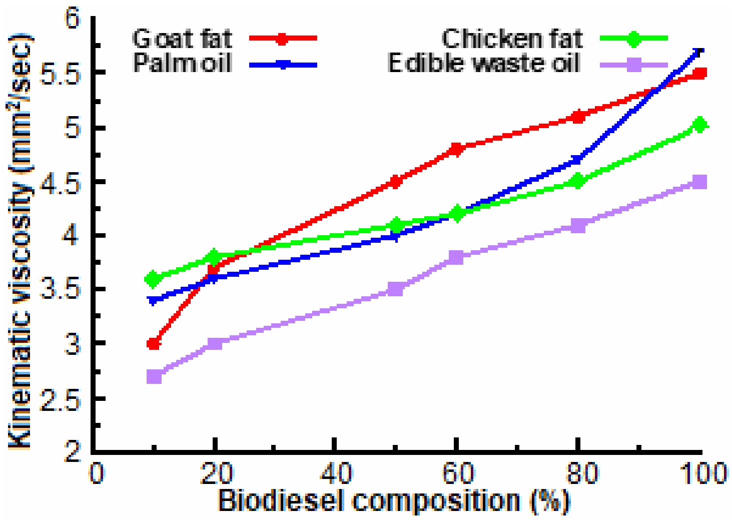

Fig. 1. The kinematic viscosity of biodiesel-diesel fuels as a function of biodiesel composition.

viscosity is high, the fuel injection system requires more energy to inject fuel, making inefficient fuel distribution; thus, the viscosity should be optimized at appropriate conditions. As a result, the amount of produced energy reduces while the exhaust particulate emissions and fumes increase [23]. Hence, the high viscosity of the produced biodiesel could be a negative factor leading to prevent the reduction of fuel injection and to decrease the erosion of injector pump parts and exhaust particulate emissions and fumes. The kinematic viscosity of petroleum diesel in Iran is about 2.5 $mm^2\ s^{-1}$, while the pure biodiesels extracted from edible waste oil, chicken fat, palm kernel oil and goat fat have the kinematic viscosity of about 4.5, 5, 5.7 and 5.5 $mm^2\ s^{-1}$, respectively. Figure 1 shows the kinematic viscosity of produced biodiesel from oils and fats as a function of the biodiesel composition. As shown in Fig. 1, by further increase in the biodiesel's percentage in the mixture, the kinematic viscosity of the mixture has considerably increased. Since the viscosity of the diesel is less than the developed biodiesel from used oil sources, the addition of biodiesel to diesel fuel increases the viscosity of the mixture. Among oil resources, the biodiesel produced from palm kernel oil had a higher kinematic viscosity indicating that it could be the best oil to produce biodiesel.

Flashpoint

Flashpoint is known as the temperature when a volatile compound evaporates to form an ignitable mixture in air. Flashpoint is an important parameter for biodiesel and other fuels representing their safety, storage, and transportation of the fuel.

The biodiesel flash point is affected significantly by the ratio of methanol in the final fuel composition. If the amount of methanol in the biodiesel increases by 5%, the flashpoint of the biodiesel will decrease to about 52 °C [24]. Flashpoint for fuels derived from oil is 52 °C, while, according to ASTM D6751-2 standard, it should be higher than 132 °C. As reported in many studies, the flash point of biodiesel lies within the range of 160-200 °C [25-26], which is higher than the ASTM D6751 value, while the flash point of the diesel products derived from oil in Iranian fuel stations is about 52 °C.

The flash point of biodiesel-diesel mixtures as a function of biodiesel composition is displayed in Fig. 2. The flash point of pure biodiesels made from edible oil waste, chicken fat, palm kernel oil and goat fat are measured to be 171, 174, 176 and 180 °C, respectively. The flash point of the biodiesel is higher than diesel products derived from oil. In order to decrease the flash point of the final composition, the biodiesel has to be blended with different ratios of diesel. It is found that the amount of the biodiesel is proportional with the flashpoint of the mixture. Also, the biodiesel produced from goat fat had a higher flash point and the mixtures of B100, B80, B60 and B50 can be used in

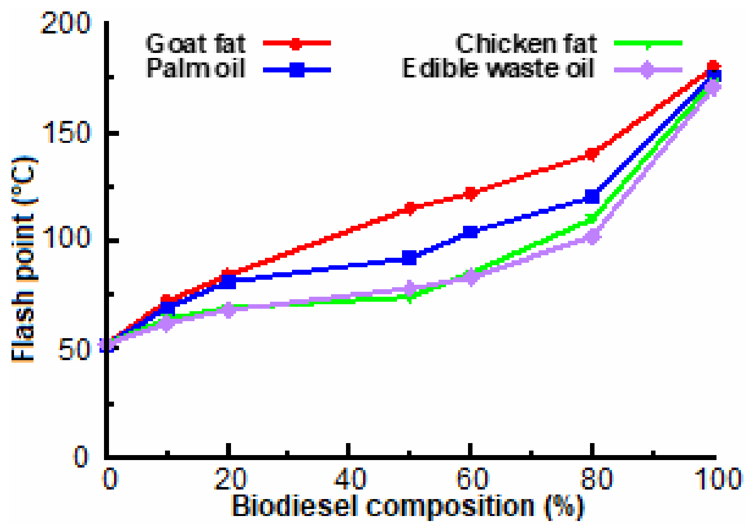

Fig. 2. The flash point of biodiesel-diesel fuels as a function of biodiesel composition.

a motor vehicle.

Pour Point

Pour point is one of the flow characteristics of fuels at different temperatures. This feature limits the use of biodiesel in a different climate and different geographical conditions. The pour point of a liquid is the temperature at which it becomes semi-solid and loses its flow characteristics leading to failure of the fuel system. Using fuel with a temperature lower than its pour point leads to lowering the engine performance. Pour point of biodiesel is independent of both the type of catalyst and the reaction conditions, but depends on the amount of saturated fatty acids in the oil [27].

The pour point of the produced biodiesels for the pure and mixed forms (states, conditions) is depicted in Fig. 3. According to Fig. 3, increase in the ratio of biodiesel in the biodiesel-diesel mixture increases the pour point of the mixture, indicating that the amount of the fatty acids in the produced biodiesels is high. The pour point of pure biodiesels made from edible oil waste, chicken fat, palm kernel oil and goat fat are calculated to be 6, 3, 15 and 2 °C, respectively. Based on the ASTM 6751 standard, no pour point is reported for biodiesels while some recent studies have reported the pour point of biodiesel produced from different resources to be in the range of -15 to 25 °C [29].

Cloud Point

Cloud point is one the temperature-dependent parameters affecting the use of biodiesel in different geographical and climatic conditions. The allowable limit for cloud point is not reported according to the ASTM D675 standard since this parameter is unique for every climatic condition in each region. Some recent studies have reported that the cloud point of biodiesel is within the range of -20 to 284 °C according to EN ISO 3016 standard [28].

The cloud point of the pure biodiesel from edible oil waste, chicken fat, palm kernel oil and goat fat is 13, 10, 15 and 8 °C, respectively. Figure 4 shows the effect of biodiesel concentration in biodiesel-diesel mixtures to their cloud point. According to the figure, increase in the ratio of the biodiesel content leads to the increase in the cloud point of the system. Therefore, the biodiesel produced in this study cannot be used in cold weather in a pure form and must be blended with diesel for use in this climate.

Density

Biodiesel is a fuel that is composed of long hydrocarbon chains. Increasing the amount of biodiesel ratio in diesel-biodiesel mixture increases the density of the mixture [4,29]. The relative density of the fuel plays a significant role in the fuel injection into the fuel injection system. In this matter, the higher the fuel density, the lower the injection speed of the fuel in car fueling system [4,30].

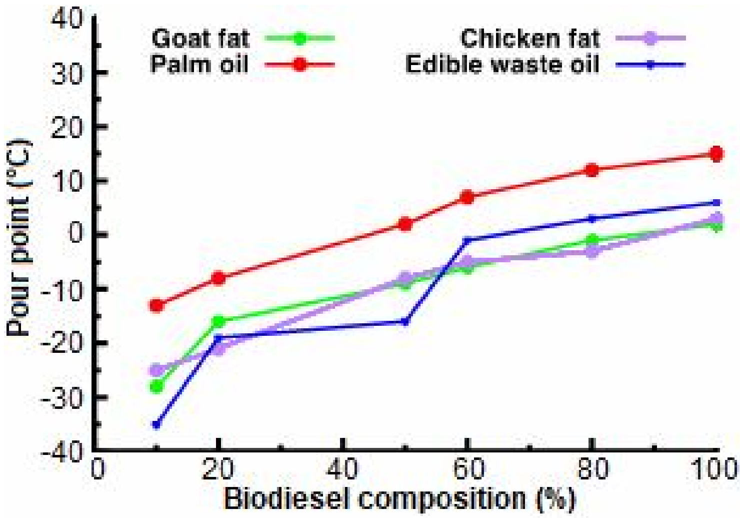

Fig. 3. The pour point of biodiesel-diesel fuels as a function of biodiesel composition.

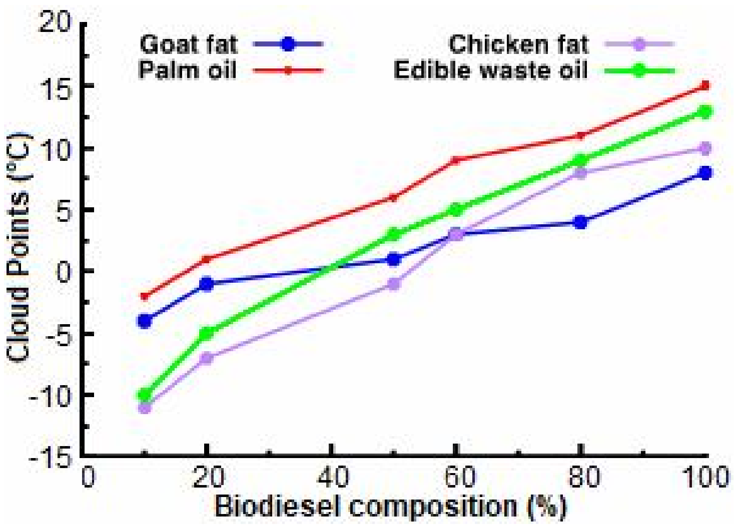

Fig. 4. The cloud point of biodiesel-diesel fuels as a function of biodiesel composition.

The density of the pure biodiesel from edible oil waste, chicken fat, palm kernel oil and goat were measured to be 872, 886, 879 and 890 kg m^{-3}, respectively. Figure 5 shows the effect of biodiesel concentration in biodiesel-diesel mixtures to their density. As shown in Fig. 5, the density of biodiesel-diesel mixture increases by further increase in the concentration of the biodiesel. Many studies reported that the density of biodiesel is within the range of 860-900 kg m^{-3} [31-32].

CONCLUSIONS

Due to the rise of world oil prices in recent years, environmental pollution from fossil fuel, and the uprising demand for energy due to the world's population, biodiesel has become attractive alternative energy sources for many

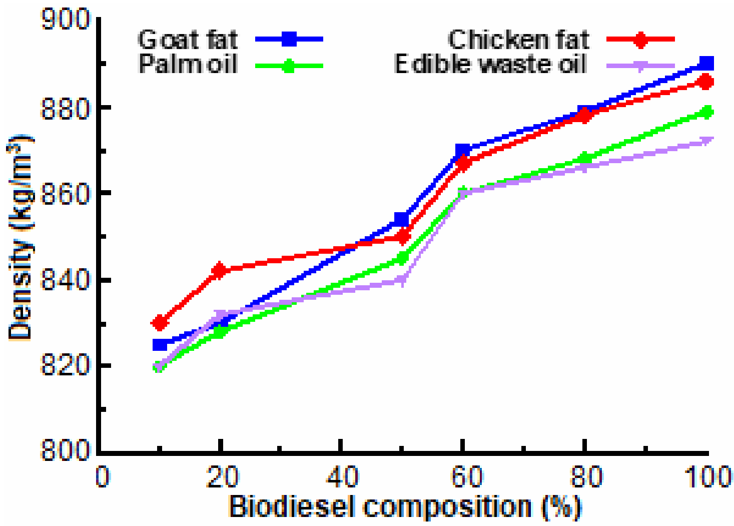

Fig. 5. The density of biodiesel-diesel fuels as a function of biodiesel composition.

nations. About 70% of the biodiesel production cost comes from the preparation of the raw materials. Hence, to decrease the final cost of the biodiesel, the usage of low-cost materials from oil and fat waste are strongly encouraged. This study presents the biodiesel production methods using low-cost and waste resources, such as edible oil, chicken fat, goat fat and palm kernel oil waste. To improve the properties of the produced biodiesels, they were mixed with commercial Iranian diesel at different ratios. Next, their properties were analyzed according to the ASTM D6751 standard. By comparing the physical properties of the biodiesel-diesel mixture with pure biodiesel, it was concluded that some properties such as density, viscosity and flash point are improved, which in turn, could decline the rate of pollution produced by the developed fuel and improve the fuel efficiency. However, some other properties such as pour point and cloud point increased by further increase in the biodiesel content. Increase in the aforementioned parameters have adverse effects on the performance of the developed fuel and can restrict the usage of the fuel in different weather conditions; in particular in cold weather due to insufficient efficiency. Obtained results also showed that the produced biodiesels from mentioned oil and fat resources are ideal alternatives for common diesel engines' fuels. Additionally, the biodiesel produced from goat fat had a higher flash point and the mixtures of B100, B80, B60 and B50 can be used in a motor vehicle. Moreover, the biodiesel produced from all oil sources cannot be used in cold weather in a pure form and must be mixed with diesel for use in this climate.

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