Properties and Spray Characteristics of Heated Pure Coconut Oil Aiming a Direct Use in Conventional Diesel Engines

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Abstract

In order to use pure coconut oil in conventional diesel engines, it is necessary to improve its properties at least by heating method. The paper presents main properties of pure coconut oil at different heating temperatures. The spray characteristics of heated oil were also investigated and compared with those of diesel fuel obtained at room temperature.

The results show that, thanks to the heating process, the viscosity, the surface tension and the density of the tested oil were improved which helps the fuel spray develop, atomize and evaporate closer to that of the diesel fuel. These findings are crucial for designing and fabricating a heating device, which utilizes exhaust and electric energy, to supply the pure coconut oil as an alternative fuel to the conventional diesel engine.

Keywords: pure coconut oil, heating method, fuel spray.

1. Introduction

Bio-oils that include vegetable oils and fats of animals have become more attractive recently because of their environmental benefits.

Using vegetable oils as fuel is not new and dates back to the end of the 19th century with the inventor of the diesel engine. In1900, at the Universal Exhibition in Paris, the OTTO Company exhibited a small engine which, at the request of the French government, ran exclusively on groundnut oil. The engine, which had initially been designed to run on diesel oils, worked with vegetable oil without any modification. During World War II, vegetable oils were used to power diesel engines in isolated areas. Many researchers from different countries are still investigating the use of different types of vegetable oils as diesel fuel substitutes. For example, soybean oil is being tested and used in the USA, as are rapeseed oil and sunflower oil in Europe, palm and coconut oil in Southeast Asia, and cottonseed oil and Jatropha curcas oil in West Africa. Besides, there are some of researches about using fats of animals.

Pure coconut oil (CO100) belongs to bio-oils and coconut trees are planted in the Southern areas in Vietnam and several countries in Southeast Asia. The advantages of CO100 as diesel fuel are liquidity, ready availability, renewability, no sulfur and aromatic content, biodegradability however the main disadvantages of CO100 are higher viscosity, higher surface tension, higher density otherwise lower volatility.

2. Properties of CO100

The physical and chemical properties of the CO100 are given in the Table 1.

Table 1: Physical and chemical properties of the CO100

Properties	Methods	Unit	Result
Higher heating value	ASTM D 240	MJ/kg	38
Water content	ASTM E 203-01	ppm	432
Sulfate ash	ASTM D 874	%wt.	0.03
Sulfur content	ASTM D 5453	ppm	170
Phosphoric content	ASTM D 3231	mg/l	25
Cetane number	ASTM D 976	-	39
Cloud point	ASTM D 97	^{o}C	21
Flash point	ASTM D 93	^{o}C	200
Distillation temperature 90% vol	ASTM D 86	^{o}C	362
Oxidation stability , 110^{o}C	EN 14112	h	>24
Acid value	ASTM D 974	mg KOH/g	0.4
Copper plate corrosion	ASTM D 130		1

The ASTM D1298 standard procedure was used to measure density, the ASTM D 445 standard was used to measure kinematic viscosity and Du Nouy ring method with a tension meter based on the ASTM D971 standard was used to measure surface tension of the CO100.

Table 2: Viscosity, surface tension and density of CO100 and diesel fuel at room temperature

Fuel	Kinematic viscosity (cSt)	Density (g/cm^3)	Surface tension(N/m)
Diesel fuel	4.15	0.8308	0.028
CO100	49.3	0.9103	0.0322

From Table 1 & 2, it is able to see clearly that, some of physical and chemical properties of the CO100 such as water content, sulfate ash, phosphoric content, and distillation temperature satisfy with the Vietnamese standard and regulation such as TCVN 5689-2005 and QCVN 1:2009. However, higher heating value and cetane number are smaller, while cloud point and flash point are higher than those of diesel fuel. Specially, the viscosity, the surface tension and the density of CO100 at the room temperature are much higher than those of diesel fuel. These above results prove that it is crucial to improve the properties of CO100 before it is injected into the combustion chamber. In this study we use the heating method to upgrade the viscosity, the surface tension and the density of CO100 aiming to help the fuel spray develop, atomize and evaporate closer to that of the diesel fuel.

The measured results of kinematic viscosity, surface tension and density of CO100 according the temperature of the CO100 are given in Table 3 and from Fig 1 to Fig 3.

Table 3: Viscosity, surface tension and density of CO100 at different temperature

Temperature (^{0}C)	Kinematic viscosity (cSt)	Density (g/cm^3)	Surface tension(N/m)
40	28.1	0.9033	0.0335
50	20.1	0.8965	0.0322
60	14.9	0.8896	0.0312
70	11.3	0.8827	0.0303
80	9.1	0.8761	0.0293
90	7.2	0.8698	0.0284
100	5.4	0.8639	0.0272
110	3.5	0.8568	0.0266

It is observed that from the temperature of 100^{0}C, the kinematic viscosity and surface tension of the CO100 satisfy with the requirements of diesel fuel based on TCVN 5689-2005 and QCVN 1:2009.

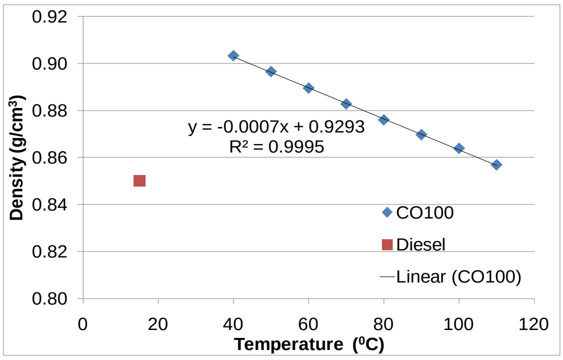


Fig 1. Relationship between density and temperature

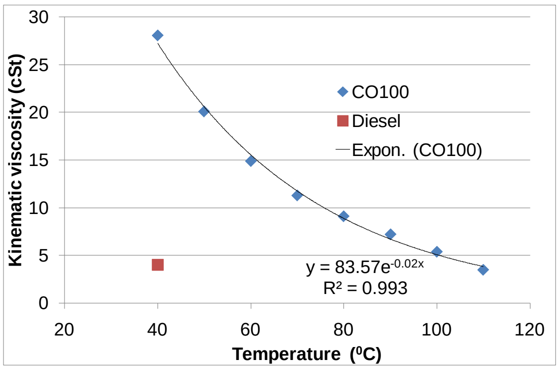


Fig 2. Relationship between kinematic viscosity and temperature

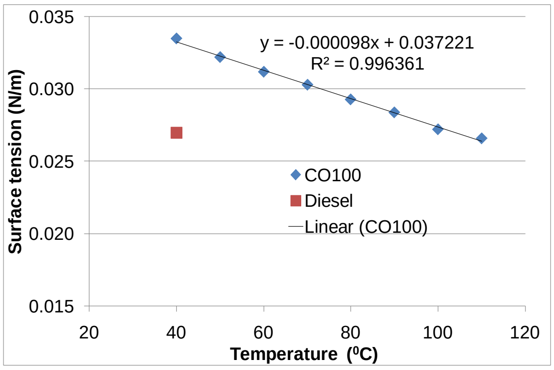


Fig 3. Relationship between surface tension and temperature

However, it is necessary to investigate the spray characteristics both of heated CO100 and of non-heated diesel fuel in order to consider applying directly CO100 in diesel engine.

3. Spray characteristics

3.1 Materials and methods

CO100 and diesel fuels have been used for analysis of the spray characteristics. According the properties and temperature curves given in Fig 1 to Fig 3, the CO100 fuel was heated up from 80^{0}C to 110^{0}C and observed the spray characteristics at different heating temperature.

3.2 Experimental set-up

Fig 4 shows the experimental set-up for investigating the spray characteristics parameters. The test-bed includes a constant volume spray chamber, automatic heater used electric line 220V, fuel injection system and high speed imaging system. The injector is a simple mechanical fuel injector with delivery valve opening pressure set at 200 bar. Fuel injector is connected to the fuel pump via a high pressure line. The CO100 fuel is delivered into the mechanical jerk pump from fuel tank where it is heated automatically to the designed temperature. A high speed camera with shutter speed of 120 frames per second and 18 megapixel resolution is located orthogonally to the spray direction to capture the spray's images.

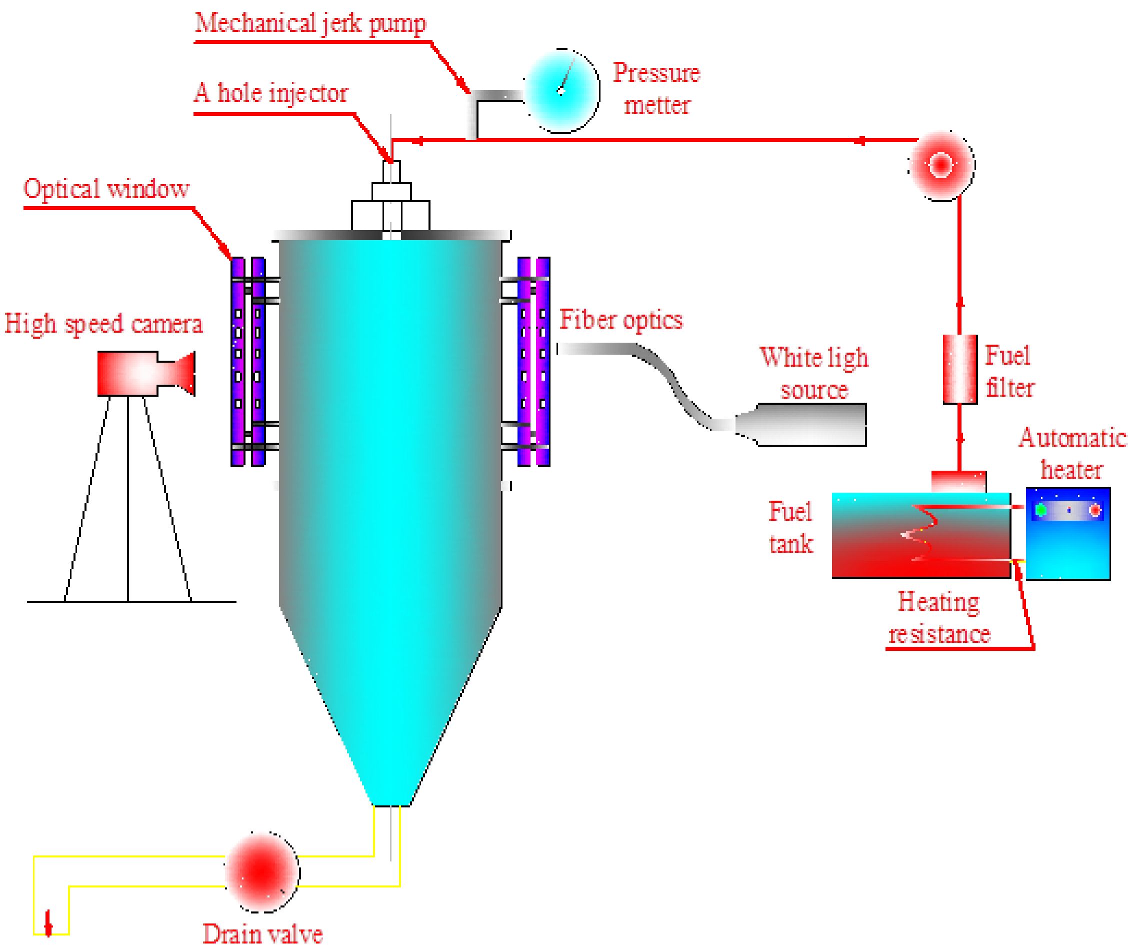
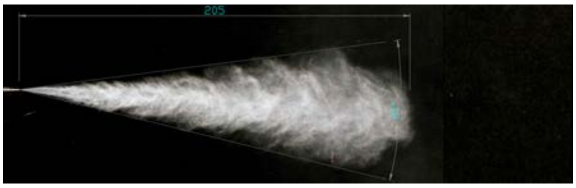


Fig 4. Schematic of the experimental set-up for fuel spray characterization

3.3 Results

Kinematic viscosity, surface tension and density of CO100 and diesel fuel have been determined. At 40°C, kinematic viscosity of CO100 is 28.1cSt, surface tension is 0.0335 N/m and density is 903.3 kg/m^3, which are higher than those of diesel fuel. The spray characteristics are therefore different for diesel and CO100 at the same temperature.

At room temperature the spray images of diesel fuel and CO100 are shown in Fig 5 and Table 4. The spray images of CO100 captured at different temperature from 80^{0}C to 110^{0}C are given in Table 5 and Fig 6.



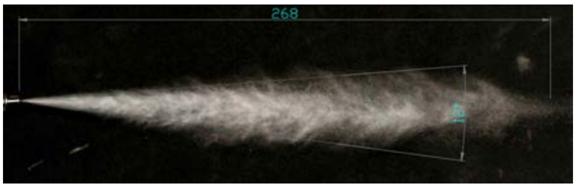
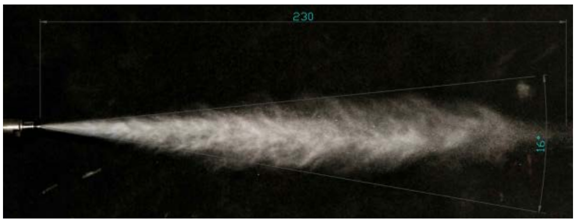
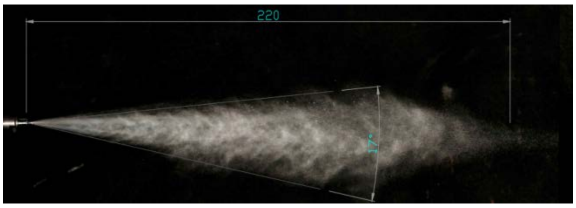


Fig 5. Spray characteristics parameters of diesel (upper picture) and CO100 (lower picture) at room temperature

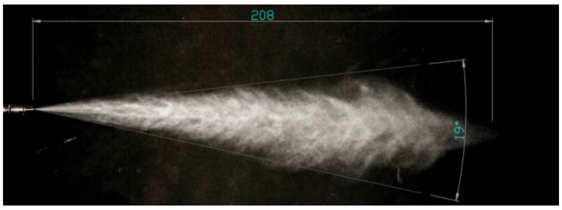


t = 80^{0}C



t = 90^{0}C

t = 100^{0}C



t = 110^{0}C

Fig 6. Spray characteristics parameters of CO100 at heated temperature from 80^{0}C to 110^{0}C

CO100 with higher density, kinematic viscosity and surface tension exhibit inferior spray and atomization characteristics. When fuel injection starts, droplets move fast and tend to break into smaller droplets. The droplet size distribution depends on the density, kinematic viscosity and surface tension of the fuel. If test fuel has lower density, atomization takes place quickly and in case of higher density fuels (such as CO100); it takes longer time to atomize because of their higher intra-molecular forces, called Van-der-Waals forces. After heating, value of Van-der-Waals forces of CO100 is reduced inversely proportional to temperature, therefore the kinematic viscosity, the surface tension and the density at the temperature ranging from 100^{0}C to 110^{0}C are similar to those of diesel measured at 20^{0}C which may help the CO100 spray develop, atomize and evaporate closer to that of the diesel fuel (Table 4). At room temperature, the cone angle of CO100 is smaller than that of diesel fuel and the spray penetration is bigger (Table 5).

Table 4: Cone angle, spray penetration of CO100 at different temperature

Temperature (^{0}C)	Cone angle (^{0})	Spray penetration (mm)

80	16	230
90	17	220
100	18	212
110	19	208

Table 5: Cone angle, spray penetration of CO100 and diesel fuel at room temperature

Fuel	Temperature (^{0}C)	Cone angle (^{0})	Spray penetration (mm)
Diesel	20	21	205
CO100	20	12	268

4. Conclusions

In this paper, the properties and the spray characteristics of CO100 has been analyzed and compared with those of diesel fuel in order to find the most accordant range of temperature to use directly CO100 in diesel engine.

The results show that, in order to use CO100 in diesel engines, it is necessary to heat the fuel up to 80^{0}C to 110^{0}C depending on the applied fields of the engines which require the dedicated properties of the fuel. Thus, in order to use CO100 in diesel engines in general, it is necessary to heat the fuel up to 100^{0}C to 110^{0}C. However, in agricultural engines or small ship engines, where the fuel requirement is not so strict, the CO100 fuel needs to be heated only up to 80^{0}C to 100^{0}C. Of course there are many issues needed to be concerned in order to use CO100 in diesel engines in practical such as fuel spray visualization, mixture of CO100 and ambient air in the real combustion chamber, lubricant degradation, corrosion, etc.

In the next research, the heating system design will be shown with the aim of integrating the electricity – exhaust energies in order to utilize the redundant exhaust energy and to benefit the environment.

5. Acknowledgements

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