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Long Run Tests of Vehicles Using Straight Vegetable Oil as Fuel

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“Straight Vegetable Oil (SVO)” method means the direct use of vegetable oil as car fuel through installation of a heater unit in the car to decrease vegetable oil viscosity. In this study, the authors carried out performance tests on the direct use of waste cooking oil using a car with a heater unit. Moreover, the authors carried out long run driving on road tests in 5 years using a public car of Minami-Aizu town in Fukushima prefecture and analyzed the case of troubles and clarified the availability and problems of SVO vehicles. As a result, the car with a heater unit shows similar performance in both cases using vegetable oil or diesel fuel as fuel. The tested SVO vehicle of Minami-Aizu town could be driven 38,127 km mainly by waste vegetable oil with a total driving distance of 52,293 km in long run driving tests in 5 years, and decreased about 3813.5 L of light oil which corresponds to 9.99 t of CO₂.

SVO (ストレート・ベジタブル・オイル) 方式は、エンジンへの加温装置取付けによる燃料としての植物油（あるいは廃食用油）の直接利用法である。本研究において、著者らは加温装置付き自動車を用い、廃食用油直接利用時の性能試験を行った。次に、廃食用油直接利用の可能性と問題点を明らかにすべく、加温装置を装備した自治体（福島県南会津町）公用車を用いて5年間にわたる長期走行試験を実施し、この間のトラブル解析を行った。性能試験の結果、加温装置付き自動車では、植物油利用時に軽油利用時とはほぼ同等の動力性能が得られることがわかった。また、南会津町における長期走行試験では、5年間の総走行距離 52,293 km のうち、38,127 km を主に廃食用油を燃料として走行することが可能であった。5年間で約 3813.5 L の軽油節約と、9.99 t の CO₂ 排出削減に相当する効果を得ることができた。

Key Words

Waste cooking oil, Straight vegetable oil, Bio-fuel

1. Introduction

Various kinds of vegetable oil and waste cooking oil are in fact used as car fuel all over the world. In general, 'bio-diesel' i.e. fatty acid methyl ester produced from such oil is utilized as fuel for vehicles. However bio-diesel has some problems such as treatment of by-products and waste materials created during transesterification.

An alternative method is “Straight Vegetable Oil (SVO)” method which means the direct use of vegetable oil as car fuel through installation of a heater unit in the car to decrease vegetable oil viscosity. SVO method has the following advantages; (1) Auxiliary materials such as methanol and catalysts are not necessary. (2) By-products such as glycerin and waste fluid are not generated. (3) It

is not necessary to treat hazardous materials on the fire defense law such as bio-diesel and methanol. (4) Operators for bio-diesel producer are not required.

As for SVO method, some studies were carried out such as study on engine performance and emissions from engines when rape seed oil or waste vegetable oil is used as fuel^{1)~3)}. However the number of studies on SVO is fewer than ones on bio-diesel. Furthermore, there are few studies on long-run driving performance of SVO vehicles.

The authors of this study carried out performance tests on the direct use of waste cooking oil using a car with a heater unit. Moreover, the authors carried out long run driving on road tests in 5 years using a public car of Minami-Aizu town in Fukushima prefecture and analyzed the case of troubles and clarified the availability and problems of SVO vehicles.

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2. Tests on Basic Performance of SVO vehicle

2.1 Tested Car

First, the authors made a car to test waste cooking oil as fuel by equipping a heater unit, a filter unit, pipes and a sub fuel tank for diesel fuel to a used TOYOTA Estima Diesel KD-CXR10G. Table 1 shows the specifications of the original car. Fig. 1 shows the systematic diagram of the direct-use-system. Fig. 2 shows the picture of a heater unit and a filter unit. Vegetable oil is heated and decreased the viscosity by heat exchange with hot water from the car radiator in the heater. Mesh of the filter element is 5 mm.

The tested car has a main fuel tank for vegetable oil and a sub fuel tank for diesel fuel. The newly established filler of the fuel tank is only different from a general car in the appearance. Two completely different pipes are used from two tanks to the engine to avoid the mixture. The tested car has a switch to change the mode between diesel fuel, vegetable oil and automatic. At automatic mode, diesel fuel is used as fuel at engine starting, vegetable oil is used

Fig. 2 Heater and filter of the direct-use-system

at more than 40 °C of hot water from car radiator, and diesel fuel is circulated after stopping the engine. This car has acquired the car certificate from the transportation bureau, so can be driven on public roads.

2.2 Results of Dynamo Tests

The authors carried out performance tests of a car with direct-use-system by chassis dynamo D-6000S of Sakura Dyno System Corporation. Diesel fuel and waste cooking oil were used as fuel for comparison. Waste vegetable oil (WVO) used for the tests was filtered by 0.5 mm mesh before refueling. Table 2 shows the characteristics of diesel fuel and waste vegetable oil that were used for the performance tests.

Fig. 3 shows the results of the chassis dynamo tests. The maximum power was 105.5 PS/3700 rpm at waste vegetable oil and 107.4 PS /3800 rpm at diesel fuel. The car showed similar performance in both cases using either waste vegetable oil or diesel fuel as fuel ^{4) 5)}.

2.3 Results of On-road Tests

The authors have continuously carried out on-road tests of the car with direct-use-system of waste vegetable oil. The data of place, altitude, velocity and acceleration of the car are sampled at every second and all recorded by GPS system installed in the car since August, 2007.

Fig. 4 shows an example of the results of on road tests. These data were obtained by driving 300 km of roads including highway and mountain roads on the 17th, October, 2007. The car could be driven on roads with 800 m of altitude difference shown in Fig. 4 (a) and on high-way by more than 100 km/h stably as shown in Fig. 4 (b). Although this car uses diesel fuel only at cold-starting and after stopping the engine, about 95% of consumed fuel was waste vegetable oil on this day.

Fig. 5 shows the results of the on-road tests during

Table 1 Specification of original car

Name	TOYOTA ESTIMA Lucida
Type	KD-CXR10G
Production year	1998
Weight	1660 kg
Size	4690*1690*1790 mm
Capacity	8 persons
Type of engine	3C-TE (In line 4 cylinders OHC IC turbo diesel engine)
Bore*Stroke	86.0 mm*94.0 mm
Displacement	2184 cc
Compression rate	22.6
Fuel supply system	EFI (Electric Fuel Injection)
Maximum power	105 PS (77 kW)/4200 rpm
Maximum torque	23.0 kg·m(225.6 N·m)/2600 rpm
Transmission	4AT

Fig. 1 Systematic diagram of SVO Vehicle (WVO: Waste Vegetable Oil)

Table 2 Characteristics of each fuel

	Light oil	WVO	Testing method
Specific gravity [-]	0.8247	0.9236	JIS K-2249
Lower heating value [MJ/kg]	45.58	39.67	JIS K-2279
Lower heating value [MJ/L]	37.59	36.64	(reference)
Kinetic viscosity [mm ² /s]	3.224 (30°C)	57.05 (30°C)	JIS K-2283
Total sulfur content [wt%]	<0.01	<0.01	JIS K-2541
Acid value [mg-KOH/g]	-	1.52	Standard of JOCS
Iodine value [g-I ₂ /100g]	-	128	Wijs method

(JOCS: Japan Oil Chemists' Society)

Fig. 3 Results of chassis dynamo tests (1 PS = 0.746 kW, 3000 rpm = 50 Hz, 1 Kgf m=9.81 N m)

the winter season. The lowest daily mean and the lowest instant (average in 10 minutes) ambient temperature in this period was 0 °C and minus 2.7 °C, respectively. In spite of such low temperature in this period, the car could be driven without any problem.

3. Long-run Driving Tests in Minami-Aizu Town

3.1 Tested Car

Next, the authors carried out long-run driving tests of the SVO vehicle. The tested SVO vehicle is an official car, which is equipped with an SVO unit, of the Minami-Aizu town in Fukushima Prefecture. Its original car was a Mitsubishi Pajero Diesel KC-V46V, which was produced

(a) Speed-Time

(b) Altitude-Time

Fig. 4 Results of on-road tests (1: Speed and altitude)

(a) Full data of 3 months

(b) Data on 5, Feb., 2008

Fig. 5 Results of on-road tests (2: Winter season)

in 1998 and its displacement is 2835 cm³ (2835 cc). Fig. 6 shows its picture. This car has also acquired the car certificate from the transportation bureau, so can be driven on public road.

The on-road tests were started from December, 2008 and continue until now. In this period, the authors recorded its driving distance, fuel consumption and number of troubles with data on position, altitude, velocity and acceleration by using GPS device. In this paper the author shows the results in 5 years from January, 2009.

3.2 Results of the Driving Distance and Fuel Consumption

Fig. 7 shows average, highest and lowest temperature of Minami-Aizu town in 5 years from 2009. It is found that the lowest temperature in this town is less than 0°C.

Figs. 8 and 9 show the driving distance and the fuel consumption of each driving mode of the SVO vehicle. Total distance of each mode was 13,395 km, 24,732 km, 14,166 km in the automatic mode, waste vegetable oil mode, and diesel fuel mode, respectively.

It was also found that the automatic mode is mainly used from January to April, and on the other hand, the

waste vegetable oil mode was mainly used from May to September. The reason is probably that the users of SVO vehicle recognized that the waste vegetable mode is fully reliable and more convenient than automatic mode under warm temperature condition.

On the other hand, it was found that the diesel fuel mode was highly used from October to December. Judging from these results, some problems might have occurred in the use of waste vegetable oil mode under cold conditions from October.

Fig. 6 Public SVO Vehicle in Minami-Aizu Town

Fig. 7 Temperature in the period of on-road test

(a) Automatic mode

(b) Waste vegetable mode

(c) Diesel fuel mode

Fig. 8 Driving-mode of tested car (in 2009)

(a)Automatic mode

(b)Waste vegetable oil mode

(c)Diesel fuel mode

Fig. 9 Driving-mode of tested car (Accumulated)

Fig. 10 shows the relation between the total mileage of each driving mode and the temperature. It is found that usage of waste vegetable oil increases on the day when the lowest temperature is higher than about 10 °C. On the other hand, diesel fuel was mainly used when the temperature is lower than 5 °C. This means the drivers selected diesel fuel mode or automatic for avoiding the troubles. In other words, the occurrence of troubles remarkably decreases at higher temperature.

So, there is a possibility to apply the SVO system to

Fig. 10 Relation between the total mileage and temperature

(a)Waste vegetable oil

(b)Diesel fuel

Fig. 11 Fuel consumption of tested car (Accumulated)

warm weather countries such as south Asia and Africa. Also, there is a possibility to apply the SVO system to engine generation systems which is used in the warm building's room, even in cold weather countries.

Fig. 11 shows the consumption of waste vegetable oil and diesel fuel. Total consumption of waste vegetable oil and diesel fuel was 3813.5 and 1580.6 L, respectively. As the CO₂ emission rate of light oil is 2.6192 kg-CO₂/L, this corresponds to a CO₂ reduction of 9.99 t in 5 years.

Table 3 Classifications of troubles in the period of on-road test

Case	Times
Trouble at starting engine	21
Instability of idling	16
Engine stopping	9

Table 4 List of Replaced parts

Date	Replacement parts	Date	Replacement parts
2009/3/9	Battery	2010/7/31	Engine oil
	Fuel hose and band		Oil pressure switch
2009/3/19	Fuel filter	2010/11/29	Engine oil
	Glow lamp		Element oil
2009/5/1	Bracket	2012/1/13	Glow plug
	Coolant	2012/3/9	Fusible link
	solenoid valve	2012/6/8	Switch
	Packing	2012/8/8	Coolant
2009/5/8	Injection pump	2012/11/30	Pulley
2009/12/7	Glow plug		Crank angle blade
	Water temp. sensor		Crank angle sensor
2010/2/25	Fuel filter		Bolts
2010/6/21	Gas for air conditioner	2012/11/30	Fuel filter
2010/6/30	Engine oil		WVO filter
	WVO filter	2013/4/24	Engine oil
	Element oil	2013/5/1	Electric code
	Fuel filter		

3.3 Analysis of Trouble Cases

Table 3 shows the number of troubles caused in the SVO vehicle of Minami-Aizu town in 5 years from 2009. It is found that trouble with starting the engine was the most common, and instability of idling, trouble of parts and engine stopping followed.

Table 4 shows the list of the replaced parts in 5 years. Battery, fuel hose, fuel filter, glow lamp, injection pump are included. The number of the occurrence gradually decreases according to passage of the time after start of the use. Most of recent replaced parts are those whose exchange is usually necessary for general cars.

4. Conclusion

The authors carried out performance tests and long run driving tests on the direct use of waste vegetable oil using a car with a heater unit.

As a result, the following conclusions were deduced:

- (1) Tested SVO vehicle could be driven 38,053 km mainly by WVO with a total driving distance of 52,219 km in long run driving tests in 5 year.
- (2) 3813.5 liters (70.7 %) of waste vegetable oil and 1580.8 L (29.3 %) were used in long run driving tests in 5 years. This corresponds to a CO₂ reduction of 9.99t.
- (3) Less than about 10 °C of the lowest air temperature, some counter plans for coldness are necessary for using SVO system.
- (4) On the other hand, no big problem was caused under the condition of more than about 10 °C of the lowest air temperature.

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