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Operation of a Diesel Engine Using Unrefined Rapeseed Oil as Fuel

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Abstract

This report deals with experiments carried out to examine the possibility of using unrefined rapeseed oil as a substitute for light oil in a small diesel engine. The authors carried out tests on short-term performance, long-term operation and no-load continuous operation using various kinds of unrefined rapeseed oil (deacidified oil, degummed oil and crude oil) produced in the process of refining, and refined rapeseed oil and light oil for comparison. Specific fuel consumption, thermal efficiency, exhaust-gas temperature, and density of black smoke in exhaust-gas were examined in tests on short-term performance and long-term operation. The amount of deposits in the precombustion chamber and on the injection nozzle was determined in tests on no-load continuous operation. As a result, it was considered that deacidified rapeseed oil can be used as fuel for a diesel engine. Degummed oil and crude rapeseed oil were found to be unsuitable for use as fuel due to the high level of incombustible materials in oil.

Discipline: Agricultural machinery
Additional key words: substitute fuel, deacidified oil, degummed oil, crude oil, incombusti bility

Introduction

Many studies on the use of plant oil as substitute fuel for a diesel engine have been carried out after the oil price increased in 1973[2,3,6,7,9–11]. The authors also carried out experiments on the possibility of using unrefined rapeseed oil as a substitute for light oil in a small diesel engine. The main reason for using plant oil as a substitute fuel is that farmers can produce the fuel material by themselves, without requiring the complex process of refining from crude oil. Rapeseed oil was selected in this study because rapeseed is cultivated widely and conveniently in Japan.

The engine must be easily started, and requires low combustion noise and good load performance[1]. In addition to these 3 conditions, reliability and stable operation performance over long running periods and low carbon coating to the combustion chamber in the no-load operation with the substitute oil are required.

In this paper, the authors carried out short-term performance tests, long-term operation tests and no-load continuous tests using various kinds of unrefined rapeseed oil (deacidified oil, degummed oil and crude oil).

Materials and methods

1) Materials

The fuel used for the experiments consisted of various kinds of unrefined rapeseed oil (deacidified, degummed and crude oil) and refined rapeseed and light oil. Preparations of deacidified, crude and refined rapeseed oil were produced by N Co., degummed rapeseed oil by R Co. and light oil consisted of No. 2 diesel oil.

The characteristics of each kind of fuel were defined by measuring the density, net calorific value, kinematic viscosity, content of incombustible materials and fatty acid composition (Table 1). The content of incombustible materials was determined by a method involving the measurement of carbon residues.

The short-term performance tests and long-term operation tests were conducted on an A-diesel engine, and no-load continuous tests on a B-diesel

Table 1. Characteristics of fuel used

	Rapeseed oil				Light oil
	Deacidified oil	Degummed oil	Crude oil	Refined oil	
Density (20°C, g/cm³)	0.920	0.919	0.919	0.922	0.837
Net calorific value (MJ/kg)	38.9	38.8	38.6	39.1	45.6
Kinematic viscosity (20°C, mm²/s)	63.4	76.6	63.9	83.4	1.64
(40°C, mm²/s)	29.4	35.2	29.7	36.9	1.20
Content of incombustible materials[a] (%)	0.012	0.141	0.050	0.004	0.007
Fatty acids (%)					
Palmitic acid	4.0	4.3	4.3		
Oleic acid	60.3	60.9	59.1		
Linoleic acid	21.1	20.9	22.4		
Arachidic acid	10.7	10.0	10.2		

a): Method involving the measurement of carbon residues.

Table 2. Specification of engines

	A-Engine	B-Engine
Manufacturing company	Yanmar Diesel Co., Ltd.	Yanmar Diesel Co., Ltd.
Engine model	NSA40G	HA4B
Type	4-Stroke cycle diesel engine	4-Stroke cycle diesel engine
Combustion system	Precombustion chamber type	Precombustion chamber type
Bore × stroke (mm × mm)	ø66 × 66	ø66 × 66
Rated output (kW/rpm)	2.57/2,200	2.57/2,400
Maximum output (kW/rpm)	2.94/2,200	2.94/2,400
Compression ratio	23.5	23.5
Injection time	10° BTDC	16.5° BTDC
Injection nozzle	Pintle type	Pintle type
Nozzle opening pressure (MPa)	13.7	15.7

A-Engine: Tests on short-term performance and long-term operation.
B-Engine: Test on no-load continuous operation.

engine (Table 2).

Engine power was measured with an electric dynamometer connected to a diesel engine by 2 V-belts of B-type. Fuel was supplied through a burette, and fuel capacity was calculated by determining the consumption time of the volume of fuel.

Density of black smoke in exhaust-gas which was inhaled for 4 s through a filter paper was measured with a smoke tester. The measuring point of exhaust-gas temperature was located about 10 cm inside of the muffler.

2) Short-term performance tests

The operating mode of the short-term engine performance tests was as follows: warming operation time was 20 min (1,800 and 2,000 rpm), 75% load operation time 160 min (2,200 rpm), no-load operation time 5 min, and rated load operation[8] time 25 min (Fig. 1). Engine power, fuel capacity, density of black smoke in exhaust-gas and exhaust-gas temperature were measured every 10 min in 75% load operation, and every 5 min in rated load operation.

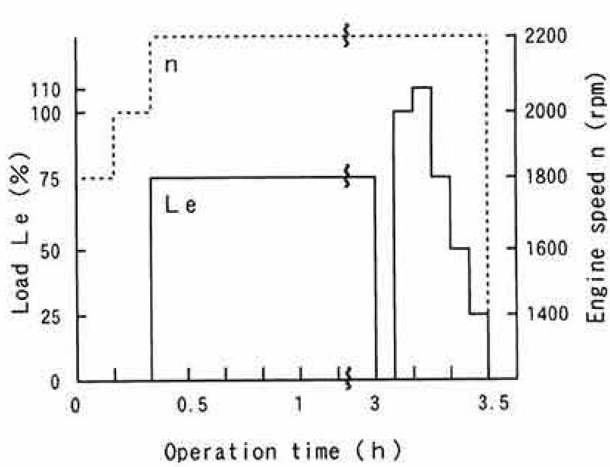

Fig. 1. Operating mode of short-term engine performance tests

Fuels used included, in the following order, light oil, deacidified oil, degummed oil and crude oil in the test.

3) Long-term operation tests

The conditions for the long-term operation involved rated revolutions and 75% load. The total target time of the long-term operation was 200 h, and of the continuous operation about 5 h in each operation. Engine performance tests were carried out every 25 h in the same way as in the rated load operation shown in Fig.1. For the engine performance tests, light oil was used as fuel every 100 h.

The amount of deposits in the precombustion chamber and on the injection nozzle in the long-term operation was monitored. Accordingly, the precombustion chamber and the injection nozzle were replaced each time fuel was replaced.

4) No-load continuous operation tests

The conditions for no-load continuous operation for each kind of fuel included rated revolutions (2,400 rpm), and the target time of the continuous operation was 100 h. As in the long-term operation, the precombustion chamber and the injection nozzle were replaced each time fuel was replaced.

The incombustibility in the precombustion chamber was expressed by the residual quantity after the deposits of the no-load continuous operation were put in the electric furnace at 550°C for 30 min. In addition, the combustible materials in the electric furnace consisted of carbon.

Results and discussion

1) Short-term performance tests

Figs. 2 and 3 depict the 75% load operation per-

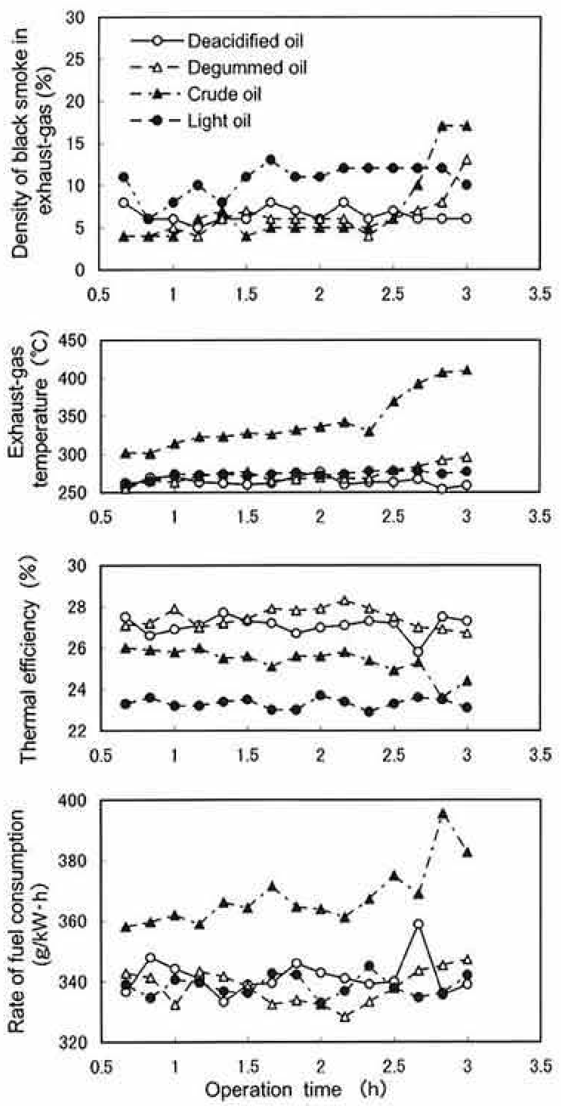

Fig. 2. Engine performance in 75% load operation

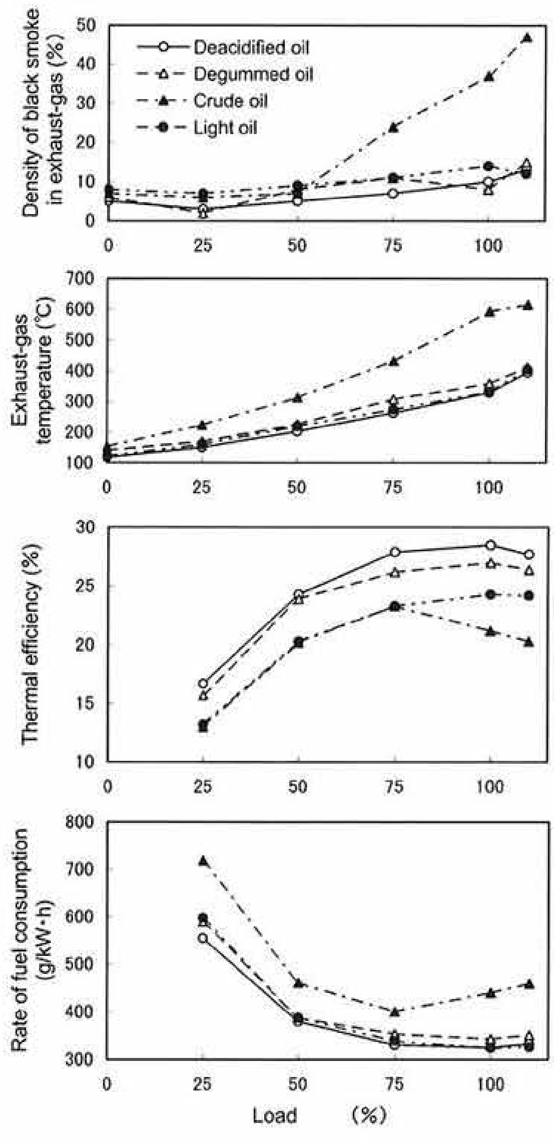

Fig. 3. Engine performance in rated operation

formance and rated load operation performance.

The consumption of deacidified oil was almost the same as or slightly lower than that of light oil. The thermal efficiency of deacidified oil was 2.2–5.8% higher than that of light oil in each performance test. The combustion speed of deacidified oil was high because of the oxygen content in the fuel, and the exhaust-gas temperature of this oil was 3–20°C lower than that of light oil. Deacidified oil also had a lower density of black smoke in exhaust-gas than light oil.

The fuel consumption of degummed oil was almost the same as or slightly lower than that of deacidified oil and light oil. The thermal efficiency of degummed oil was the same as that of deacidified oil. The exhaust-gas temperature and density of black smoke in the exhaust-gases of degummed oil were about the same as those of deacidified oil and were lower than those of light oil.

The consumption of crude rapeseed oil as fuel was higher than that of deacidified oil and light oil. The thermal efficiency of crude rapeseed oil showed a lower value than that of deacidified oil. The exhaust-gas temperature of crude rapeseed oil in the 75% load operation increased gradually in relation to the running time and increased suddenly after 2 h and 30 min. The density of black smoke in the exhaust-gas also increased suddenly after 2 h and 30 min of operation.

The thermal efficiency of refined rapeseed oil in a diesel engine with 2.57 kW rated power, 2,000 rpm rated revolution and 21.6 compression ratio, was almost the same as that of light oil[6]. The thermal efficiency of refined rapeseed oil in a diesel engine with 4.41 kW rated power, 1,200 rpm rated revolution and 20.0 compression ratio was higher for high load and high revolutions, and lower for low load and low revolutions[4] than that of light oil. And the thermal efficiency of refined rapeseed oil in a large diesel engine with 41 kW rated power, 3,000 rpm rated revolution was about 2% higher than that of light oil in low to high load operations[5].

It was considered that the thermal efficiency increased not only under high load but also low load operation conditions, because deacidified oil with defective ignition showed a shorter ignition lag, causing high temperature in the combustion chamber when the engine conditions involved high compression ratio and high revolutions.

Incombustible deposits were detected on the injection nozzle and injected fuel spray was adversely affected by this build-up, which was associated with the incombustible materials present in crude rapeseed oil. As a result, the loaded performance decreased while the exhaust-gas temperature and density of black smoke in exhaust-gas increased.

2) Long-term operation tests

Fig. 4 shows the thermal efficiency of engine performance every 25 h.

Throughout the 200 h of operation using deacidified oil, the power was stable for the entire period and no accumulation of deposits was found on the injection nozzle although an amount of 0.153 g of incombustible deposits was detected in the precombustion chamber.

Irregular revolution and detonation noise started to occur after about 20 h of operation in the engine

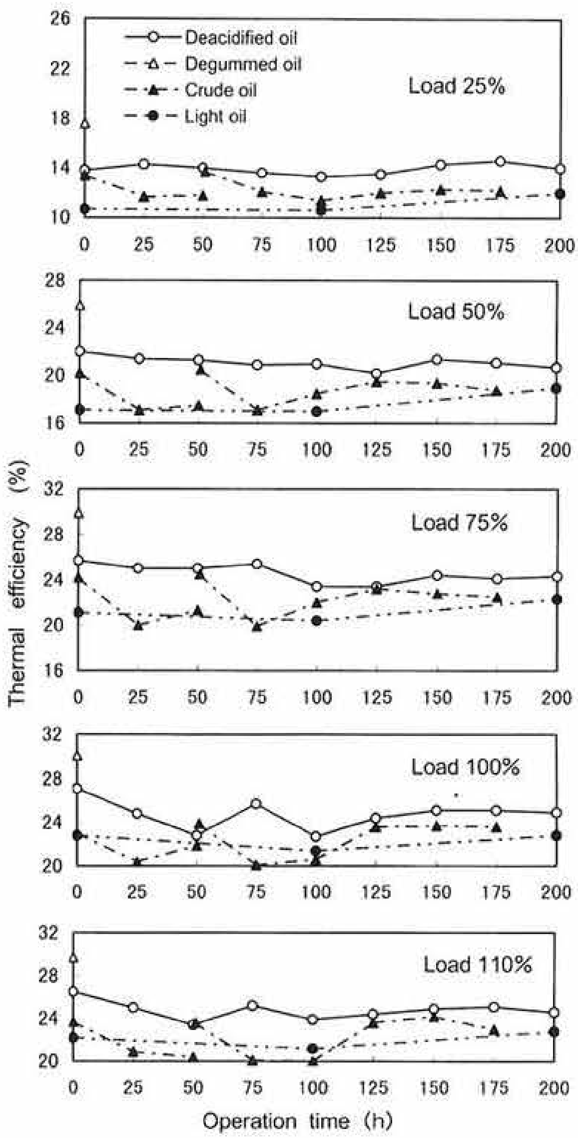

Fig. 4. Thermal efficiency in rated load operation

when degummed oil was used as fuel, leading to the interruption of the operation after 25 h. A large quantity of incombustible deposits was detected around and on the injection nozzle after 25 h of operation. Therefore degummed oil produced a large quantity of incombustible materials in the combustion chamber, precombustion chamber and on the injection nozzle. This phenomenon is due to the fact that degummed oil contains a large quantity of incombustible materials which affected the length of the operation time. Since the injected fuel spray was impeded by the incombustible deposits on the nozzle, the ignition lag increased and the engine performance was reduced. Therefore the operation of the engine was impossible under such adverse conditions. Engine operation using degummed oil was satisfactory only when the build-up of incombustible deposits was low.

In the engine fueled by crude oil, irregular revolution and detonation noise started to occur after about 40 h of operation. After 50 h, the precombustion chamber and the injection nozzle were cleaned. But, again after 160 h, irregular revolution and detonation noise were observed, leading to the interruption of the operation after 175 h. A large amount of incombustible deposits was detected in the port connected to the combustion chamber, on the injection nozzle and in the precombustion chamber (Fig. 5).

3) No-load continuous operation tests

Fig. 6 shows the relationship between the amount of deposits in the precombution chamber and the content of incombustible materials in fuel. Fig. 7 shows the amount of incombustible materials in the precombustion chamber.

Fig. 5. Injection nozzle after long-term operation using crude rapeseed oil

The amounts of carbon and incombustible materials in the precombustion chamber were 0.222 g and 0.003 g, respectively in the no-load operation when deacidified oil was used (Table 3). The deposits consisted almost completely of carbon due to the incomplete combustion associated with the low combustion temperature. The content of incombustible materials of the fuel was significantly correlated with the accumulation of deposits in the precombustion chamber in the no-load operation, and the amount of accumulated deposits could be estimated by measuring the content of incombustible materials.

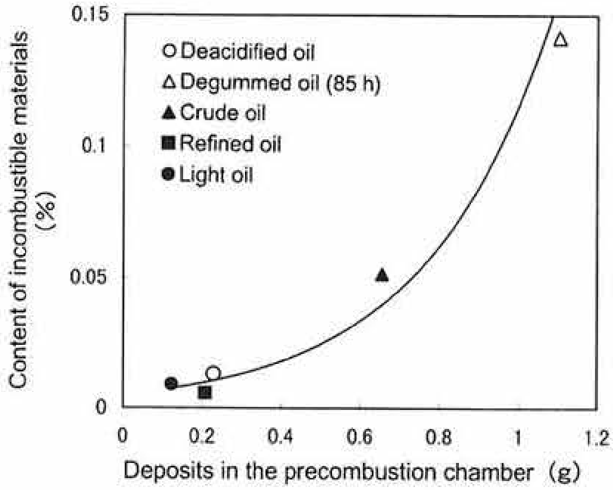

Fig. 6. Relationship between the amount of deposits in the precombustion chamber and the content of incombustible materials in fuel

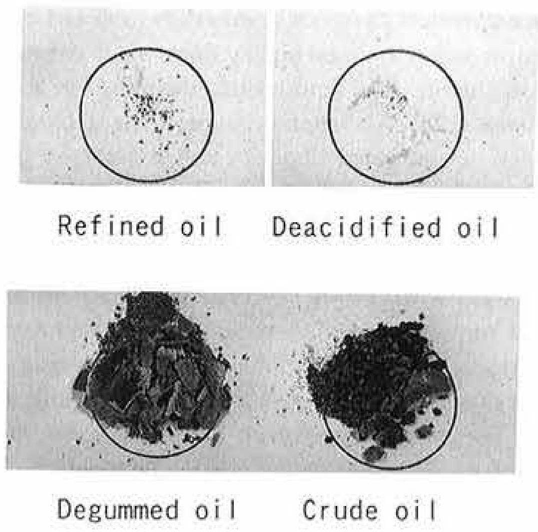

Fig. 7. Amount of incombustible materials in the precombustion chamber after no-load continuous operation using rapeseed oil

Table 3. Deposits and incombustibility in the precombustion chamber after 100 h of no-load continuous operation

(unit: g)

	Deposits[b)]	Incombustibility
Rapeseed oil		
Deacidified oil	0.225	0.003
Degummed oil[a)]	1.103	0.833
Crude oil	0.655	0.245
Refined oil	0.208	0.001
Light oil	0.123	0.012

a): Operation time; 85 h.
b): Carbon = deposits - incombustibility.

In the fuel a very small amount of carbon was found around the injection nozzle when deacidified oil, refined oil and light oil were used as fuel.

During the no-load operation, irregular revolution and detonation noise started to occur after about 80 h of operation in the engine fueled by degummed oil. As a result, the operation of the engine stopped after 85 h. The accumulation of deposits in the precombustion chamber of the engine operating with degummed oil was 1.103 g, a value about 5 times higher than when deacidified oil was used. The amount of incombustible materials was 0.833 g. The accumulated deposits contained a large quantity of gum which coated the wall of the precombustion chamber and produced a thin film on the injection nozzle. The gum adhered to the head of the injection nozzle in the no-load operation when degummed oil was used as fuel (Fig. 8).

Accumulated deposits amounted to 0.655 g in the precombustion chamber when crude rapeseed oil was used, a value 3 times higher than when deacidified oil was used. The amount of incombustible materials was 0.245 g. Gum accounted for a large part of the accumulated deposits and it adhered to the wall of the precombustion chamber and the port connected to the combustion chamber. Gum adhered to the head of the injection nozzle in the no-load operation when crude rapeseed oil was used, in the same way as when degummed oil was used as fuel.

A recently developed method of removing gum from rapeseed oil by the elimination of organic acids does not always remove all of gum present in oil. Therefore, in terms of diesel fuel the degummed oil provided by the manufacturer is, in fact considered to be comparable to crude oil.

The maximum content of incombustible materials in oil for use as substitute fuel was estimated to be about 0.01%.

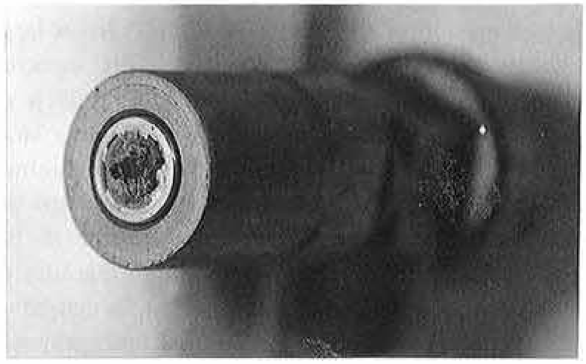

Fig. 8. Injection nozzle after no-load continuous operation using degummed rapeseed oil

Conclusion

This report deals with experiments carried out to examine the possibility of using various kinds of unrefined rapeseed oil (deacidified oil, degummed oil and crude rapeseed oil) as a substitute for light oil in a small diesel engine.

The results are summarized as follows:

(1) Deacidified rapeseed oil was superior to light oil in terms of load performance and black smoke density in exhaust-gas. The amount of accumulated deposits in the precombustion chamber and on the injection nozzle after long-term load operation and no-load continuous operation tests was almost the same for deacidified rapeseed oil and refined oil. Deacidified rapeseed oil was considered to be suitable for use as fuel for a diesel engine.

(2) The degummed oil provided by the manufacturer was considered to be comparable to crude oil. When there were no incombustible deposits on the nozzle, the use of degummed oil was preferable to that of light oil in terms of operation performance, and both the exhaust-gas temperature and the density of black smoke in exhaust-gas were lower compared with light oil. However in the long-term load operation and no-load continuous operation, deposits of incombustible materials consisting essentially of gum adhered to the inside of the precombustion chamber and the injection nozzle. The normal spray of injected fuel was difficult, leading to a reduction of the performance and to the interruption of the operation of the engine.

Rapeseed degummed oil produced by the method of removal of organic acids was found to be unsuitable for use as diesel fuel.

(3) The load performance when crude rapeseed

oil was used was slightly lower than when deacidified oil was used. A large quantity of incombustible materials, chiefly gum, was deposited in and adhered to the combustion chamber, precombustion chamber and the injection nozzle. The size of the build-up was related to the running time. As a result, the nozzle became blocked, detonation noise occurred and eventually the engine stopped. Crude rapeseed oil with a high content of incombustible materials was found to be unsuitable for use as fuel for a diesel engine.

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