

Improvement of Fuel Consumption of Neat Biofuel Diesel Engine with Reduced Injection Driving Torque

Taizo Shimada and Mitsuo Notomi
Meiji Univ.

Junya Tanaka and Koji Korematsu
Kogakuin Univ.

ABSTRACT

In recent years, trans-esterified vegetable oils have been widely applied to diesel engine in order to suppress greenhouse gas emissions. However, “neat” vegetable oils are expected to be directly used to resolve some difficulties faced in their use, such high viscosity and slightly high fuel consumption. In this study neat linseed oil has been investigated as a neat vegetable oil. It was found to show higher fuel consumption than diesel fuel, however at the same time it showed lower indicated fuel consumption than diesel fuel. These results suggest some increase in engine friction loss in a neat biofuel diesel engine. Studies have been extensively investigated the difference in friction loss and a newly developed “improved deceleration method” has been applied. Doing so confirmed the higher fuel injection driving torque caused by the higher viscosity of neat linseed oil relative to diesel fuel and the effect of the enlarged inner diameter of the fuel injection pipe on reducing the engine friction of high-viscosity fuel. Finally, a neat linseed oil engine with an optimized fuel injection pipe showed lower fuel consumption than a diesel fuel engine. The enlargement of the fuel injection pipe and fuel heating which may be more relevant for high-viscosity fuel, were compared from the view- point of fuel injection driving torque to organize the results of fuel consumption improvement in a neat biofuel diesel engine.

CITATION: Shimada, T., Notomi, M., Tanaka, J., and Korematsu, K., "Improvement of Fuel Consumption of Neat Biofuel Diesel Engine with Reduced Injection Driving Torque," *SAE Int. J. Engines* 6(3):2013, doi:10.4271/2013-01-2475.

INTRODUCTION

Biodiesel fuel (BDF), which is a carbon-neutral fuel made from trans-esterified vegetable oil, is now being widely used in diesel engines as a means to suppress global warming. However, the production of BDF involves many expensive processes and its co-products, such as crude glycerol, require management of safe disposal[1]. So inherently “neat” vegetable oil has been expected to be applied, but some difficulties to be kept up with such as higher viscosity, slightly higher fuel consumption and so on are recognized. In this study as the first step for practical application of neat vegetable oil to diesel engine, neat linseed oil of reagent bottle as shown in Table 1 has been examined to clarify how dose essential “neat” vegetable oil work in its stable content and condition. It makes us possible to concentrate to studies without nonessential trouble for example caused by impurities such as water, phosphorus ash, oxide of fuel and so on.

Table 1. Properties of Neat Vegetable Oil and Diesel Fuel

Test Fuel	Boil. Point K	Hu MJ/kg	Kinetic Viscosity mm ² /s
Linseed Oil	603~	36.90	28.8 at313K
Diesel Fuel	443~633	42.90	2.3

Measured value under atmospheric condition

For reducing the slightly higher fuel consumption of the neat bio-fuel diesel engine, not only the combustion performance but also the friction loss, especially fuel injection driving torque, were investigated in this study. Fuel injection system of the test engine is conventional type of a pump-line-nozzle (P-L-N) system, and the fuel injection driving torque in this tested engine is shown in Fig.1.

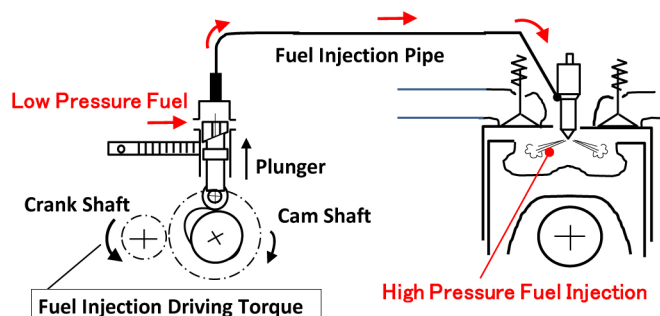


Fig.1. Injection Driving Torque in Tested Diesel Engine

ENGINE PERFORMANCE TEST

Fuel Viscosity

To apply neat bio-fuel to a normal diesel engine, it is first necessary to consider how to decrease its higher fuel viscosity to the same level as diesel fuel, which is presupposed fuel for a normal diesel engine. For example, the neat linseed oil used in this study has high viscosity that is more than ten times that of diesel fuel as shown in Table 1. One of the means to reduce the high viscosity of the fuel is to reduce the large number of molecules contained within via chemical trans-esterification as mentioned above. Another approach is to heat the fuel as is done in a large marine engine.

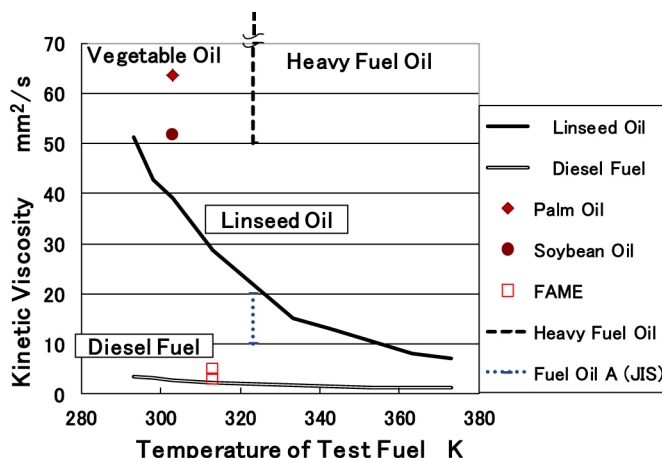


Fig.2. Kinetic Viscosity of Tested Neat Linseed Oil

Fig.2 shows the large effect of the temperature on the kinetic viscosity of neat linseed oil. In actual use, high viscosity fuel, ex. "Fuel Oil A"(JIS), having kinetic viscosity of up to ~ 20 mm²/s at 323 K can be applied to a normal diesel engine without fuel heating at normal atmospheric temperature. Therefore, neat linseed oil having viscosity similar to that of "Fuel oil A"(JIS) can be used to drive a diesel engine without fuel heating being required; however, in most cases, neat bio-fuel must be treated to reduce its viscosity before being applied to a diesel engine. These are

considered that the high viscosity of the fuel may lead to an increase in the droplet size of the fuel spray, thus delaying diesel combustion and increasing the brake specific fuel consumption (BSFC). In previous studies[2,3], it has been shown that heating neat linseed oil apparently reduced its BSFC. However, in this study, the third approach for reducing the BSFC of high-viscosity neat bio-fuel without fuel heating or fuel esterification was sought.

Experimental Setup

Table 2 shows the specifications of the test engine, which consists of an air-cooled single cylinder for wide use without a fuel injection timing advancer and injection timing is fixed at 23° BTDC. Table 3 shows the specifications of the fuel injection system of the engine. The maximum fuel injection pressure at the rated output was measured to be ~ 30 MPa, which is rather low in comparison with today's latest automotive diesel engines with common rail fuel injection system.

Table 2. Engine Specifications

	D.I. Diesel Engine
Engine Type	Air-cooled 4 stroke
Displaced volume	412 cc
Bore $\times$ Stroke	82 $\times$ 78 — Single Cylinder
Rated Output / Engine Speed	5.1 kW / 3000 rpm
Mean Effective Pressure	495 kPa
Max. Torque / Engine Speed	19.6 Nm / 2400 rpm
Mean Effective Pressure	598 kPa
Compression ratio	21:1
Static Fuel Injection Timing	23° BTDC fixed

Table 3. Specifications of Fuel Injection System

Injection Pump Type	PFR
Plunger Diameter	ϕ 5.5
Delivery System	w/ Dumping Valve
Injection Pipe	ϕ 2 — 370
Injection Nozzle	ϕ 0.22 $\times$ 4
Nozzle Opening Pressure	19.5 MPa

The experimental setup is shown in Fig. 3. Dynamometer ⑧ is of the water-cooled eddy current type Tokyo Plant ED-20-LC. The specification of the full absorption torque is up to 42 Nm and the measurement accuracy is ± 0.2 % of full scale. The smoke meter ⑨ is a Zexel DSM-10N. The cylinder pressure sensor ③ installed at the cylinder head of the engine is a Kyowa PEF-S-20MPSA1 of the water-cooled flush mount type. An N₂ gas high-pressure vessel ⑫ is prepared to inject N₂ gas into the inlet port of the engine when it is required to control the diesel combustion.

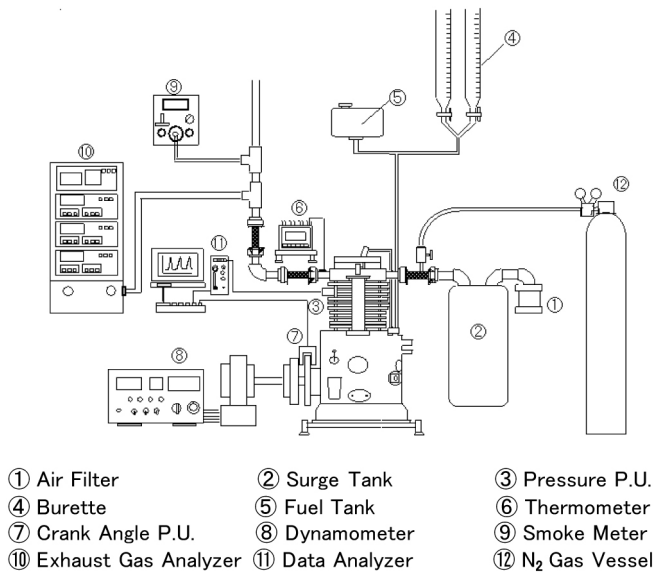


Fig.3. Experimental Apparatus

Result of Engine Performance Test

Fig.4 shows the NO_x, smoke, BSFC and ISFC (indicated specific fuel consumption) of neat linseed oil in comparison with diesel fuel. Fig.4 also shows the higher BSFC of neat linseed oil relative to diesel fuel, at the same time, the lower ISFC of neat linseed oil relative to diesel fuel is confirmed. The higher BSFC of neat vegetable oil has occasionally been attributed to its poor fuel spray atomization which is caused by the high fuel viscosity, however, the lower ISFC of linseed oil suggested the possibility of a higher combustion speed relative to diesel fuel owing to the oxygenated fuel that leads to low smoke and high NO_x. The start of injection timing for both fuels is the same as that for the fixed static injection timing of 23° BTDC. The higher BSFC and lower ISFC of linseed oil, as mentioned above, necessarily result in the supposition of higher engine friction loss in the case of neat linseed oil relative to diesel fuel owing to the difference in the fuel viscosity.

Fig.5 shows the nozzle lift and the rate of heat release of diesel fuel and neat linseed oil. Despite almost the same actual injection timing of both fuels, the peak rate of heat release of linseed oil is higher than that of diesel fuel.

In the next stage, engine friction losses with driving force to inject neat linseed oil and diesel fuel were measured to confirm the supposition of difference in friction loss.

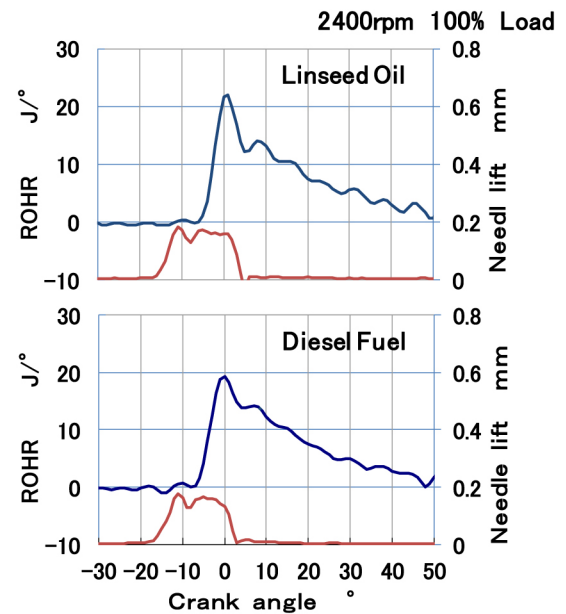


Fig.5. Rate of Heat Release of Linseed Oil & Diesel Fuel

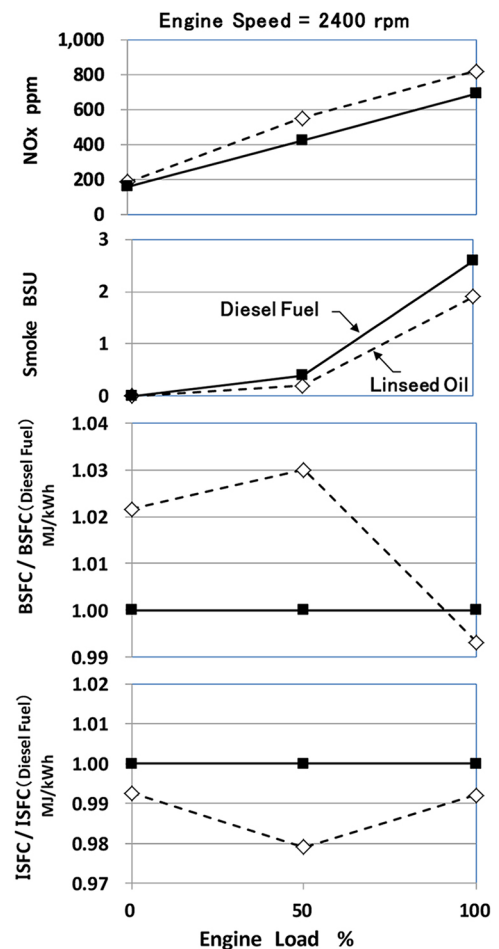


Fig.4. Fuel Consumption of Neat Linseed Oil & Diesel Fuel

Engine Friction Measurement

To measure the engine friction torque with and without fuel injection under actual engine running conditions, the conventional Willans-line method is essentially unsuitable because of its long extrapolation of the “no load” condition. The motoring method is also unsuitable despite its high measurement accuracy because of the difficulty in reproducing all the thermal conditions of an actual engine and the fuel injection equipment of an running engine. The in-cylinder pressure measurement method for comparing the indicated and the brake mean effective pressure appears mostly suitable, although it is difficult to keep its measuring accuracy to less than the level of the fuel injection driving torque itself. Ultimately, the deceleration method [4,5] was selected in this study because of its relatively high accuracy in almost actual thermal conditions and the ease of shifting the measuring engine performance and engine friction alternately and instantaneously in the same engine. This method is based on the relationship between engine deceleration without combustion and friction torque at each engine speed and load, as shown in Fig.6. Here, the engine friction loss or torque implies a wide definition that includes not only the mechanical loss with subsidiary equipment but also the pumping loss of air breathing in the inlet and exhaust strokes. When the fuel to the engine is cut, the engine runs by inertia with friction torque T_f , and the engine speed decreases with angular deceleration $\dot{\omega}$, as shown in Fig. 6, T_f is given as follows;

$$T_f = I_t \times \dot{\omega} \quad (1)$$

where “ I_t ” is the total moment of inertia of all rotational parts of the engine, dynamometer, and coupling. “ I_t ” can be calculated using design data; however, in almost all cases, it is difficult to obtain enough design information about the engine's moving parts and calculate it within a short time. In this study, “ I_t ” was obtained experimentally by varying the dynamometer setting. When the dynamometer adds additional loads of “ ΔT ” on the engine and the engine runs by inertia with deceleration of “ $\dot{\omega}_d$ ”, then, $T_f + \Delta T$ is given by

$$T_f + \Delta T = I_t \times \dot{\omega}_d \quad (2)$$

From equations of (1) and (2), “ I_t ” is given by

$$I_t = \frac{\Delta T}{(\dot{\omega}_d - \dot{\omega})} \quad (3)$$

As the first step toward engine friction measurement using the deceleration method, “ I_t ” was measured with equation (3) in each representative engine speed, load, and appropriate additional load of ΔT . “ I_t ” was stable enough under several test conditions to be fixed as a basic common standard value of 0.354 kgm² for these tests.

Finally, the fuel injection driving torque for linseed oil and diesel fuel could be obtained using equation (1) from the difference between each engine friction torque with and without fuel injection.

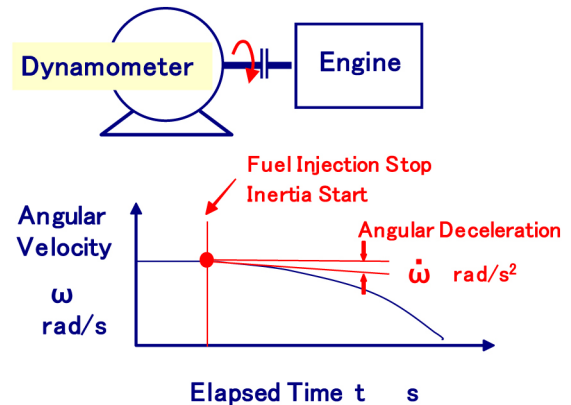


Fig.6. Friction Measurement with Engine Deceleration

Development of Deceleration Method

To measure the fuel injection driving torque, it is necessary to make the engine run by inertia with fuel injection. First, deceleration method A was used with a switching function to inject fuel in and out of the cylinder, as shown in Fig.7. The fuel injection switching valve consisted of parts appropriated from a high-pressure distributor-type VE injection pump, as shown in Fig.8.

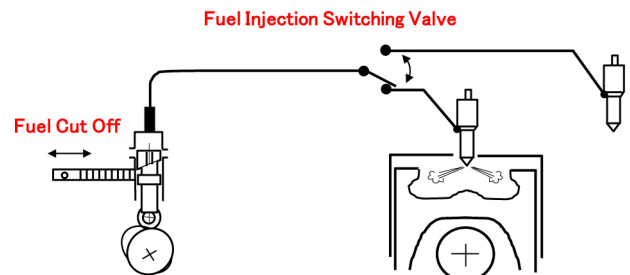


Fig.7. Concept of Deceleration Method A

With deceleration method A, it is easily measured the engine friction loss of arbitrary engine conditions i.e. various engine speed, load, oil temperature and so on. If the engine was operated in a certain condition, then started the deceleration by suppressing the combustion, the measured engine friction loss with deceleration method is considered as that in the engine condition just at the start of deceleration. The difference of engine conditions between just before and after the start of deceleration is considered almost negligible in temperature of bearing metal, cylinder liner, cylinder head, and so on, however only cylinder pressure should be different.