Experimental Research on the Impact of Lubricating Oils on Engine Friction and Vehicle Fuel Economy

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Abstract. The engine friction loss and vehicle fuel economy aiming at several kinds of energy-conserving engine oils with different quality standard, viscosity grade, friction modifier, and viscosity index improver were tested in this paper. Experimental results showed that the engine friction loss was reduced and vehicle fuel economy was improved by lowering the viscosity of engine oil and adding high-performance friction modifier and new-type viscosity index improver. Among which, the effect of energy-conserving engine oils Dexos1 5W-20 adding 1% friction modifier and new type viscosity index improver was most significant with 12.45% engine friction reduction rate and 2.33% vehicle fuel economy improvement rate.

Introduction

With the continuous increase of car ownership in China, environment pollution and energy shortage are increasingly prominent, and automobile fuel consumption standards are increasingly strict as well, such as the average fuel economy standard of passenger car is 6.9L/100km in 2015 and shall be down to 5.0L/100km in 2020. So the vehicle fuel economy improvement has become the focus for all countries in the world. Studies have shown that 60% of the energy of fuel combustion loses in cylinder cooling and exhaust emissions, 40% provides the effective power, but 25% of the effective power loses in the friction of engine parts [1]. Therefore, it is necessary to improve fuel economy by reducing engine friction loss. The ways to reduce engine friction loss are various, compared to the improvement of engine design and new materials processing technology, developing the energy-conserving engine oil is more practical and cost-saving.

Many studies have evaluated on the impact factors of engine oil fuel economy at home and abroad [2-3], but mostly lack of experimental verification. There are also many tests about the impact of lubricating oil viscosity and friction modifier on fuel economy [4], but the kind of test oil is limited and lack of vehicle test.

In this research, several kinds of energy-conserving engine oils were blended to evaluate the effect of viscosity, friction modifier and viscosity index improver on the fuel economy improvement of engine oil. And the engine friction torque and vehicle fuel consumption were tested to verify the improvement effects of these candidate oils.

Test Oils

Test Oils Blending. When normally running, the engine parts have different lubrication characteristics on account of the difference of temperature, load, and speed. Usually, the crankshaft and bearings are in hydrodynamic lubrication regime; friction between piston and liner is under mixed lubrication regime; and valve mechanism is a boundary lubrication regime [5]. According to different lubrication regimes, the approaches for energy-conserving lubricating oils to reduce engine friction are also quite different. The friction loss under hydrodynamic lubrication regime can be reduced with low viscosity engine oil. Besides, friction modifier (FM) can directionally adsorb on the metal surface through polar group, form a protective oil film preventing the direct contact of metals, so as to reduce the friction loss under the boundary lubrication regime [6]. In addition, the viscosity index of engine oils can be improved through adding a certain amount of viscosity index improver (VII), which makes the oils have better rheological properties and viscosity-temperature characteristic，thus to reduce friction and improve fuel economy. Six kinds of engine oils were blended aiming at the three aspects mentioned above. The formulations of the oils were specified in table 1.

Table 1 Formulation of the Test Oils

Type	Reference	Candidate①	Candidate②	Candidate ③	Candidate④	Candidate ⑤
Standard	API SM	API SN	API SN	Dexos1	Dexos1	Dexos1
Vis-grade	5W-30	5W-20	0W-20	5W-20	5W-20	5W-20
Base oil	III type	III type	III type	III type	III type	III type
Additives	10~15%	10~15%	10~15%	10~15%	10~15%	10~15%
FM	0	0	0	0	H.P*; 1%	H.P*; 1%
VII	5~10%	5~10%	5~10%	5~10%	5~10%	N.T*; 5~10%

H.P*: High Performance; N.T*: New Type

Physical Indicator Test of the Engine Oils. According to relevant standards and rules, the physical indicators of engine oils were respectively tested. The results are shown in fig. 1 and table 2. Among the results, the viscosity index is calculated by the following equations:

$$VI = [(L-U)/(L-H)]\times 100 \quad (1)$$

If the viscosity index of oils is greater than or equal to 100, using the following equations:

$$VI = [(\text{antilog}\, N)-1]/0.00715+100 \quad (2)$$

$$N = (\log H - \log U)\times \log Y \quad (3)$$

Where VI =viscosity index of test oils; L =KV40 of the oils whose KV100 is same to the test oil and the VI is 0; H =KV40 of the oils whose KV100 is same to the test oil and the VI is 100; U = KV40 of test oils.

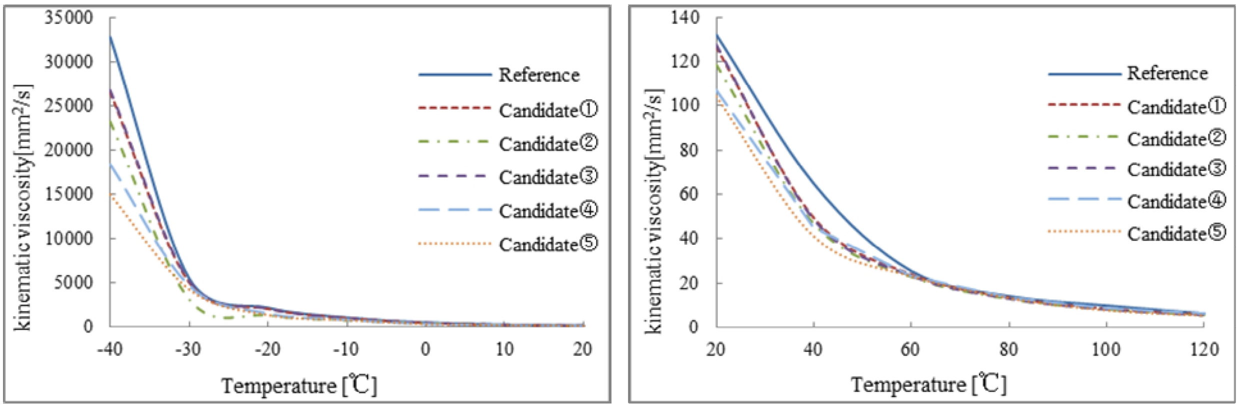


Fig. 1 Viscosity-Temperature Curve of the Test Oils at (-40~20˚C) & (20~120˚C)

Table 2 Physical Indicator of the Test Oils

Type	Reference	Candidate①	Candidate②	Candidate③	Candidate④	Candidate⑤
KV100[mm^2/s]	9.95	8.570	8.2	8.610	8.210	8.020
KV40 [mm^2/s]	64.70	49.41	46.77	48.67	45.89	41.10
CCS [mPa.s]	5460	5200	3100	5280	4660	4220
HTHS[mPa.s]	3.12	2.71	2.57	2.72	2.69	2.62
Pour point[˚C]	-38	-42	-44	-43	-41	-43
VI	135	151	150	142	168	178

As shown in figure 1 and table 2, the viscosity of oil decreases with the temperature rising and it is most obvious from -40˚C to 0˚C. The lower the Vis-grade of engine oils, the lower is the pour point, the less significant do the low temperature viscosity change. The reference oil has solidified at -40˚C while the candidate oils have also been in a state that difficult to flow. And the application of new type VII can improve the viscosity index significantly.

Tests

Engine Friction Tests. The test engine is used on a domestic mini-automobile, and the technical specifications are shown in table 3. The schematic diagram is shown in fig. 2, test engine is driven by an outside motor, and torque meter is placed between motor and test engine to measure the engine friction. The couplings are used to make the crankshaft, torque meter and motor be in alignment.

Table 3 Specifications of the Test Engine

Engine type	4-cylinder、DOHC、DVVT
Displacement	1.485L
Compression ratio	10.2:1
Bore × stroke	74.7mm × 84.7mm
Max power/speed	78kW/5800rpm
Max torque/speed	146.5N.m/(3600～4000 rpm)
Quantity of oil	4L

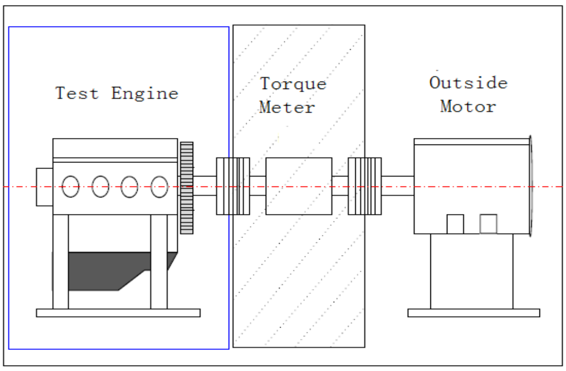


Fig. 2 Schematic Diagram of Engine Friction Test

Due to the strong surface activity of additives of the energy-conserving engine oils, the metal surfaces can be adsorbed firmly, which means “Carry Effect”. Measures that do flushes frequently should be taken before adopting the next test oil. The flushing principle is: Replace oil filter firstly, then flush twice with flush oil and flush once with test oil keeping the engine oil temperature 80 ~ 90 ˚C.

Test model to measure the engine friction is the common operating conditions in NEDC fuel consumption test cycle and actual life, including three stages with different oil temperatures from 60˚C to 100˚C at 20˚C intervals. Each stage has eight steps with different speeds from 800r/min to 3200r/min. When respectively using six kinds of lubricating oils, the engine friction torque at each temperature stage is shown in Fig. 3, Fig. 4 and Fig. 5. The arithmetic average of all operating conditions of the test model can be a solution to evaluate the effect of different oil on friction reduction. The friction reduction rate for five candidate oils relative to the reference oil is shown in Fig. 6.

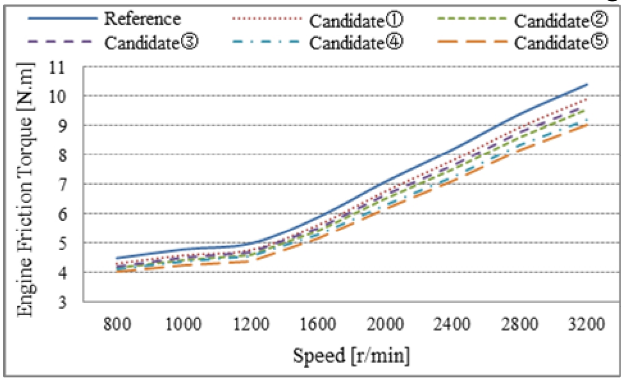


Fig. 3 Engine Friction of Test Oils at 60˚C

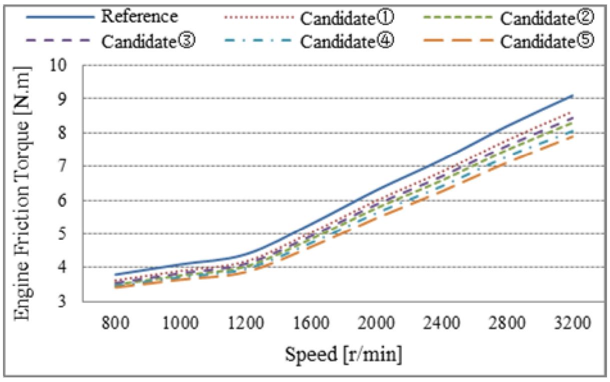


Fig. 4 Engine Friction of Test Oils at 80˚C

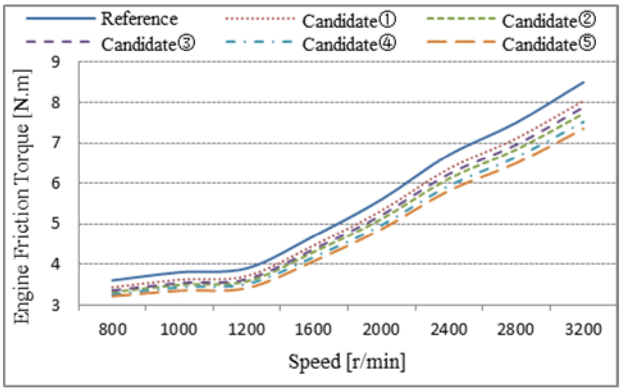


Fig. 5 Engine Friction of Test Oils at 100˚C

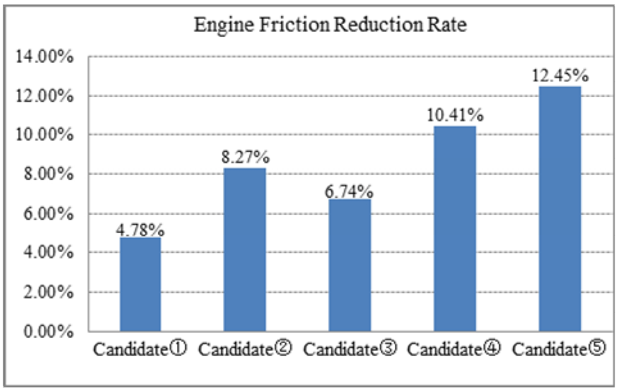
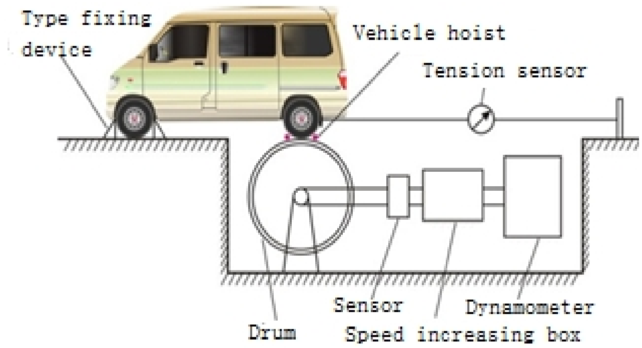


Fig. 6 Engine Friction Reduction Rate

The results indicated: (1)Five kinds energy-conserving engine oils reduced engine friction loss, but showed to different extent, candidate⑤ performed best. In other words, reducing the engine oil viscosity, adding high-performance FM or new-type VII could all reduce engine friction loss to some degree, among which, the engine oil Dexos1 5W-20 with 1% FM and new-type VII worked best with 12.45% engine friction reduction rate. (2)When Vis-grade was the same, the engine oil of Dexos1 standard had a better result in friction reduction than API SN standard. (3)The friction reduction of energy-efficient engine oil was influenced by the operation conditions. The higher the speed, the more significant the reduction. The higher the temperature, the lower the engine friction. Because the viscosity of engine oil lowers with the temperature rising, which reduces the friction in hydrodynamic lubrication regime. But if the viscosity is too low, the friction in boundary lubrication regime may increase.

Vehicle Fuel Economy Test. According to the national standard “Measurement methods of fuel consumption for passenger cars”(GB/T 12545.5-2008), the tests were completed on the chassis dynamometer under New European Driving Cycle (NEDC) operation in a mini car manufacturer's emissions-laboratory which mainly included AVL 48 "compact chassis-dynamometer, AVL five components emission analyzer, HORIB emission analyzer and some other auxiliary equipments, with strictly controlled test condition like temperature, humidity and pressure. Testing site sketch and NEDC graph are shown in Fig. 7 and Fig. 8 respectively.



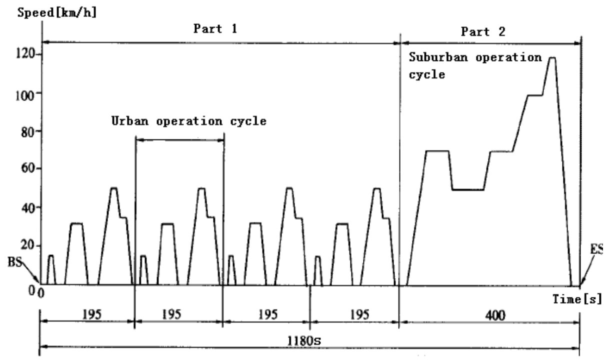


Fig. 7 Diagram of Vehicle Fuel Economy Test Fig. 8 NEDC Cycle

The fuel consumption is calculated by the following equations in GB/T 19233-2008 Light vehicle fuel consumption test method:

$$Q = 0.1154 \times \left(0.866 Q_{HC} + 0.429 Q_{CO} + 0.273 Q_{CO_2}\right) / D \tag{4}$$

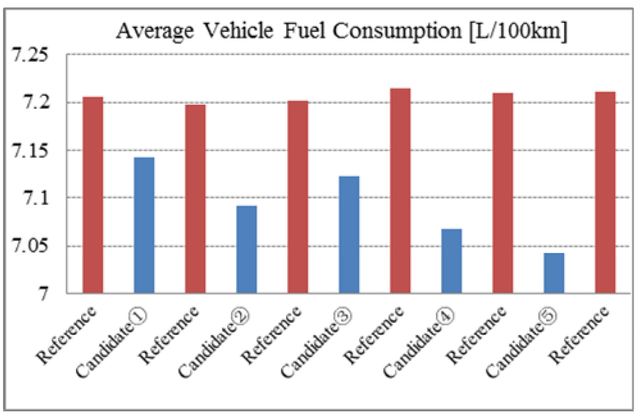
Where Q=fuel consumption [L/100km]; Q_{HC}=HC emission value [g/km]; Q_{CO}= CO emission value [g/km]; Q_{CO2}= CO_2 emission value [g/km]; D=density of fuel oil at 15˚C [kg/L].

The impact of engine oil on vehicle fuel economy is complicated and subtle, especially the testing precision. All the factors which may cause test errors, including initial temperature, driver, tire, voltage and equipment calibration, must be controlled strictly to keep consistent.

Test procedure, test times and analysis of statistical data must be strictly controlled as well. Table 4 shows the details of test procedure. The oil tank must be flushed before every test according to the "flushing principle" mentioned above, the reference oil and candidate oils were alternately tested, and every kind oil test was repeated five times, only the test data of last four times were valid. The results of candidate oils must be compared with the results of two neighboring reference oil groups. The results of average vehicle fuel consumption using different engine oil are shown in fig. 9. And the results of Vehicle Fuel Economy Improvement Rate of candidate oil are shown in fig. 10.

Table 4 Test Procedure

Step No.	Cycle	Oils
1	Oil flush	Flush oil (2×)+Reference oil (1×)
2	NEDC+ NEDC(4×)	Reference oil
3	Oil flush	Flush oil (2×)+Test oil (1×)
4	NEDC+ NEDC(4×)	Test oil
5	Oil flush	Flush oil (2×)+Reference oil (1×)
6	NEDC+ NEDC(4x)	Reference oil



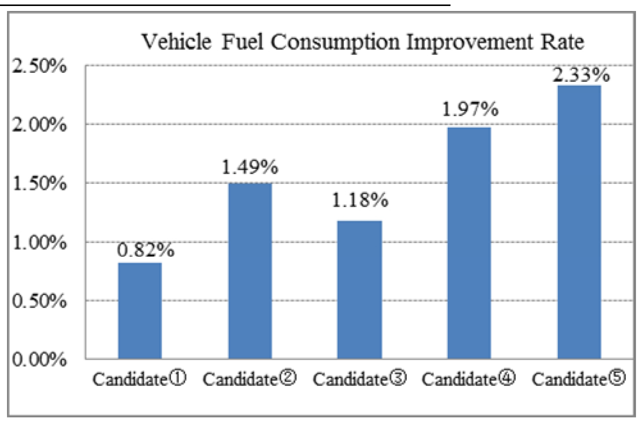


Fig. 9 Average Vehicle Fuel Consumption Fig. 10 Vehicle Fuel Economy Improvement Rate

The results showed as follows: (1)The results of six reference oil groups kept small fluctuation, which proved reliable testing precision and stability. (2)Five kinds of energy-conserving engine oil improved vehicle fuel economy to different degree, which means reducing the oil viscosity, adding FM and new-type VII worked to a certain degree, among which, the engine oil Dexos1 5W-20 with 1% FM and new-type VII worked best with 2.33% vehicle fuel economy improvement, which was consistent with the result of engine friction loss reduction. (3)The fuel economy of Dexos1 engine oil was 0.36% higher than the one of API SN engine oil with the same viscosity grade.

Conclusions

(1)Several kinds of energy-conserving engine oils with different Standard, Vis-grade, FM, and VII were blended and showed different extent performance in engine friction loss reduction and vehicle fuel economy improvement.

(2)The effect of energy-conserving engine oils Dexos1 5W-20 adding 1% FM and new-type VII was most significant with 12.45% friction reduction and 2.33% vehicle fuel economy improvement.

(3) At the same viscosity grade, the vehicle fuel economy of Dexos1 engine oil is 0.36% higher than the one of API SN engine oil.

(4)The vehicle fuel economy is highly correlated with engine friction loss. 5.5% engine friction loss reduction is approximately equivalent to 1% vehicle fuel economy improvement.

(5) High Standard, low viscosity and the high-performance special additives of engine oil formulation technology has further potential for fuel economy improvement.

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