

# The Effect of Viscosity and Friction Modifier on Fuel Economy and the Relationship Between Fuel Economy and Friction

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## ABSTRACT

Higher energy-conserving engine oils are becoming important in the face of the saving of natural resources. When it comes to energy-conserving engine oil, we consider low viscosity oil with special additives like friction modifiers.

In this research, the effect of viscosity was studied, especially HTHS(High Temperature High Shear) viscosity on friction reduction. Then the best oil for friction reduction was used to learn how such oils work on friction reduction with different FM (Friction Modifier). We have used two types of FM, organic and inorganic, because of different friction reduction mechanisms.

Our study of FM treated low viscosity engine oil has been continued to evaluate how such oils work at different part in the engine. Through the friction test, engine friction and engine friction without head (cam) was measured. Then, the effect of each FM on friction reduction at different engine parts was also studied.

Finally, from the vehicle test for fuel economy, we also found that the relation between friction at non-firing friction tester (NFFT) and fuel economy test using passenger car.

## INTRODUCTION

Recently, CO<sub>2</sub> reduction techniques have become a mainstream of the automobile industry due to stringent emission regulations. CO<sub>2</sub> reduction can be achieved by state-of-the-art engine electronic control techniques to improve thermal efficiency. Friction reduction in engines can also reduce vehicle fuel consumption. Therefore,

many research projects looking at oils to reduce friction have already been conducted.

Specifically, previous researchers have conducted some experiments to find out the effects of viscosity and viscosity index of engine oil on fuel economy [1], the effect of additives (FM,VM) on improvement of fuel consumption [2], and the effect of oil temperature on FMEP(friction mean effect pressure)[3].

This paper includes a study of the relation between different types of FM and friction reduction. Furthermore, the head was dismantled from an engine to define the friction loss mechanism specifically and to discover other effects of two types of FMs on different engine components. We also tried to determine the different effects of two types of FMs in different operating conditions.

## EXPERIMENTAL SETUP & CONDITIONS

A 2.0L CRDI (Common-rail direct injection) diesel engine was used to study the effect of oil including FM on friction reduction in engines.

The specifications of the test engine are summarized in Table 1. The engine is a typical diesel engine with a bore of 86.2mm and a stroke of 85.6mm. A schematic diagram of the engine is shown in figure.1. The motor is not connected directly to the test engine. Torque meter (ONNOSOKKI Ltd) is placed between motor and test engine to measure friction from the engine. Bellows type couplings are used to compensate for shaft misalignment because crank shaft and motor should be in alignment with torque meter. The

pistons of the test engine are drilled as shown in figure 2 to reduce pumping loss when they are in the compression stroke. Several parts of test engine were removed if they did not affect engine friction related with oil.

Generally, the viscosity of engine oil is changed by differences in temperature, oxidation, soot contamination and fuel dilution. In this research, test engine was modified to measure the effect of viscosity on friction reduction. Through the engine modification, the viscosity of the oil was controlled only by temperature. For example, fuel line was disconnected to block oil dilution by fuel. The test engine was driven by an electric motor having an inverter. Soot contamination by fuel combustion did not happen naturally, because test engine was controlled by an electric motor.

Temperature and pressure data were measured to monitor engine condition and to get repeatable data. Data for six temperatures (Room, Torque meter, Oil fan, Head cover, Bearing, Engine block, Oil sump) and one pressure (Main gallery) was gathered by DAQ (data acquisition system).

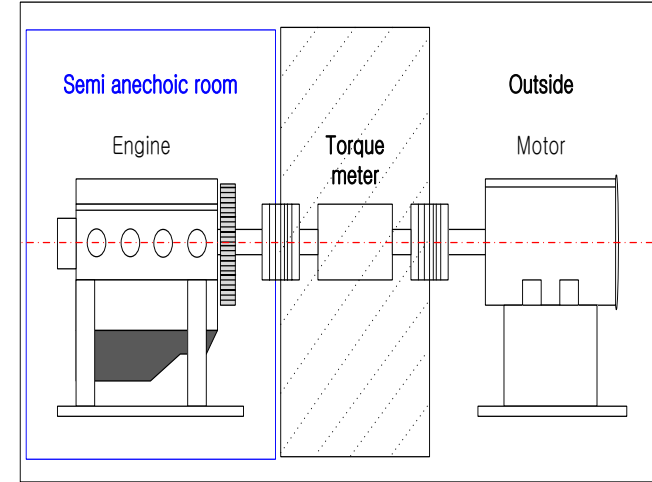


Figure.1 Schematic diagram of experimental facilities



Figure.2 Piston geometry

Table1 Specifications of the test engine

|                 |                           |
|-----------------|---------------------------|
| Engine type     | 4-cylinder, DOHC, 16valve |
| Displacement    | 2 liter                   |
| Bore x stroke   | 86.2 mm x 85.6 mm         |
| Quantity of oil | 8 liter                   |

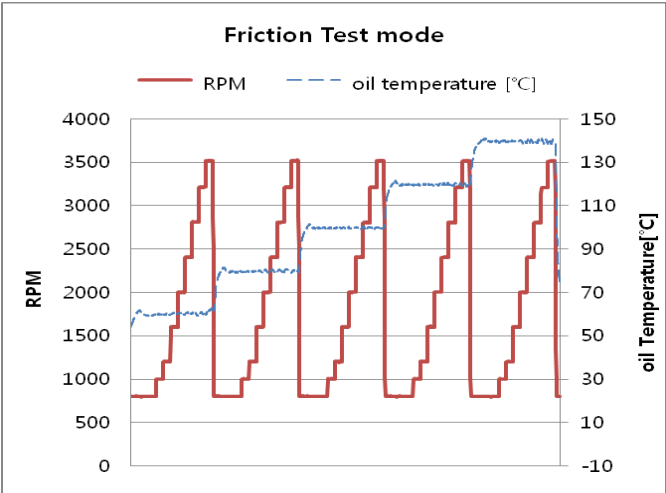


Figure.3 Test mode to measure friction

Table2 Properties of test oil

| sample                                | Viscosity grade | HTHS(cP) | FM    | dosage |
|---------------------------------------|-----------------|----------|-------|--------|
| A                                     | 5W-30           | 3.0      | NO    |        |
| B                                     | 5W-30           | 3.0      | Org   | 0.5%   |
| C                                     | 5W-30           | 3.0      |       | 1.0%   |
| D                                     | 5W-30           | 3.0      | Inorg | 0.5%   |
| E                                     | 5W-30           | 3.0      |       | 1.0%   |
| – HTHS : High Temperature High Shear  |                 |          |       |        |
| – Org : Organic Friction Modifier     |                 |          |       |        |
| – Inorg : Inorganic Friction Modifier |                 |          |       |        |

Test mode to measure the friction is composed of five stages with different oil temperatures from 60 °C to 140 °C at 20 °C intervals. When each stage was finished, the engine was run at idle speed for 60 minutes to stabilize the temperature. Every stage has nine steps that have different engine speeds from 800rpm to 3500rpm. Each step is operated for ten minutes.

When the test mode was finished, forty five pieces of friction data were gathered. The friction could be changed easily, when the oil temperature and engine speed were changed. The used oil in the before condition is able to affect further tests if the used oil is not drained perfectly or flushed enough. So, flushing mode was conducted twice or three times with flushing oil. Then, test mode with test oil was also conducted once for preparation.

## DISCUSSION

### REFERENCE OIL

**ENGINE FRICTION** - Generally, as oil temperature increases the friction coefficient decreases due to oil's viscosity reduction. The reason for this phenomenon can be explained by the Stribeck curve shown in figure 4. When the viscosity of test oil decreases due to increased oil temperature, the non-dimensional Stribeck number (viscosity\*velocity/load) decreases at the hydrodynamic lubrication regime. As the Stribeck number decreases, the friction coefficient can be reduced in the hydrodynamic lubrication regime. Therefore, when the viscosity of oil decreases due to the increased oil temperature, the total friction of the engine can be reduced. The reason is that the crank shaft is one of the major friction-creating-parts of the engine, being a hydrodynamic lubrication regime of the engine. However, when the oil temperature is increased up to 120°C, engine friction does not decrease with increasing temperature. This is because there are many parts having different lubrication characteristics. As mentioned above, the crankshaft is a hydrodynamic lubrication regime; friction between piston and liner is mixed lubrication regime; and cam in head is a boundary lubrication regime [4, 5]. The friction of the crank shaft can be reduced by low viscosity oil. But another friction-creating-part of the engine, like the cam mechanism, can be a source of increased total friction coefficient in the case of using very low viscosity oil. In this research, a strip-down method was used to define the friction loss mechanism for each of the engine components [6].

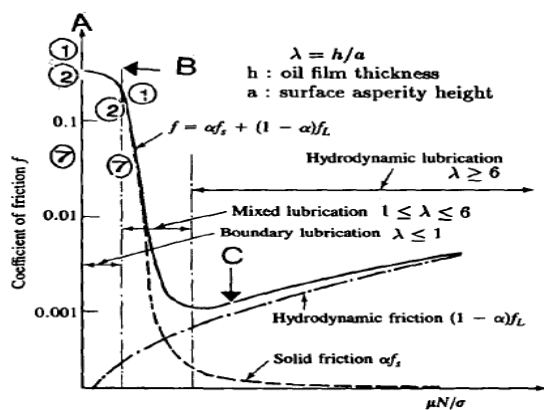


Figure.4 Stribeck diagram : coefficient of friction versus dimensionless duty parameter.[4,5]

As shown in figure 5, the engine friction at high temperature [140°C] and low speed [800~1000rpm] did not decrease. We assumed that the increased friction coefficient of the cam mechanism would be bigger than

the decreased friction coefficient of the crank shaft and other parts. To examine this assumption, the friction without head was measured. Then, the friction was subtracted from the total friction. The subtracted friction was considered as cam friction originating from the cam mechanism.

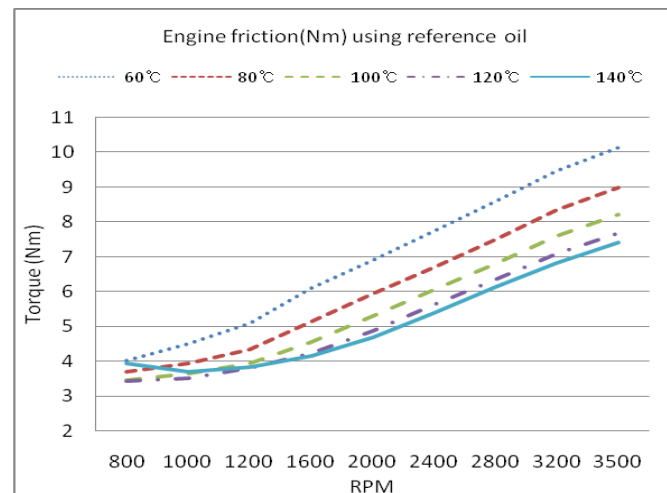


Figure.5 The effect of oil temperature on engine friction (reference oil : 5W-30,HTHS 3.0,w/o FM)

**ENGINE FRICTION WITHOUT HEAD** - Engine friction data can be a good source to use to evaluate the effect of oil on engine friction reduction. However, the intrinsic effect of the oil on reduction in mechanical friction is hard to discover because there are many lubrication regimes in the engine. Furthermore, each part of the engine has its own lubrication regime and this can be changed rapidly by different oil temperature. So, we dismantled the head to isolate the friction of the cam mechanism from the engine friction. Engine friction without head means the friction without boundary lubrication regime by cam mechanism. In other words, we can calculate the percentage of cam friction and engine friction by isolating cam friction.

As shown in Figure 6, engine friction without head has the same trend as engine friction. For example, as the oil temperature increases, the friction decreases due to reduction of viscosity of oil. However, there is a slight difference at high temperature and low speed. The friction without head is reduced at high temperature and low speed. The reason is that the engine friction is composed of several frictional contacts like the cam mechanism, the crank shaft, and so on. The friction of the cam mechanism is a located boundary lubrication regime; high temperature conditions make the friction at the boundary lubrication regime increase. Therefore, the friction without head at high temperature and low speed decreased with the disappearance of the cam mechanism in the boundary lubrication regime.