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# The Change Rate of Fuel Consumption for Different IRI of Paved Roads

# 포장도로의 거칠기 변화에 대한 차량 연료소모량 변화율

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**요지**

높은 차량운행비용(VOC : Vehicle Operating Cost)은 포장도로 복구작업의 주요한 원인이고, 차량운행비용(VOC)은 연료소모량, 오일소모량, 부품교체비용 등으로 구성된다. 이중 연료소모량이 VOC에서 차지하는 비중이 높고, 다른 도로조건에 비해 도로 표면 거칠기가 도로의 노화 정도를 대표적으로 지시하는 값이기 때문에, 본 연구에서는 포장도로의 표면 거칠기(IRI : International Roughness Index) 변화에 따른 차량의 연료소모량 변화를 측정하였다. 차량의 연료분사 인젝터의 전압변화를 측정하여 연료소모량을 계산하였고, 속도는 GPS센서를 사용하여 측정하였다. 본 실험 결과를 이용하여 IRI 변화에 대한 연료소모량의 변화율을 계산할 수 있었다. 계산 결과, 40~100km/h 속도영역에서 중형 및 대형 승용차의 연료소모량(L/100km)은 3.5m/km 정도의 IRI 수준에서 IRI(m/lm) 증가율의 7배 정도로 증가하였고, 60km/h의 속도에서 가장 연비가 우수하였다.

**핵심용어**

*연료소모량, 도로거칠기, 연비, 차량운행비용*

**ABSTRACT**

High VOC(Vehicle Operating Cost) is the main reason for the rehabilitation of paved road and VOC is composed of fuel consumption, lubricant oil consumption, parts consumption, etc. Fuel consumption is one of the largest components of VOC and the roughness of road represents the deterioration level of the road. For these reasons, the fuel consumption is measured for different IRI(International Roughness Index) in this study. The fuel consumption was measured by processing the voltage signal of fuel injector of vehicle and the speed was measured with GPS. The change rate of fuel consumption for different IRI can be calculated with the results of this test. It's concluded that fuel consumption(L/100km) of medium and large passenger car increases 7 times fast of the increase of IRI(m/km) around 3.5m/km in the speed range of 40 ~ 100km/h, and fuel consumption is the best at 60km/h.

**KEYWORDS**

*fuel consumption, road roughness, fuel economy, IRI(International Roughness Index), VOC(Vehicle Operating Cost)*

## 1. INTRODUCTION

High VOC(Vehicle Operating Cost) is the main reason for the rehabilitation of paved road and VOC is composed of fuel consumption, lubricant oil consumption, parts consumption, etc. Fuel consump is one of the largest components of VOC and the roughness of road represents the deterioration level of the road. Because road surface gradient, curve radius, weather condition are the geographical conditions, on the other hand surface roughness indicates the level of deterioration of the road. Therefore we can say that the road should be rehabilitated because of the high VOC when the fuel consumption is high and this fuel consumption is influenced by the road surface roughness directly.

But this important change rate of fuel consumption for the road surface roughness has not measured in Korea yet. Of course this change rate is calculated with HDM?4(Highway Development & Management) computing program in Korea as many other countries, but the conditions of road and vehicle can be different from ones of the countries who developed HDM-4.

So we measured the change rate of fuel consumption for the road surface roughness and various speeds of Korean vehicles in this study. We can determine to rehabilitate the road or not with the results of this study. And we can compare the measured fuel consumption results with the calculated results of HDM-4 afterwards.

## 2. TEST CONDITIONS

### 2.1. Test vehicles

The HDM-4 is accepted worldwide to calculate VOC and investment or rehabilitation for roads is determined by this computing program. VOC is calculated with the variables like vehicle type, operating speed, road type, etc in HDM-4. We selected the test vehicles with the standard of HDM-4. And we measured the fuel consumption of the selected Korean vehicles for different speed and road.

Table 1. Vehicle type of HDM-4

| Vehicle No. | Type | description |
|---|---|---|
| 1 | Motorcycle | Motorcycle or scooter |
| 2 | Small car | Small passenger car |
| 3 | Medium car | medium passenger car |
| 4 | Large car | Large passenger car |

There are three types of passenger car in HDM-4 as shown in Table 1, and these three types are small, medium and large car.

The operating weight is about 1.0 ton for small car, 1.2 ton for medium car and 1.4 ton for large car each. So it's medium car if engine displacement is about 2000cc and large car if it's about 3000cc for Korean vehicles.

We selected test vehicles which have highest market share in Korea, namely NF Sonata for medium car and Grandure TG for large car. These test vehicles can represent the same class of Korean vehicles and it's suitable for the characteristics of HDM-4 calculating average operating cost of whole vehicles passing the specific roads. The specifications of these two cars are shown in Table 2.

Table 2. The specifications of test vehicles

| Spec. | NF Sonata | Grandure TG |
|---|---|---|
| Model Year | 2007 | 2006 |
| Mileage | 60,000km | 80,000km |
| Transmission | Automatic | Automatic |
| Gross weight | 1795kg | 2014kg |
| Engine displacement | 1998cc | 3342cc |
| No. of cylinder | 4 | 6 |
| Power/RPM | 144PS/6000RPM | 233PS/6000RPM |
| Fuel | Gasoline | Gasoline |
| Certified Fuel Economy | 10.8km/L | 9.0km/L |
| Picture |  |  |

### 2.2. Test speeds

The VOC is calculated with characteristic speeds of each vehicle type in HDM-4 as shown in Figure 1, and the characteristic speed is free speed(S1~S3), operating speed(S3~Snom) and congested speed(Snom~Sult). The free speed is a vehicle speed when the traffic volume is small and this speed is limited by traffic regulation, engine power or safety(like braking power in declined road). The operating speed is a limited speed by other passing cars, pedestrians or traffic signal as the traffic volume increases. And the congested speed is a limited speed by extremely large traffic volume.

The average vehicle speed is calculated by relating these

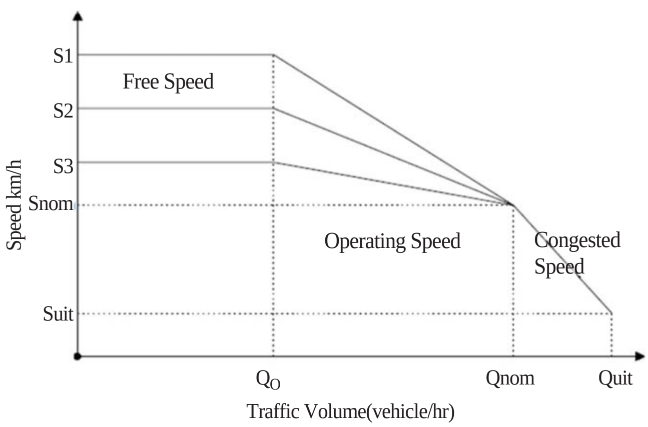



Figure 1. The Characteristic speed in HDM-4

characteristic speeds with traffic volume for the road. So the average vehicle operating speed varies with vehicle and road types and traffic volume. The test speed was determined at 4 points from 40 to 100km/h with increase of 20km/h(i.e. 40, 60, 80, 100km/h) in this study, so that the test results can be used for different operating speeds.

### 2.3. Test roads

It's important to measure precise road roughness because the goal of this study is to understand the relation of fuel consumption and road roughness. The conditions of roads differ with the materials of pavement and are composed of surface roughness, gradient, curve radius, dryness, width, number of lanes, etc. in HDM-4. Among these conditions surface roughness is a key characteristic representing road deterioration level because other conditions are geographical ones. Therefore other conditions but surface roughness are excluded in this study.

This test should be performed in a straight and level road to eliminate the effect of gradient and curve radius of road. The fuel consumption was measured for constant speed in a straight level road and by averaging fuel consumption for rounding trip to eliminate the direction of wind and gradient of road. And the traffic volume should be small because the test speed is from very low speed(40km/h) to high speed(100km/h) and the speed should be constant during the measurement of fuel consumption of each round trip.

Therfore we selected 2 sections of roads satisfying above conditions(straight and level road with small traffic volume) for this measurement. One is a side road of sea wall in Nampo, and the other is also a side road of sea wall in Sukmun. And these two roads are in Chungnam, South Korea. Both of these two roads are typical country roads in Korea which have two lanes and very small traffic volume. The length of these roads is about 3km for round trip. The pictures of these test roads are shown Figure 2.

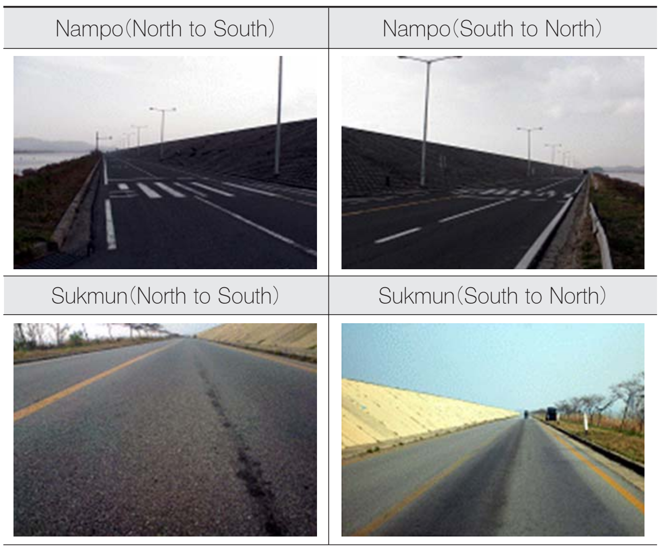



Figure 2. Test Roads

### 2.4. Measurement of fuel consumption

It's necessary to measure fuel consumption and driven distance for calculation of fuel economy. The fuel consumption was measured by using the electronic control method of injectors of gasoline engine. There are two wires for each injector as shown in figure 3.

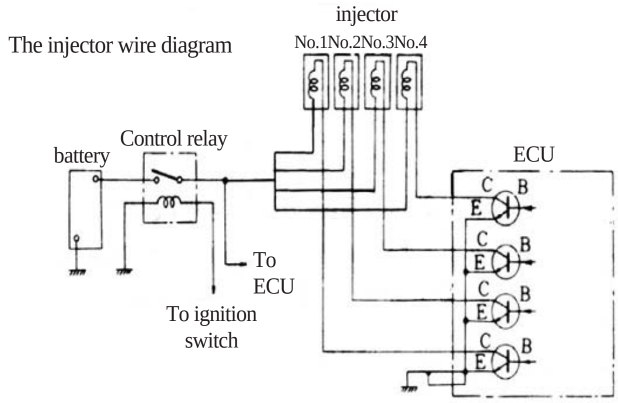



Figure 3. The injector wire diagram

One is for supplying electricity to injector from battery and the other is connected to ECU(Engine control unit). The injector is open when the wire connected to ECU is set to ground, i.e, zero voltage by ECU. In other words, injectors spray fuel when the voltage of wire connected to ECU is zero as shown figure 4.

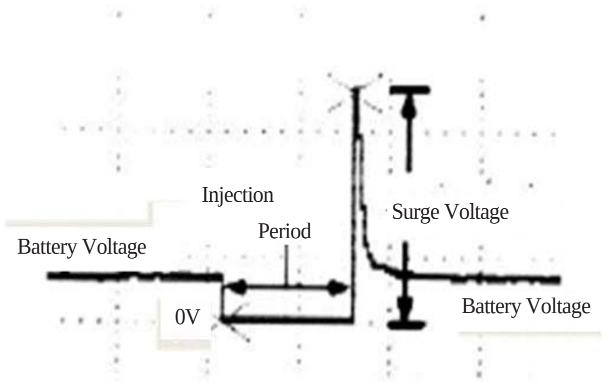



Figure 4. The electric signal of injector

And the amount of injected fuel is proportionate to the length of this zero voltage period. Therefore we can compute the injected fuel by measuring the time period of zero voltage of this wire connected to ECU. The fuel consumption is calculated as formula (1).

$$\text{The amount of injected fuel[mcc]} = \text{Correction factor} \times \text{Injection period[ms]} \quad (1)$$

We could fix the correction factor by measuring vehicle weight difference after driving the vehicle about 400km because the weight difference is due to the fuel consumption. And the results are summarized in Table 3. The fuel consumption by injector voltage is about 99% of the data determined by weight difference.

Table 3. Fuel consumption by weight difference

| Weight diffrenece (kg) | (A)_Fuel consumption by weight difference(L) | (B)_Fuel consumption by injection voltage(L) | (A)/(B) (%) |
|---|---|---|---|
| 15.5 | 21.23 | 21.48 | 98.8 |
| 15.4 | 21.10 | 21.35 | 98.8 |
| 15.6 | 21.37 | 21.52 | 99.3 |

By this method we can measure the fuel consumption without direct measuring fuel flow rate in and out from fuel pump which varies with fuel temperature. The work of connecting hose to/from fuel pump is very cumbersome and the flow meter is very expensive. We can avoid these problems by measuring just voltage signal of injectors.

The driven mileage was measured by GPS sensor. We can calculate the fuel economy with these two data, i.e., fuel consumption and driven distance. And the road surface roughness was measured as IRI(International Roughness Index)(Willian, 1982).

# 3. TEST RESULTS

## 3.1. Fuel consumption by engine size

Test results of Nampo and Sukmun seawall side road is summarized in Table 4 and Figure 5. The fuel economy is the best at speed of 60km/h for both engine displacement of 2,000cc and 3,300cc as about 18~19km/L in this study. And the maximum speed of traffic regulation for these two roads is 60km/h. Therefore it's good in the view of fuel economy's point when the traffic volume is small and the vehicle can speed up to the highest speed of traffic regulation at 60km/h which is the best for fuel economy. As the traffic volume grows, the speed will be slow down and then the fuel economy becomes bad. The fuel economy gets bad a little as the engine displacement becomes larger as expected.

Table 4. Test results of each road

| Road | Speed (km/h) | IRI (m/km) | Fuel Economy(km/L) | |
|---|---|---|---|---|
| | | | TG(3,300cc) | NF(2,000cc) |
| Nampo | 40 | 3.56 | 14.34 | 15.97 |
| | 60 | | 18.92 | 19.33 |
| | 80 | | 16.18 | 17.59 |
| | 100 | | 12.93 | 13.92 |
| | Average | | 15.59 | 16.70 |
| Sukmun | 40 | 3.59 | 13.62 | 15.62 |
| | 60 | | 18.44 | 18.92 |
| | 80 | | 15.87 | 16.05 |
| | 100 | | 12.73 | 13.78 |
| | Average | | 15.16 | 16.09 |

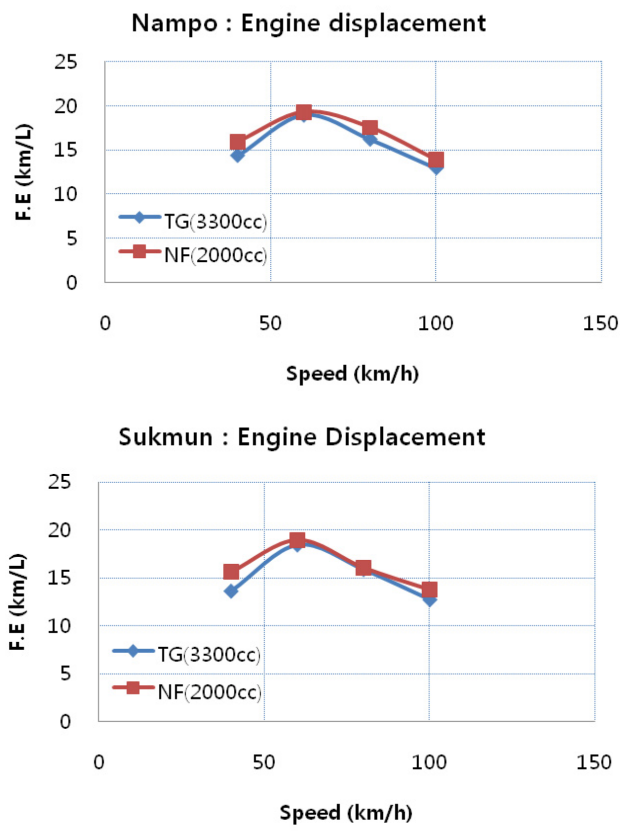



Figure 5. Fuel economy with engine displacement

### 3.2. Fuel consumption by roughness

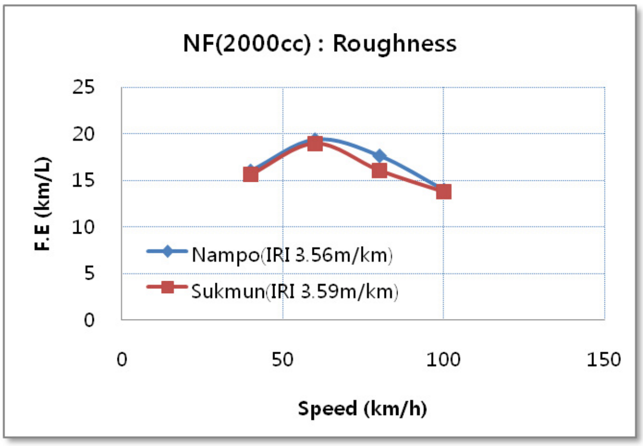
The road surface roughness was measured as IRI(International Roughness Index), vertical vibration per horizontal driving and its unit is [m/km](Gorski, 1982). The IRI is 3.56m/km for Nampo, 3.59m/km for Sukmun sea wall side road each. The test results are shown in Table 5 and Figure 6. The fuel consumption per 100km in Table 2 is an average of 2,000cc and 3,300cc test results for 4 points of speeds(40, 60, 80, 100km/h).

There is slight deterioration in the fuel economy as IRI increases. The VOC is linearly proportionate to IRI, and the fuel consumption is a large term in VOC. Therefore the fuel consumption can be expressed as 1st order of the IRI in this study as formula (2)(R. Ulslam, 2008).

Table 5. Test results of Fuel Economy and IRI

| IRI (m/km) | F.E (L/100km) | △FE / △IRI [(L/100km) / (m/km)] |
|---|---|---|
| 3.56 | 6.19 | 7.0 |
| 3.59 | 6.40 | |

$$FE[L/100km] = a \times IRI[m/km] + b \qquad (2)$$



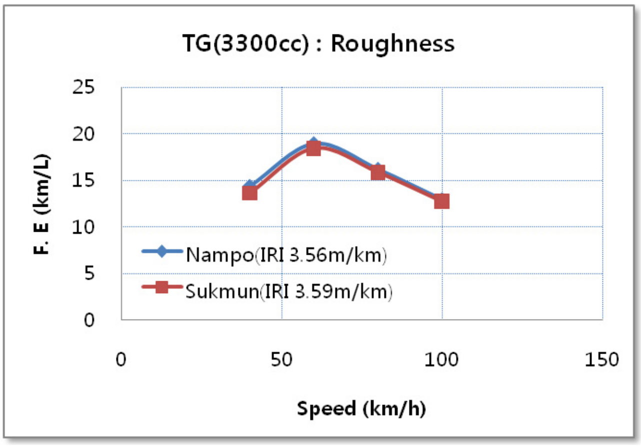




Figure 6. Fuel economy for surface roughness

And the constants, $a$ and $b$ can be calculated with these test results as $a$ = 7.0, $b$ = -18.73. This means that fuel consumption[L/100km] increases 7 times of increase of IRI[m/km]. But this result is calculated with only two data, and the IRIs of the test result are 3.56 and 3.59, which is so close to each other. So we should be careful to apply this results, and the conclusion is that the fuel consumption(L/100km) for medium and large car increases 7times fast with increasing IRI around 3.5m/km in the speed range of 40~100km/h. And it's necessary to do more fuel consumption tests for different road surface roughness.

## 4. CONCLUSIONS

Fuel economy was measured for different road surface roughness with medium(2,000cc) and large(3,300cc) passenger cars in the speed range of 40~100km/h. The fuel consumption was measured by measuring injection period of injector of vehicle and driven distance by GPS sensor. The IRI of test roads were 3.59 and 3.56m/km.

The fuel economy deteriorates as engine displacement increases and best at 60km/h which is the highest speed of traffic regulation of the test roads.

The fuel consumption(L/100km) is linearly proportionate to IRI(m/km) because VOC($/km) is linearly proportionate to IRI and the fuel consumption is large term in VOC.

The fuel consumption(L/100km) of medium and large car increases 7 times fast of the increase of IRI around 3.5m/km in the speed range of 40 ~ 100km/h.

It's necessary to do more tests for different surface roughness to relate fuel consumption and IRI.

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