# ANALYSIS OF EFFECT OF ROLLING RESISTANCE COEFFICIENT ON AUTOMOBILE FUEL CONSUMPTION

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**ABSTRACT**

Three types of pavements represented by different rolling resistance coefficients with specific values of 0.018, 0.027 and 0.035 were used to compare the simulated calculated values of the emission coefficients using the carbon balance technique to evaluate fuel consumption of vehicle. This technique is based on a model of the carbon dioxide emission coefficient that shows the maximum percentage difference in value to each different rolling resistance coefficient corresponding. This shows that the application of this simulation technique will be successful to the extent that it can be applied to calculate the total amount of carbon in the vehicle's moving process. Matlab Simulink software used to simulation, based on principle of determine fuel consumption level in gasoline engine of Toyota Vios 2017. In the results, this paper can be used for different types of engines in order to save cost and times of experiments.

***Keywords:*** *Rolling resistance coefficient, Fuel consumption, Carbon balance method*

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## 1. INTRODUCTION

The tire's RRC coefficient of rolling resistance affects the vehicle's fuel economy. Some studies on passenger cars have demonstrated that when RRC changes by 10%, vehicle fuel economy changes by 2% but this relationship is not linear [1]. The developing EPA fuel economy models, demonstrated that a 0.001 RRC change would change the vehicle's fuel consumption by 1% in the city and on the highway by 2% [2]. Schuring estimated that for passenger tires when RRC is reduced by 10% fuel economy increases by 1.4% on average and the increase is almost linear in the range of 0.7 to 2%, depending on tire duty cycle and vehicle operating conditions [3]. Hall and Moreland (20017) showed that when RRC is reduced by 10%, fuel economy increases from 0.5 to 1.5% [4]. When the vehicle's fuel consumption is reduced, it will reduce harmful emissions of $NO_x$, NO, HC and $CO_2$ into the environment. Thus, three related parameters include fuel consumption, rolling resistance and emissions. Exhaust gases produced in engine's combustion are characterized by emission coefficients. There are many researches of methods to estimate emission level. One of the most popular methods is to experiment to measure the emission rate and fuel consumption of vehicles. However, experiments are time consuming and there are errors due to inconsistency in sampling. One solution for these errors is the principle of preserving carbon atom of fuel, known as the "carbon balance method", based on the produce of carbon dioxide ($CO_2$), carbon monoxide (CO), hydrocarbon (THC) and material particles (TSP) in the engine's combustion [5].

Now a day, with the development of sensor technology and specialized software, carbon balance method enhances measuring emission and particulate concentration in order to simulate calculating emission coefficients and fuel consumption, in laboratory as well as in practice. Simulink module in Matlab software is a strong tool to fully calculate total mass of all particles containing $CO_2$, CO, THC and TSP, and to adjust theoretical $CO_2$ coefficients of combustion process. Ratios of THC:CO and TSP:CO measured in experiments are input parameters for calculating total fuel consumption in carbon balance model [6].

Fuel consumption (FC) is the inverse of fuel economy, and is a technical measure of fuel consumed over a given distance. FC is measured directly by volume (appeared in table for user's watching), in order to calculate the average fuel economy of a team of vehicles in different operating cycles ( in cities, in highways,…), or to compare annual fuel economy in case of changing vehicles [7].

## 2. SIMULATION OF FUEL CONSUMPTION

### 2.1. Fuel consumption reduction rate

Relationship of fuel consumption FC and rolling resistance coefficient f is calculation in equation (1) [8].

$$FC_r = \frac{f \times \Delta FC}{Z^{\alpha} P^{\beta}\left(a + b \times V + c \times V^2\right)} \times k \times \Delta M \qquad (1)$$

Where: $FC_r$: Fuel consumption of reference vehicle [1/100km]; Mr:The mass of reference vehicle [kg]; ΔFC: Fuel consumption reduction achieved by reduced vehicle's mass [1/100km]; ΔM: Reduction of vehicle's mass [kg]; k: Proportional constant depending on vehicle's mass, engine, aerodynamics and the ratio of power to vehicle's mass; a, b, c, α, β: Coefficient of material; Z: Vertical force; P: Tire pressure.

### 2.2. Assumptions

Threre are many factors that affect vehicle's fuel consumption, so it is difficult to determine exactly which parameters have the greatest influence. Therefore the research is limited as followings: The survey vehicle has traditional gasoline engine (Spark Ignition - SI); The powertrain has a constant output; The fuel consumed by the engine is totally converted into mechanical energy for vehicle's moving; Only rolling resistance with tire's rubber deformation is considered. Aerodynamics resistance, inertial resistance and slope resistance are determined and their values are fixed [9].

### 2.3. Software to simulation

Use "Conventional Vehicle Spark-Ignition Engine Fuel Economy and Emissions" tool in Matlab Simulink to simulate the determining FE and FC for gasoline engine of spark ignition (SI) 1.5L. The input blocks are driving cycle FTP75 of city (FTP75) with distance 17.77 (m), time 1874 (s), average speed 34.1 (km/h) and highway (HWFET) cysles with 16.45 (m), time 765 (s), average speed 77.7 (km/h) followed by driver's block, ECU block, vehicle's body and display bolck of simulation results [15, 16].

The Simulink diagram simulating FE shown in Fig. 1 [17].

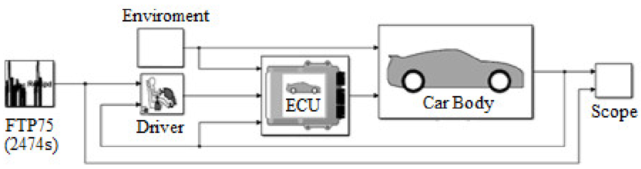



Fig. 1. Simulink diagram simulating FE

The simulation time is determined in 2 ways. The 1st way is to use the test time of 2479 (s) of cycle FTP75 which is the total time of 4 periods: starting period (505s), stable period (876s), shutdown period (600s) and hot starting period (505s). Combining cycle FTP75 (total time is 1874s) and highway fuel economy test HWFET (total time is 765s) we achieve the simulation time as followings: T(s) = 1874 + 765 = 2639 (s). In this paper, simulation time uses the 1st way of 2479(s) of cycle FTP75 as shown in Fig. 2.

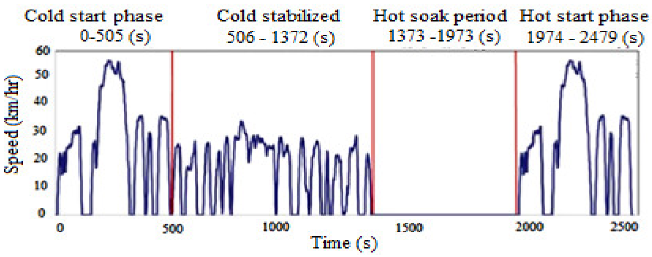



Fig. 2. Total time of cycle FTP75

### 2.4. Vehicle parameters

Toyota Vios 2017 model is selected for the modelling. It is a used car with 136'000 km mileage. It is selected in order to exlclude the fuel consumption norm provided by the manufacturer. In simulating according to simulink, there are 2 groups of vehicle's parameters including: wheel specification and body specification. Wheel's main specifications are nominal inflation pressure, NOMPRES [Pa], 220000 (2.243 kg/cm$^2$); Rolling resistance torque coefficient, QSY1, 0.007/0.018/0.035 with asphalt/ concrete asphalt/ foot-path corresponding roads; and maximum normal force, FZMAX, 10000 [N] [10]. Body's main specifications of car body mass are 1200 (kg), and frontal area is 2.0 (m$^2$) [11]

### 2.5. Carbon balance method

Carbon balance method is used to simulate calculating fuel economy (FC) from collected carbon in exhausted gas. It is assumed that in combustion process, all the carbon from fuel is released in exhausted gas. It bonds totally with oxygen from the air, producing carbon dioxide ($CO_2$), carbon monoxide (CO) or hydrocarbon (HC). Fuel economy FC then is calculated in equation (2) for gasoline engines [12].

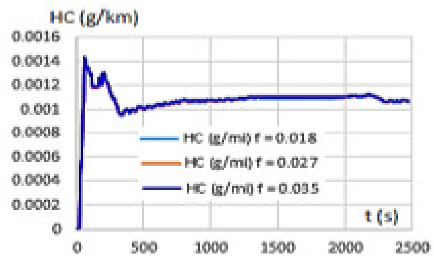
$$FC = 0.1154/\rho \times [(0.866 \times HC) + (0.429 \times CO) + (0.273 \times CO_2)] \quad (2)$$

Where:

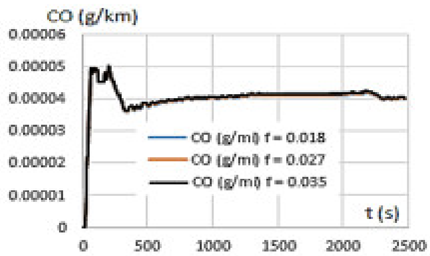
FC: Fuel economy (l/100km); HC: Total hydrocarbon (g/km); CO: Carbon monoxide (g/km); $CO_2$: Carbon dioxide (g/km); ρ: Fuel density at 15°C; Index 0.0866: the percentage of carbon in gasoline is 86.6%; Index 4.249: the percentage of carbon in CO is 42.9%; Index 0.273: the percentage of carbon in $CO_2$ is 27.3% [14].

## 3. ANALYZING RESULTS

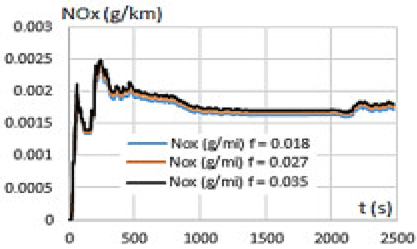
Although the exact amount of $CO_2$ emitted per liter of fuel depends on many factors (such as temperature, ambient pressure and fuel quality), but the ratio of $CO_2$ and C is constant at 3.67 (the ratio of molecular mass of $CO_2$ (12 + 2*16 = 44) and the atomic mass of carbon (12). Thus, basically 1 liter of consumed gasoline produces 2.35kg $CO_2$ and 2.35/3.67 equal to 0.64kg carbon. But due to many factors affecting FE, this figure is no longer accurate [14].



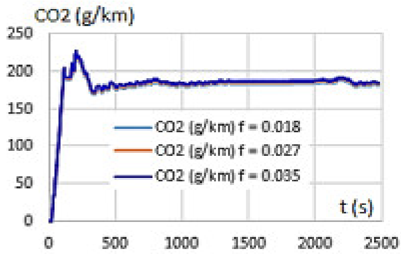

a) HC




b) CO




c) $NO_x$




d) $CO_2$

Fig. 3. Emission of car in different rolling resistance coefficient

We can see the influences of parameters including: driving cycle type, rolling resistance from road surface to mass ratio of HC, CO, $NO_x$ and $CO_2$ of total vehicle's operation. Rolling resistance coefficients increase from f = 0.018 (of good asphalt type) to f = 0.027 (of medium asphalt type) and to f = 0.035 (of flat dirt road) with the same driving cycle FTP75. From the 1st 100 (s) to 500 (s), the emission increases. After that, from 500 (s) to 2747 (s), the emission decreases and the rate of reduction is uneven. It can be explained as followings: in driving cycle FTP75, periods from 500 (s) are steady period, shutdown period and hot starting period. In the simulation, the input exitation force value is the average of these 3 periods.

In Fig. 4 shows fuel economy FE (km/g) of 3 types of roads, calculated by formula (2). For about the 1st third of the time, fuel economy increases linearly, then decreases, and increases, and decreases steadily. During this starting period, the engine is not "hot" enough to reach the temperature of the best performance.

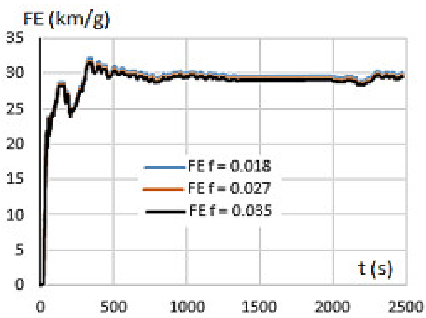



Fig. 4. Fuel economy of car in different rolling resistance coefficient

## 4. CONCLUSION

Using computer model and Matlab Simulink software to simulates vehicle's fuel economy based on 2 main libraries including driving cycle FTP75 and rolling resistance coefficient affecting emission rate HC, CO, $NO_x$ and $CO_2$. At the rolling resistance coefficient f = 0.018, mass ratio of HC = 0.0015g/km, CO = 0.00005g/km, $NO_x$ = 0.0025 and $CO_2$ = 225g/km. Approximated values of rolling resistance have been proven in practice, therefore the simulation accuracy depends much on average values of driving cycle.

Carbon balance technique allows laboratory measurements and accurate simulation.

Vehicle's operating process that exhausts emission, includes starting engine, idling, suddenly stopping when facing an obstacle or stopping before shutting down. Therefore experimental and simulation results are approximately. Actual experiments are necessary to ensure accurate results of emission rate and fuel economy.

This study can be developed to consider the influence of other parameters such as mass, vehicle's speed, emission rate and fuel economy.

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