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Notes and comments

Modelling of the fuel consumption for passenger cars regarding driving characteristics

Haikun Wang, Lixin Fu *, Yu Zhou, He Li

Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, PR China

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ABSTRACT

Road transportation is a major consumer of fuel in China. This paper explores the influence of driving patterns on fuel consumption using a portable emissions measurement system on ten passenger cars. It shows that vehicle fuel consumption per unit distance is optimum at speeds between 50 and 70 km/h, fuel consumption increasing significantly with acceleration. A VSP-based model was developed to calculate vehicle fuel consumption in this study, and produced good results compared to the measured data.

1. Introduction

Variations in vehicle fuel consumption and emission rates are usually associated with changes in cruise speeds, driver acceleration aggressiveness, and road grade (El-Shawarby et al., 2005; Zhang and Frey, 2006; Chen et al., 2007). Quantitation of the effects of these factors on fuel consumption is necessary to develop methods and strategies for fuel consumption prediction and fuel economy improvement.

Physically and empirically based methods are usually considered in modeling fuel consumption and emissions. An example of the former is the physical emissions rate estimator (PERE), which uses vehicle parameters and second-by-second driving traces as inputs, and estimates second-by-second fuel consumption rates (Nam and Giannelli, 2005). The empirically based modal is exemplified by the motor vehicle emission simulator (MOVES), of the US Environmental Protection Agency (EPA) (2005) to estimate energy consumption for vehicles. MOVES2004 and PERE are complementary models. When possible, MOVES2004 is based on second-by-second measurements of vehicle fuel use and emissions obtained either using dynamometers in a laboratory or from real-world measurements with portable emissions measurement system (PEMS). Where such data are not available, PERE may be used to fill data gaps in energy consumption rates.

Here, a PEMS (Hu et al., 2004) built by the Department of Environmental Science and Engineering of Tsinghua University was used to collect vehicle fuel consumption and emissions data under actual driving conditions. The relationship between fuel consumption and vehicle driving parameters is used to provide insight into the effect that different levels of cruise speed and acceleration have on vehicle fuel consumption. An empirically based model of fuel consumption for light-duty gasoline vehicles based on vehicle specific power (VSP) is established, which can be used to estimate the vehicle fuel consumption when the driving parameters are introduced.

2. Methodology

The PEMS used consists of three major systems: the Corrys–Datron Microstar non-contact velocity sensor, Corrys–Datron DFL-2 fuel flow meter and OTC Microgas 5-gas exhaust analyzer. They are used to measure the vehicle driving parameters, fuel consumption rates and tailpipe emissions second-by-second (Hu et al., 2004; Yao et al., 2006).

* Corresponding author. Fax: +86 10 62771465.
E-mail address: fuchen@mail.tsinghua.edu.cn (L. Fu).

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Table 1
Overview of the tested vehicles

No.	Model	Engine displacement (L)	Weight (kg)	Mileage (10^4 km)	Year of manufacture	Air/fuel control
1	VW Santana	1.8	1070	3	2002	EFI
2	VW Jetta	1.6	1030	4	2001	EFI
3	VW Santana	1.8	1070	–	1998	Carbureted
4	VW Santana	1.8	1070	20	1997	Carbureted
5	Toyota Jinbei	1.6	2800	12	2001	EFI
6	VW Jetta	1.8	1470	16	1999	Carbureted
7	VW Passat	1.8	1775	9	2002	EFI
8	VW Jetta	1.6	1480	60	2001	EFI
9	VW Santana	1.8	1585	30	2003	EFI
10	Buick SGM	2.0	1863	1.56	2004	EFI

Table 1 shows information on the 10 vehicles tested, 7 cars equipped with electronic fuel injection (EFI) and 3 with carburetors. They are representative of gasoline passenger cars in China.

Each vehicle was tested over three periods of a day: 7:00–9:00 am, 11:00 am–1:00 pm and 5:00–7:00 pm, designed to represent peak and non-peak hours of city traffic. They were driven under different driving conditions with speeds ranging from 0 to 80 km/h and acceleration from $-5\ \mathrm{m/s^2}$ to $5\ \mathrm{m/s^2}$ from October, 2004 to March, 2005. About 13,000 samples of second-by-second data for each test vehicle were collected.

VSP is defined as the instantaneous power per unit mass of the vehicle and is a core parameter of MOVES (Koupal et al., 2002). We used the following EPA's simplifying for light-duty gasoline vehicles (US Environmental Protection Agency, 2002):

$$\mathrm{VSP(kW/ton)} = 2.73 \times \sin(\mathrm{slope}) \times v + 0.085 \times v \times a + 0.0593 \times v + 0.0000653 \times v^3 \tag{1}$$

here v and a are the vehicle speed and acceleration in mile/h and mile/h/s; and slope is the road slope in degrees.

The characteristic of vehicle fuel consumption at idle is very different from when the vehicle is moving and so it was separated as a bin. The non-idle category is divided into three sections: low speed ($0\ \mathrm{km/h} < v \leqslant 30\ \mathrm{km/h}$), moderate speed ($30\ \mathrm{km/h} < v \leqslant 60\ \mathrm{km/h}$) and high-speed ($v > 60\ \mathrm{km/h}$). Each speed section has 16 VSP bins giving 49 speed-VSP bins. Average fuel consumption rates is calculated for each speed-VSP bin.

The trip-based fuel consumption is estimated as:

$$\mathrm{FC} = \sum_{i=1}^{I} \mathrm{FR}_i \times T_i \tag{2}$$

where, FC is the trip fuel consumption, L; i is the speed-VSP bin index and I is the number of bins; FR_i is fuel consumption rate for speed-VSP bin i, L/s; and T_i is the vehicle trip time spent in speed-VSP bin i, s.

3. Results

Fig. 1 summarizes the impact of cruise speed on the fuel consumption per unit time (L/h) and per unit distance (L/100 km) for Number 2 test vehicle. Fuel consumption per unit time appears to be positively correlation with the cruise speed: an increase in speed from 40 km/h to 80 km/h results in a 94% increase in the vehicle fuel consumption rate. However, too high or too low a speed can both lead to a high fuel consumption rate in L/100 km. The optimum fuel economy occurs between

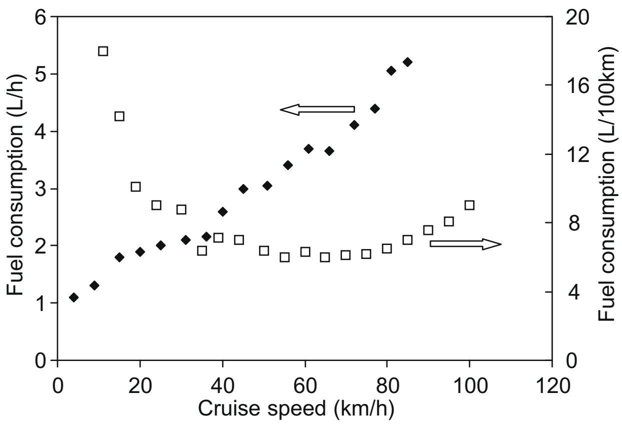

Fig. 1. Influence of cruise speed on fuel-consumption rate for #2 test vehicle.

50 km/h and 70 km/h, as has been suggested elsewhere (El-Shawarby et al., 2005). For this special vehicle, a cruise speed of 65 km/h results in a minimum fuel consumption rate of approximately 6.0 L/100 km. Acceleration significantly increases fuel consumption, although the impact of deceleration is much less noticeable.

As seen in Fig. 2, fuel consumption rates show periodic variations between VSP Bins. For EFI vehicles, the curves indicate a linear relationship between fuel consumption rates and VSP Bins, with R^2s of 0.974, 0.984 and 0.997 for the different speed categories. Exponential relationships are found for the carbureted vehicles with R^2s of 0.977, 0.996 and 0.957. This all indicates a strong relationship between fuel consumption rates and VSP Bins making it possible to estimate vehicle fuel consumption rates using VSP rather than measuring it with a fuel flow meter.

Vehicles 1–4 were used to develop the fuel consumption model for carbureted and EFI vehicles, with five successive 300-second-long measurement trips by the other vehicles used for validation. The modeled and measured trip fuel consumption

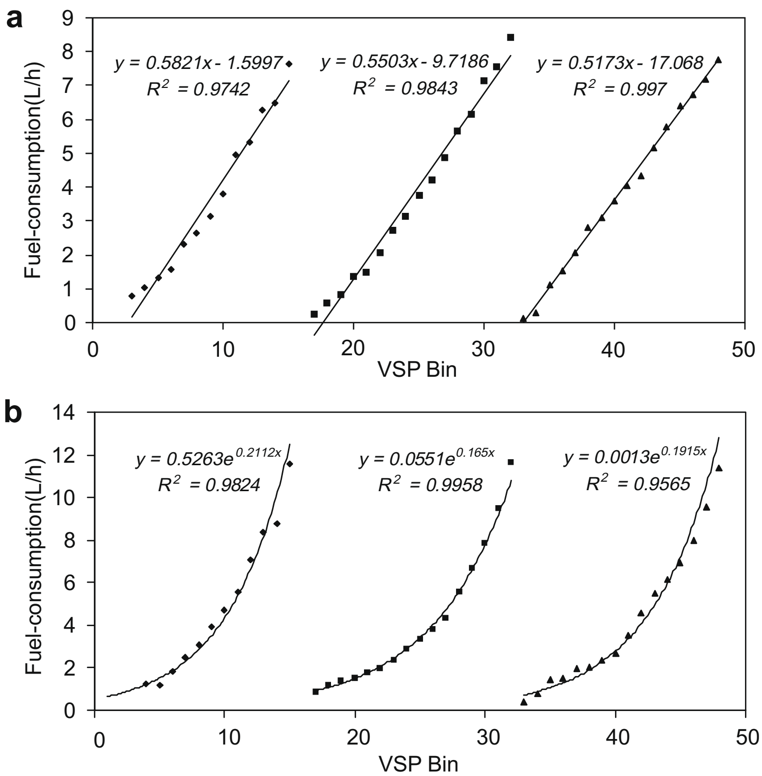

Fig. 2. Fuel consumption rate variation due to VSP Bin (a) EFI; (b) carbureted.

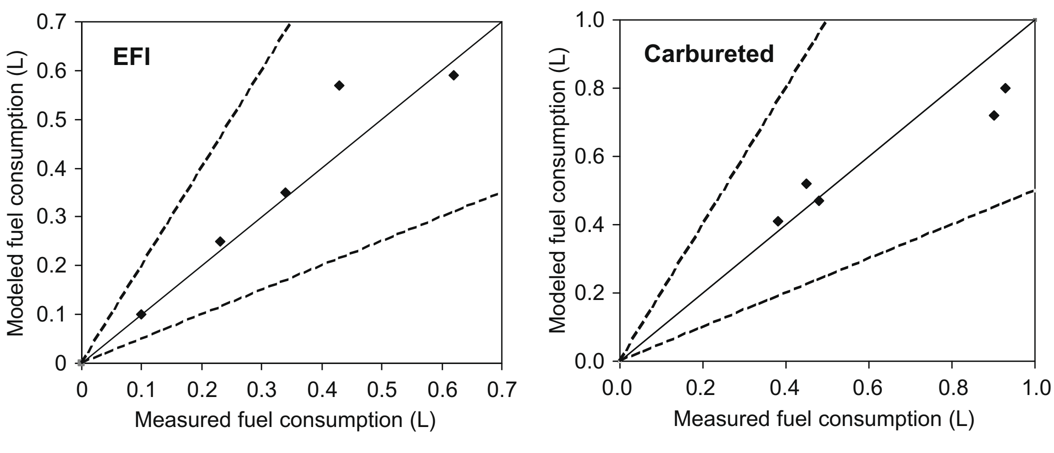

Fig. 3. Validation of fuel consumption simulation for EFI and carbureted vehicles.

Table 2
Comparison of the fuel consumption rates from modeled and measured values (L/h)

Vehicle No.	#5	#6	#7	#8	#9	#10
Modeled	2.15	2.32	2.25	2.82	1.98	2.08
Measured	2.81	2.01	2.63	2.70	1.92	2.03
Error (%)	−23.49	15.39	−14.70	4.34	3.40	2.47

values calculated using Eq. (2), for EFI and carbureted vehicles are plotted in Fig. 3. The modeled and measured fuel consumption for EFI and carbureted vehicles only differ by less than 15%.

Table 2 illustrates that the modeled and measured fuel consumption rates for vehicles 5–10 are in good agreement, and most of the differences between them are within 20%. However, a large difference appears for vehicle Number 5. This is because it weights 2800 kg, more than twice that of vehicles 1–4, which used to develop the fuel consumption model. According to Li (2006), a 1% changes in vehicle weight could mean a 2.07 L/h change in fuel consumption for passenger cars. Frey et al. (2007) also point out that vehicle weight has a significant effect on the fuel consumption.

4. Conclusions

This paper presents an application of PEMS to characterize vehicle fuel consumption under different driving patterns and develops a VSP-based fuel consumption model. Vehicle fuel consumption rate per unit time and the cruise speed show a strong positive correlation. The fuel consumption rate per unit distance appears to be optimum in the speed range of 50–70 km/h. Fuel consumption rates increase significantly when the vehicles are accelerated and change little during deceleration. In each of the three speed categories, linear functions and exponential functions were derived between fuel consumption rates and VSP bins for EFI and carbureted vehicles, respectively. A VSP-based model produces trip fuel consumption and fuel consumption rates that are accurate to within ±15% and ±20%.

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