Study on the Influence of Bangkok Driving Characteristics on Exhaust Emissions and Fuel Consumption of Gasoline Passenger Car

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Abstract: Bangkok is now suffered from air pollution emitted from automobiles under congested traffic conditions. An effective way to lessen the air pollution is to issue regulations on maximum allowable limits of exhaust gas from vehicles in the city. One way to assess the allowable limit of exhaust gas emissions is to establish a generic driving cycle to represent a driving pattern for the vehicle population of a city. The Bangkok driving cycle is constructed to study the influence of Bangkok driving characteristics on exhaust emissions and fuel consumption of the gasoline passenger car. In this study, a gasoline passenger car is equipped with a real time data logger to collect speed-time data during weekday and weekend under actual traffic along the selected road routes in Bangkok urban area for two months. Two driving cycles for Bangkok are constructed to represent the driving pattern in traffic conditions on those weekday and weekend periods by the statistical method. The exhaust gases: CO, HC and NO\(_x\) and fuel consumption are measured at the Automotive Emission Laboratory of the Pollution Control Department by driving a gasoline passenger car on the chassis dynamometer according to the Bangkok driving cycles on weekday and weekend.

Keywords: Driving Cycle, Driving Characteristics, Exhaust Emissions, Fuel Consumption.

1. INTRODUCTION

Due to the high increasing rate of vehicle numbers, Bangkok now faces with serious air pollution emitted from the exhaust pipes of those automobiles under congested traffic conditions [1]. One effective way to alleviate the air pollution situation is to issue regulations on maximum allowable limits of exhaust gas emissions that a vehicle in the city can release [2]. These limit levels vary from place to place, depending on the standard of living and affordability of costly less-polluted technology, as well as the severity of traffic conditions.

It is widely known that the amount of emissions and rate of fuel consumption of a vehicle are influenced, by its design parameters as well as the operating conditions [3-4]. However, the estimation of the emission level and fuel consumption from the design parameters operating at average conditions obtained from traffic data may not be realistic. One possible and practical way is to establish a generic driving pattern which is a characteristic for any vehicle traveling in the traffic of the city under consideration. This driving pattern is so-called the “Driving Cycle”. The driving cycle provides the variation of the vehicle speed with time for a certain period of travel [5]. It can be interpreted in such a way that the vehicle, when traveling in the traffic of the considered city, would experience this driving pattern repetitively throughout its journey. In statistical aspects, it represents a typical driving pattern for the vehicle population of a city.

In present, the driving cycle used for the assessment of the exhaust emissions of newly registered automobiles in Thailand [6] is based upon the standard European driving cycle. The European driving cycle shows the characteristics of vehicles operating conditions for various speeds and acceleration ranges, but does not represent realistic speed-time history of a vehicle in actual traffic. This cycle consists of artificially formed phases of constant speed, acceleration and deceleration, which are different from realistic transient patterns [5].

Therefore the European driving cycle may not produce a realistic assessment of the emissions for Bangkok traffic since traffic conditions in Bangkok are heavily congested. The vehicles travel in Bangkok area with frequent stop, acceleration and deceleration which lead to high exhaust gas emissions and inefficient fuel consumption. From the study of Andre et al. and Hammarström [7] found that the speed pattern of the vehicles influences the pollutant emissions. Two cases of the different driving speed situations but similar in term of average speed are examined in order to evaluate and compare the amount of CO emission and fuel consumption. For the first case, the vehicle is driven at a constant speed of 40 km/h for 100 km. While in the second case, the vehicle is driven at a speed of 20 km/h for 25 km and at 60 km/h for 75 km. The average speeds of both cases are equal to 40 km/h. This study shows that the amount of CO emissions and fuel consumption are different significantly even though the average speed of the vehicle are the same while the driving speed pattern are different. From some studies [8-10] found that the exhaust gas emissions and fuel consumption are highly related to driving modes: idle, steady-state cruise, acceleration and deceleration.

It can be noted that the pollutant emissions is relatively sensitive to the quality and accuracy of description to the driving speeds. Thus, a certain level of detail in the speed description is necessary for an accurate evaluation of emissions.

Therefore, the objective of this study is to develop driving cycle of weekday which represents the serious traffic conditions and driving cycle of weekend which represents the light traffic conditions. These two driving cycles are constructed in order to investigate the influence of driving characteristics of those two distinctly different driving modes on the exhaust gas emissions and fuel consumption. This would give more realistic results for the assessment of emissions and fuel consumption of vehicles traveling in Bangkok and would be beneficial to both government authorities in making environmental policies and measures, and automobile manufacturers in improving their products to meet the required standards.

2. METHODOLOGY

2.1 Route selection

Typically, the driving cycle is constructed to represent the driving pattern of vehicles in a considered city that would experience this driving pattern repetitively throughout its journey when traveling in the traffic. The typical driving cycle
must be obtained from the adequate number of routes. However, to conduct actual measurements on the whole road routes is impossible. One feasible method is to select appropriate number of routes that can represent the dominant traffic situations throughout the city. This study presents the generic method to select appropriate road routes for data collection.

In order to select the best representative of routes, the real situations occur along each road route must be known. Travel speed is one of the traffic parameter that is widely used to describe the real traffic situations [11]. One practical method to determine travel speeds is calculated from the traffic flow model. Generally, a main road route in urban area compose of the sections of road which are connected with the intersections. Thus, it is necessary to determine the traveling speed of each section of that road route in order to determine the average travel speed along the interested road route. After the travel speeds of all main road routes in the interested area are obtained, the distributions of those travel speeds are determined. These distributions reflect the driving speed patterns that occur in actual situations. Therefore, the representative routes can then be obtained by select the number of routes which match to the proportions of actual speed patterns of that interested area. The selected road routes from this method can cover major speed patterns which best represent the actual traffic situations.

By using the method as described above, seven road routes are then selected. The results obtained from the proposed route selection method are shown in Table 1. It consists of Silom road, Petchaburi road, Sukhumvit road, Ladprao road, Paholyothin road, Jarunsanitwong road and Wipawadee road. Silom Rd. is selected to represent the highest congested traffic conditions (average travel speed is less than 10 km/h) while Petchaburi Rd., Sukhumvit Rd., Ladprao Rd. and Paholyothin Rd. are selected to represent the lighter traffic conditions (average travel speed is more than 10 km/h to 20 km/h). Jarunsanitwong Rd. characterizes the moderate traffic conditions (average travel speed is more than 20 km/h to 30 km/h) and Wipawadee Rd. characterizes the lightest traffic conditions (average travel speed is more than 30 km/h).

Table 1 Detail of the selected road routes

<table>
<thead>
<tr>
<th>Road (Flow direction)</th>
<th>Road details (begin to end junction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Silom (east bound)</td>
<td>Silom → Saradang</td>
</tr>
<tr>
<td>2. Petchburi (west bound)</td>
<td>Klongton → Pratunum</td>
</tr>
<tr>
<td>3. Sukhumvit (west bound)</td>
<td>Bangna → Pleonjit</td>
</tr>
<tr>
<td>4. Ladprao (west bound)</td>
<td>Meanburi → Ladprao-Pahol</td>
</tr>
<tr>
<td>5. Paholyothin (south bound)</td>
<td>Laksi → Victory Monument</td>
</tr>
<tr>
<td>6. Jarunsanitwong (south bound)</td>
<td>Banglad → Mahaisawan</td>
</tr>
<tr>
<td>7. Wipawadee (south bound)</td>
<td>Bangkhen → Din ding</td>
</tr>
</tbody>
</table>

2.2 Speed-time data collection

In this study, passenger car of no more than seven passengers or so called “sedan” which accounts for highest number of vehicles registered in Bangkok [12] is selected. Most sedan cars are used for traveling from home to working places and vice versa. Therefore traveling routes considered should be along the roads connecting between the suburban housing estates and the downtown areas. Once the routes obtained from the method of route selection described in the previous section are selected, the speed-time data collections are carried out using a real time data logger equipped on a selected sedan traveling along the routes under actual traffic. The vehicle used in this study is a Toyota Corona year 1993 with gasoline engine, manual transmission and capacity of 1.6 liters. The instrumented vehicle is driven following the time schedule along the designated routes to collect the speed-time data. The speed-time data are collected at the morning peak period from 7:00 a.m to 9:00 a.m during November and December in 2003. Such the speed-time data collections are carried out on Monday or Friday to represent the heavy congested traffic condition of weekday while on Tuesday or Wednesday or Thursday to represent the light congested condition of weekday. For the weekend traffic conditions, the data collections are carried out on Saturday or Sunday.

2.3 Driving cycle construction

From the speed-time data obtained from an on-roads collection, the acceleration (or deceleration) in every second throughout the trip and actual driving parameters are calculated. These actual driving parameters include average speed ($V_{avg}$), average running speed ($V_{1\text{st}}$), times in acceleration ($\%\text{Acc}$), in deceleration ($\%\text{Dec}$), at cruise ($\%\text{Cruise}$) and at idle ($\%\text{Idle}$), number of stops per kilometer travel (stop/km), average acceleration ($\text{Acc}_{avg}$) and deceleration ($\text{Dec}_{avg}$) and positive kinetic energy (PKE). The actual driving parameters indicate the actual on-roads driving situations and are used as the criteria for the driving cycle construction. These real parameters will be called “Target Parameters”.

The whole driving data are then separated into microtrips to determine the predominant patterns occurred in the actual driving situations. The microtrip is defined as the sequences of driving data between successive stops in the trip [13-14]. The driving parameters of each microtrip are calculated. These microtrips are then grouped based on their average velocities. For each velocity interval, every microtrip is given an equal probability the value of which is calculated based on the number of microtrips in the interval.

A computer simulation program is written in order to construct a driving cycle. The program will generate a random number to select the velocity interval and another random number to select a microtrip from that selected velocity interval. The driving parameters are calculated from the selected microtrip and compared with the target parameters. The target parameters used to select the next microtrip in this study are the average velocity, the proportion of number of microtrips in each velocity interval and the proportion of time which microtrips spent in each velocity interval. Each time the new microtrip is selected, their average speed, percent of number of microtrip in each velocity interval and percent of time spent in each velocity interval are re-determined to check whether the values of these parameters are lower or higher than those of target parameters. If the percent proportion of number of microtrip in some velocity interval of the selected microtrip is higher than the target values, the rest of microtrips contained in that speed range will be rejected. The probability of the remaining microtrips in the rest of each speed range is then recalculated again. To select the next microtrip, the determined average speed from the selected microtrips is checked whether it is lower or higher than the target average speed. The next microtrip is then selected from the remaining microtrips so that the new average speed become closer to the target value and the selected pattern become reasonable and cover all of the predominant patterns occurs in the actual driving situations. The satisfied microtrip is then connected to
the previously established series of microtrips. This procedure is repeated until the specific cycle duration is complete. The duration of each driving cycle is set at 1200 seconds. The selected driving cycles to represent the driving pattern of the weekday and weekend condition in Bangkok are cycles of which their target statistical parameters close to those of the actual data.

2.4 Emissions and fuel consumptions measurements

Two driving cycles are obtained from the method of driving cycle construction. They are weekday driving cycle (WDDC) and weekend driving cycle (WEDC). Then emissions and fuel consumption are test under driving pattern following those two driving cycles.

Emissions and fuel consumption test are performed on a chassis dynamometer (SCHENCK EMDY48) at the Automotive Emission Laboratory of the Pollution Control Department. Exhaust gas flow is measured using a constant volume sampler (CVS). Emissions are measured as follows: carbon monoxide (CO) with a non-dispersive infrared analyzer (NDIR), total unburned hydrocarbons (HC) with flame ionization detector (FID), and oxides of nitrogen (NOx) with chemiluminescence analyzer (CLA). Fuel consumption is calculated using carbon balance method.

To simulate under real road conditions, the air ventilation is placed in front of the tested vehicle for cooling the tested vehicle and the vehicle load is simulated by adapting the inertia weight setting. In order to give representative unit emissions, the fuel used comes from the same local petrol station.

The tested vehicle is selected in order to represent the vehicle fleets in Bangkok. This selected car is TOYOTA SOLUNA year 2000, gasoline engine, automatic transmission with capacity of 1.5 liters and odometer reading 48900 km. It is equipped with three-way catalytic converter (TWC). Exhaust emissions are measured when the vehicle is operated on a chassis dynamometer according to the obtained driving cycles with hot start engine follows the TIS 1870-1999 operating conditions.

3. RESULTS AND DISCUSSIONS

3.1 Bangkok driving characteristics

From the obtained speed and acceleration data of weekday and weekend, a speed-acceleration frequency distribution (SAFD) of each data set is constructed and converted to probability distribution (SAPD). It is basically a 3-dimensional normalized histogram with the probability density in the vertical axis and the speed and acceleration on the horizontal plane. The SAPD of the gathering data between weekday and weekend are depicted in Fig.1. Each pile in the histogram represents the frequency (probability) of an acceleration level which is likely to occur at a specific speed of the vehicle. Obvious results show that, traffic in the weekday is much more congestion than weekend. More than 40 percents of time are wasted during idle on weekday while only 20 percents are spent during idle on weekend. Moreover, the varieties to choose speed are forced by the congested traffic on weekday while freely speed chooses when driving on weekend. The vehicles are driven with lower speed on weekday than driving on weekend. It can be found that maximum acceleration and deceleration rates on weekday are 3.1 and 3.9 m/s² respectively. On the other hand, the maximum acceleration and deceleration rates on weekend are 2.8 and 3.1 m/s². In addition, driving on weekday identifies the lack of cruising conditions; in contrast driving on weekend distinguishes the moderate of the same conditions.

3.2 Bangkok driving cycle

The driving cycle construction procedures described above are applied to the weekday and weekend collected data. The obtained weekday and weekend driving cycles whose driving parameters are closest to target parameters are shown in Fig. 2. Different shape of the microtrips between these two driving cycles is noticed. It can be inferred that the vehicles can travel more freely on weekend than on weekday. Hence higher number of microtrips occurred at high speed can be observed on weekend driving cycle. In contrast, the vehicles are forced by the traffic conditions to travel with low speed on weekday. Thus, the major microtrips that can be observed on weekday driving cycle are the short trips with low speed as a result of traffic problems.

Tables 2 show the results of the driving characteristics between weekday and weekend driving cycles. It is observed that the driving characteristics between weekday and weekend are distinctly different. For instance, as a result of the large proportion of idling mode occur between weekday and weekend, average speed of weekday is 14.2 km/h while average speed of weekend is 35.7 km/h. Additionally, because of the traffic congestion problems usually occurred on weekday, the frequency of stop per distance travel is arise to 3.3 while the frequency of stop per distance travel in weekend is 0.5 perceived. This severe traffic congested conditions in...
weekday may cause impact on exhaust emissions and fuel consumption. For the relative time proportion of four driving modes of weekend: idling, cruising, acceleration and deceleration modes are 41.1%, 22.6%, 14.4% and 21.9%, respectively while the relative time proportion of those four driving modes on weekday are 19.6%, 35%, 18.1% and 27.3%. It can be noticed that the proportion of deceleration mode is higher than the proportion of acceleration mode which results from the congested traffic that the drivers drive the car with low speed and frequently slow down.

### 3.3 Exhaust emissions and fuel consumption

Table 3 shows the exhaust emissions obtained from WDDC and WEDC. It can be observed that all exhaust emissions: HC, NO\textsubscript{x}, CO, and HC+NO\textsubscript{2} from WDDC are much higher than those from WEDC. The HC, NO\textsubscript{x}, and CO from WDDC are about 56%, 38% and 27% higher than that from WEDC, respectively. It can be explained that the exhaust emissions from WDDC are higher because the average speed and percent of cruise mode of WDDC is quite lower than that of WEDC while the percent idle is much higher. Moreover, the high value of stop per kilometer traveled of WDDC indicates the high frequency of stop. In the aspect of fuel consumption, it is found that driving with the conditions of WDDC consume approximately 40% more fuel than driving with the conditions of WEDC. This implies that driving the car with low speed, frequent stop and high fluctuation of the instantaneous speed are the cause of rising of emissions and fuel consumption. Therefore, driving the car in Bangkok area on weekday with those conditions concerned may tend to be increasing of emissions and fuel consumption level than on weekend.

### 4. CONCLUSIONS

The Bangkok driving cycles are constructed to study the influence of Bangkok driving characteristics on exhaust gas emissions and fuel consumption of the gasoline passenger car. Two different driving cycles are constructed to represent the driving pattern in traffic conditions on those weekday and weekend periods by the statistical method. The exhaust gas: CO, HC and NO\textsubscript{x} and fuel consumption are measured by driving a gasoline passenger car on the chassis dynamometer according to those two driving cycles.

<table>
<thead>
<tr>
<th>Driving cycle</th>
<th>Emissions, g/km</th>
<th>Fuel Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HC</td>
<td>NO\textsubscript{x}</td>
</tr>
<tr>
<td>WDDC</td>
<td>0.159</td>
<td>0.325</td>
</tr>
<tr>
<td>WEDC</td>
<td>0.070</td>
<td>0.203</td>
</tr>
</tbody>
</table>
The results show that the different driving characteristic results in different exhaust emission and fuel consumption as well. This result would lead to the construction of appropriate driving cycle which can represent the realistic traffic in Bangkok which would give more realistic results for the assessment of emissions and fuel consumption of vehicles traveling in Bangkok. From the results, it would be beneficial to both government authorities in making environmental policies and measures, and automobile manufacturers in improving their products to meet the required standards.

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