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Influence of driving cycles on exhaust emissions and fuel consumption of gasoline passenger car in Bangkok

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Abstract

The influence of different driving cycles on their exhaust emissions and fuel consumption rate of gasoline passenger car was investigated in Bangkok based on the actual measurements obtained from a test vehicle driving on a standard chassis dynamometer. A newly established Bangkok driving cycle (BDC) and the European driving cycle (EDC) which is presently adopted as the legislative cycle for testing automobiles registered in Thailand were used. The newly developed BDC is constructed using the driving characteristic data obtained from the real on-road driving tests along selected traffic routes. A method for selecting appropriate road routes for real driving tests is also introduced. Variations of keyed driving parameters of BDC with different driving cycles were discussed. The results showed that the HC and CO emission factors of BDC are almost two and four times greater than those of EDC, respectively. Although the difference in the NO_x emission factor is small, the value from BDC is still greater than that of EDC by 10%. Under BDC, the test vehicle consumes fuel about 25% more than it does under EDC. All these differences are mainly attributed to the greater proportion of idle periods and higher fluctuations of vehicle speed in the BDC cycle. This result indicated that the exhausted emissions and fuel consumption of vehicles obtained from tests under the legislative modal-type driving cycle (EDC) are significantly different from those actually produced under real traffic conditions especially during peak periods.

Key words: driving cycle; driving pattern; driving characteristics; microtrip characteristics; exhaust emissions; fuel consumption

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Introduction

One effective way to alleviate the air pollution situation in a city is to issue regulations on maximum allowable limits of vehicle exhaust gas release (Ergeneman *et al*., 1997). 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 not only its design parameters but also the operating conditions (André *et al*., 1995; Booth *et al*., 2001). Estimations of the emission levels and fuel consumption of a vehicle can be determined from its design parameters with an assumption that the engine operates at average condition obtained from traffic data. However, the results may not be realistic as the actual operating conditions are not constant but fluctuate, especially driving in the city. A possible and practical way is to establish a driving pattern, which can represent the driving characteristic for any vehicle traveling in the traffic. This driving pattern is so-called the "driving cycle" which provides the variation of the vehicle speed with time for a certain period of travel (Tong *et al*., 1999).

Presently, there is no such driving cycle officially developed for representing Bangkok traffic. The legislative driving cycle used to assess the exhaust emissions of newly registered automobiles in Thailand is based upon the standard driving cycle of the European community (EDC cycle) (TISI, 1999), which characteristics are apparently different from actual driving in Bangkok. It is a modal driving cycle with constant speed and very smooth acceleration profile (Pelkmans and Debal, 2006). Thus it underestimates the vehicle load which directly results in fuel consumption and exhaust emission. Moreover, the engine only uses a very small area of its operating range. In order to comply with the emission test, engine manufacturers only have to optimize emission in these operating zones. Therefore, the European driving cycle may not produce a realistic assessment of the vehicle exhaust emission and fuel consumption for heavily congested traffic condition in Bangkok. The study of André and Hammarström (2000) has revealed the influence of speed pattern of the vehicles on the pollutant emission. Two cases of the different driving speed situations but similar in term of average speed were examined. The results showed that the amount of CO emission and fuel consumption are different significantly due to different driving speed patterns. It is also shown in other studies

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(André *et al*., 1994; Leonidas and Zissis, 2000; Bullock, 1982) that the exhaust gas emission and fuel consumption are highly related to driving modes: idle, steady-state cruise, acceleration and deceleration. It can be noted that the pollutant emission 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 emission.

The objectives of this study were: (1) to develop a new driving cycle based on the actual traffic condition in Bangkok; (2) to conduct the actual measurements of exhaust emission and fuel consumption of a test vehicle driving on a standard chassis dynamometer using the newly established Bangkok driving cycle (BDC); and (3) to compare the obtained results with those driving under EDC to investigate the difference between the legislative and real driving values.

1 Methodology

1.1 Road route selection

In order to obtain a driving cycle that resembles the actual driving characteristics in city, appropriate road routes that can represent the dominant traffic situations should be selected. However, to date, research subjected to the detailed study on how to select appropriate road routes for collecting real on-road driving data has not been found. Most road routes were selected on a basis of the researchers' simple judgments that these routes would cover the driving conditions from one end of the city to the other passing through the city downtown area. The current study, therefore, intends to propose a practical methodology for road route selection so that the vehicle driving characteristics along these selected routes would represent the real traffic conditions for most vehicles traveling in city.

To select the routes the real situations of each road route in city must be known. Travel speed is commonly used to describe the real traffic situations (Traffic Research Board, 2000) and it can be determined according to a traffic flow model introduced by Greenshield (Dirks *et al*., 2003). The traffic flow data contains the number of vehicles passing over the sections along the main roads during desired period of the day. Traffic authorities normally conduct these data collection in most big cities.

The route selection starts with the determination of the travel speed in major road by applying the traffic flow model. The distribution of travel speeds in the area then can be established. The second step is to select a few major road routes so that their distribution of vehicle speeds of all road sections is closely matched to that of the whole major roads previously established. These few major road routes are, therefore, expected to cover all driving speed patterns occurring in the city. They can be used as representative road routes for conducting real driving tests to collect the driving characteristics (i.e., speed versus time data), which will be later used for the construction of the driving cycle. More details for road route selection method have been described by Tamsanya (2006).

1.2 Driving cycle development

1.2.1 Determination of target driving characteristics

As widely known, the principal basis to develop a representative driving cycle is to construct a driving cycle which the driving characteristics can match well to the target value determined from the entire speed-time data under actual traffic. The driving characteristics include ten parameters: average speed (V_{avg}), average running speed (V_{1avg}), acceleration rate ($R_{AC\text{-}avg}$), deceleration rate ($R_{DE\text{-}avg}$), driving mode variation: idle (%), cruise (%), acceleration (%) and deceleration (%), positive acceleration kinetic energy (PKE) and frequency of vehicle stop (number of stop/km). These parameters are generally well known and accepted as the indicators of the actual on-road driving situations (Hung *et al*., 2005). On one hand, they are used to describe the actual on-road driving characteristics. On the other hand, they are also being the factors that have influences on the amount of vehicle emissions and fuel consumption. Therefore, these parameters will be used to identify the characteristics of Bangkok traffic and will be used as the target driving parameters to select the best representative driving cycle for Bangkok.

However, to ensure that the constructed driving cycle would reflect the proper proportion of a broad range of vehicle operation in actual traffic, another set of parameters is introduced. This set is called microtrip characteristics, which would also be determined from the real speed-time profiles obtained from speed-time data collection. Real speed-time profiles are comprised of small portions of driving data separated by idling parts which are worldwide called as microtrips (Watson *et al*., 1982; Austin *et al*., 1995). Therefore, the whole driving data are separated into microtrips and they are analyzed to determine the predominant patterns occurred in the actual driving situations. The driving parameters of these microtrips are firstly calculated, and then classified into different intervals based on their average speeds. The number of microtrips occurred as well as the total time spans, during which these microtrips spent in each speed interval are determined and their proportions of the number of microtrips (N_m) and of time spans of microtrips (T_m) distributed under different speed intervals are then calculated. These two additional microtrip parameters and the previously mentioned ten driving parameters are assigned to be a set of criteria as "target parameters" to select the best representative cycle for driving cycle construction.

1.2.2 Driving cycle construction procedure

The driving cycle construction approach used in this study is based on building up a series connection of a number of randomly selected microtrips which were analyzed from the on-road collected speed-time data. The construction procedure is designed according to that the driving characteristics of the obtained driving cycle match with target parameters of the actual driving characteristics occurred in Bangkok within the desired cycle duration. The total duration of the driving cycle is considered based

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on the fact that it should be long enough to describe all traffic situations and obtain the emissions sufficiently. Therefore, the total driving cycle duration in this study is set as 1200 s, and it is within the range used by various well-known driving cycles. In the procedure, three target driving parameters: the average running speed (V_{1avg}), the percentages of N_m and T_m distributed over different speed ranges are firstly used for guiding in the microtrip random selection process. With this guiding selection, a number of generated driving cycles can be obtained and almost all these generated driving cycles would have their driving characteristics very close to the target driving parameters derived from the real on-road data. In order to represent the actual driving conditions greatly, its driving parameters must be statistically closest to all the target driving parameters described in Section 1.2.1. The sum of standard errors of estimates of these parameters is used as the criterion for the best representative cycle. More details for the driving cycle development have been described by Tamsanya (2006).

1.3 Effects of driving cycles on emissions and fuel consumption

In order to investigate the effects of driving cycles on emissions and fuel consumption, experiments on a test vehicle are carried out on a standard chassis dynamometer at the Automotive Emission Laboratory of the Pollution Control Department of Thailand. Exhaust emissions are measured when the vehicle is operated on a chassis dynamometer according to the specified driving cycle with hot start engine as described in the TIS 1870-1999 operating conditions. The exhaust emissions including carbon monoxide (CO), carbon dioxide (CO_2), total unburned hydrocarbons (HC) and oxides of nitrogen (NO_x) were measured according to a constant volume sampling (CVS) method.

For the purpose of comparison, emissions and fuel consumption of the test vehicle are tested following two different driving cycles. One is BDC developed based on the method described in Section 1.2.2, and the other is EDC, which is currently used by Thai Industrial Standards Institute to test new gasoline vehicles. The EDC cycle consists of a phase representing urban driving called ECE and a phase representing extra-urban driving called EUDC (Pelkmans and Debal, 2006). In addition, results of emissions and fuel consumption tests from other research work are also investigated on the relationship of emissions and fuel consumption among the in-service and legislated cycles.

2 Results and discussion

2.1 Bangkok road route selection

The road route selection method described in Section 1.1 is applied to collect traffic flow data along 20 main road routes in Bangkok. Distribution of the average vehicle travel speed from the whole 20 main road routes in Bangkok is shown in Fig. 1. Seven road routes which give a good agreement of the travel speeds distribution were selected. The details of these seven selected routes are as follows. Silom Rd., located in the downtown business center with high-rise office buildings, is selected to represent the highly congested traffic condition with average travel speeds of less than 10 km/h. Four roads leading to downtown areas, those are Petchaburi Rd., Sukhumvit Rd., Ladprao Rd. and Paholyothin Rd.; represent the congested traffic condition having an average speed range 10–20 km/h. On the other side of the city river, Jarunsanitwong Rd., which runs through several local markets, is selected to characterize the moderate traffic condition (average speed range 20–30 km/h). Wipawadee Rd., the only highway reaching the inner area of the city is chosen for representing the lightest traffic condition with average travel speeds of more than 30 km/h.

The speed-time data collection was carried out using a real time logging system equipped on a selected sedan traveling along the routes under actual traffic. The selected vehicle was a Toyota Corona of the year 1993, gasoline engine, manual transmission with capacity of 1.6 L. The instrumented vehicle was driven following the time schedule along those seven road routes. The speed-time

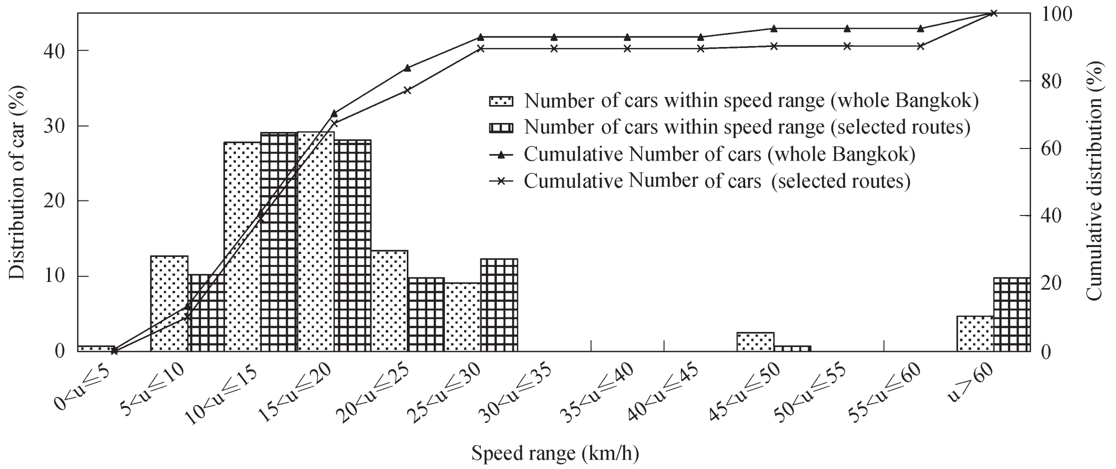

Fig. 1 Comparisons between vehicle travel speed distributions from the selected seven road routes and those from the whole 20 main road routes in Bangkok.

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data were collected during the morning peak period from 7:00 a.m. to 9:00 a.m. During this period, the high traffic volume beyond the handling capacity of the road system is frequently observed in Bangkok. Therefore, collecting speed-time data in the morning peak period would capture the driving conditions that have a large impact on exhaust emissions and fuel consumption. The data of each road route were collected twice on Mondays, Wednesdays and Saturdays to cover almost all of the driving patterns occurring in Bangkok during the week.

2.2 Bangkok target driving characteristics

The target driving parameters determined from the real driving data collected from the seven selected road routes are shown in Table 1. The average speed in Bangkok is equal to 17.4 km/h while the average running speed (when idle condition is excluded) is 28.1 km/h. The large difference is attributed to the large difference in the proportion of idling periods. The Bangkok driving characteristics show that the idle mode remains the highest proportion of 37.7% while the cruising condition is only 23.7%. Hence, the large proportions of idle, acceleration and deceleration moments (about 76% of the driving time) under this congested Bangkok traffic would cause severe impact on vehicle exhaust emissions and fuel consumption rates.

The result of target microtrip parameters of Bangkok is shown in Table 2. It is clearly seen from the number of microtrip distributed over the speed range (N_m,%) that about 70% of driving situations in Bangkok (excluding idle conditions) are the driving with low average speeds of less than 20 km/h, especially those with less than 10 km/h which account for 45.9%. For the total time span of microtrips spent in each speed interval (T_m,%), it is found that only 33.5% of driving time is spent at low speed intervals of less than 20 km/h. This indicates that although a large number of microtrips are at low speeds, the times spent in these microtrips are short. It can be concluded that the major driving patterns in Bangkok are the short trips with low speed used and frequent stop (idle speed) as a result of the traffic problems. The studies of Ericsson (2001) and Haan and Keller (2000) indicate 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 a car in Bangkok area under such traffic conditions would result in a substantial increase of emissions and fuel consumption.

2.3 Generated Bangkok driving cycle

The driving cycle construction and selection procedures described in Section 1.2.2 were applied to the on-road driving data collected from the seven selected road routes of Bangkok. The obtained driving parameters of BDC are best match to the target parameters as shown in Fig. 2. The cycle is 5.71 km in length, 1160 s in time duration and involves 14 intermediate stops. It can be seen in Tables 1 and 2 that its driving characteristics are found to be in good agreement with the Bangkok target driving parameters previously discussed in Section 2.2.

The comparison of the obtained BDC characteristics with those urban portions of the well known regulatory driving cycles, i.e., ECE, US-FTP75 and Japan 10-15 mode cycles are also shown in Tables 1 and 2 (Concawe, 1997). The EDC (consisting of both ECE and EUDC) regulatory driving cycle, which is currently used in Thailand as a legislative driving cycle, is also taken into the comparison. It reveals that the Bangkok cycle has the lowest average speed (V_{avg}) and exhibits the greatest idle time. For the value of PKE, the Bangkok cycle is found to give the highest value. It shows that the vehicles traveling in Bangkok would require more energy in acceleration than

Table 1 Comparisons of driving parameter of the generated BDC with the target values and those of other well known regulatory driving cycles

Driving cycle	Length (km)	Duration (s)	V_{avg} (km/h)	V_{1avg} (km/h)	$R_{AC\text{-}avg}$ (m/s^2)	$R_{DE\text{-}avg}$ (m/s^2)	Idle (%)	Cruise (%)	R_{AC} (%)	R_{DE} (%)	PKE (m/s^2)
Bangkok arget	–	–	17.4	28.1	0.71	–0.71	37.7	23.7	15.2	23.4	0.45
BDC	5.71	1160	17.7	28.8	0.67	–0.69	37.7	23.8	15.3	23.2	0.47
US-FTP75	17.77	1877	34.1	41.6	0.61	–0.71	18	20.4	33.1	28.5	0.35
Japan 10-15	4.2	660	22.7	32.7	0.57	–0.65	31.4	21.2	25.9	21.5	0.33
ECE	1.0	195	18.7	27.6	0.64	–0.75	30.7	32.3	18.5	18.5	0.29
EDC (ECE+EUDC)	10.9	1180	33.4	44.4	0.541	–0.789	23.7	42.2	18.3	15.8	0.224

BDC: Bangkok driving cycle; EDC: European driving cycle which combines ECE and EUDC; ECE: European urban driving cycle (also known as UDC or ECE15); EUDC: European extra urban driving cycle.

Table 2 Comparisons of microtrip parameter of the generated BDC with the target values and those of other well known regulatory driving cycles

Driving cycle	N_m (%)					T_m (%)				
	Average speed range					Average speed range				
	0–10) (km/h)	10–20 (km/h)	20–30 (km/h)	30–40 (km/h)	> 40 (km/h)	0–10 (km/h)	10–20 (km/h)	20–30 (km/h)	30–40 (km/h)	> 40 (km/h)
Bangkok target	45.9	25.4	14.7	8.9	5.1	12.2	21.3	22.8	21.4	22.2
BDC	42.9	21.4	14.3	14.3	7.1	9.3	23.6	10.3	28.3	28.6
US-FTP75	0	0	40.0	30.0	30.0	0	0	25.1	38.6	36.4
Japan10-15	0	42.9	42.9	0	14.2	0	18.8	46.4	0	34.8
ECE	0	33.3	33.3	33.3	0	0	12.1	34.8	53.1	0
EDC (ECE+EUDC)	0	30.8	30.8	30.8	7.6	0	7.2	20.7	31.6	40.5

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if they were driven in accordance with the other driving cycles. The higher average acceleration rate of BDC than those of other 4 cycles also indicates the more aggressive driving situations. For the microtrip characteristics, it is clearly seen that driving trip with low average speeds of less than 10 km/h occurs most frequently in BDC while these situations could not be observed in others. The proportions of high average speed microtrips ($V >$ 40 km/h) of the US-FTP75 and Japanese cycles are much higher than that of the Bangkok while it could not be observed in the ECE cycle. Despite a large number of microtrips occur at low speed ranges, the time period that the vehicle spends in these ranges is small. Hence, prominence of microtrips in the Bangkok cycle is the short trip with low speed used and frequent stop (idle speed). On overall consideration, it can be concluded that the traffic pattern in Bangkok is much more congested than that of the EDC cycle, which is presently the legislative cycle for testing vehicles in Thailand. Therefore the values of both emissions and fuel consumption obtained from the test of vehicles under this legislative cycle would tend to be underestimated comparing with those actually occur in real traffic in Bangkok.

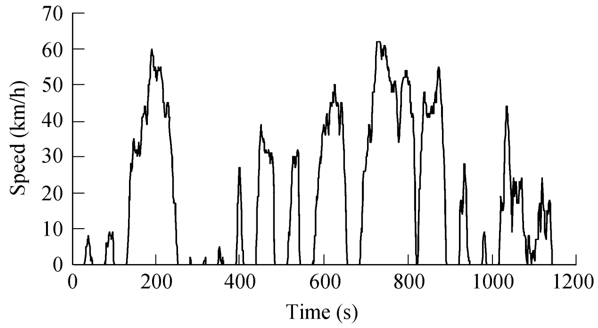

Fig. 2 Bangkok driving cycle (BDC).

2.4 Instantaneous emissions measurement results

The test vehicle, which was selected for the measurements of emissions and fuel consumption from the tests conducted on the standard chassis dynamometer described in Section 1.3, was Toyota Soluna of the year 2000, gasoline engine, and automatic transmission with capacity of 1.5 L and odometer reading of 48900 km. It was equipped with a three-way catalytic converter. Unleaded gasoline with octane number 95 was used as the vehicle fuel for all tests. In order to maintain consistency in comparisons, the fuel used was taken from the same petrol station. The tests were done under two driving cycles: one is the developed Bangkok driving cycle, and the other is EDC.

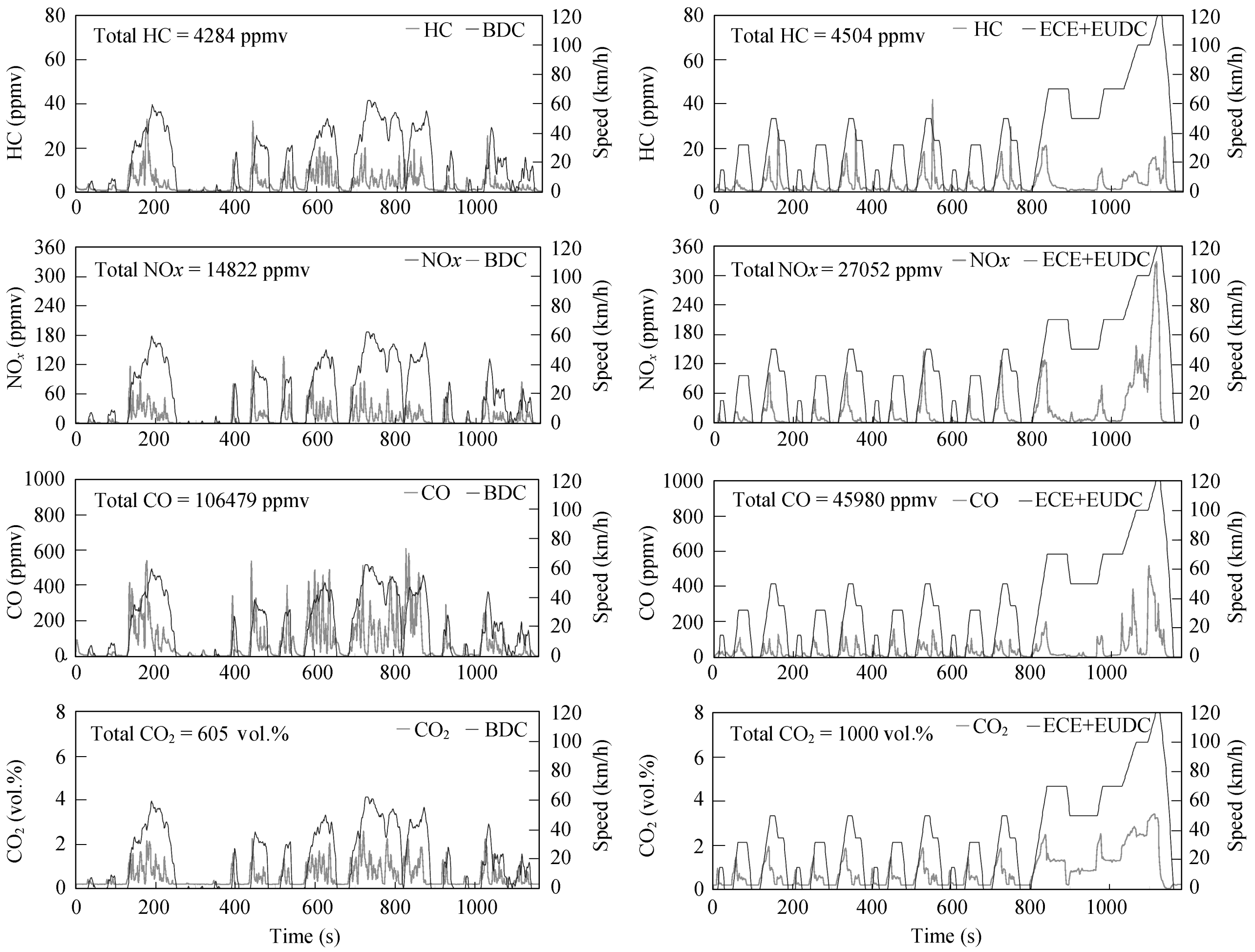

Fig. 3 Instantaneous exhaust emissions obtained from the test under BDC and EDC (ECE+EUDC).

The tests were conducted twice for each driving cycle for consistency.

The results of instantaneous exhaust emissions measured from the tests under BDC and the EDC (both ECE and EUDC) are shown in Fig. 3. It presents the instantaneous concentrations of HC, NO*x*, CO in ppmv and CO_2 in percent of volume (vol.%) emitted from the test vehicle with respect to the speed profile of the specified driving cycle. The total value of each emission integrated over the driving cycle is also indicated on each corresponding graph. It can be observed that the fluctuations of emissions occur due to the changes in vehicle speed. All the emissions appear to increase greatly and rapidly during vehicle accelerations and decrease sharply if sudden deceleration occurs. The emissions tend to drop gradually if the driving after any acceleration falls into cruising or idling condition. Very low emissions can be observed when the vehicle is running at cruise and at idle. This is because the engine when driving at constant speed can operate properly according to the design conditions. Hence, complete combustion can be expected and low polluted gases would be emitted. Furthermore, most engines with catalytic converters when operated at the desired level will produce fewer emissions during idle period.

2.5 Total emissions and fuel consumption under BDC and EDC cycles

The results of the total exhaust emissions and fuel consumption obtained from the experimental tests under the newly developed BDC and the EDC cycle (ECE+EUDC) are shown in Table 3. The values shown in the table are the averages from the two tests conducted for each driving cycle. To help explaining the effect of driving parameters on the obtained results, the measured values for two sub cycles of the EDC driving cycle, i.e., ECE and EUDC, are also separately illustrated. Note that the ECE sub cycle, which is the first part of the EDC cycle, contains low vehicle speed, low engine load and low exhaust gas temperature driving mode. On the contrary, the second sub cycle, which is called the extra urban driving cycle or EUDC, is added to represent the high vehicle speed-driving mode.

As shown in Table 3, three terms are determined from the measured values to describe vehicles emissions, those are: (1) the total emissions emitted for a cycle in unit of gram (g), (2) the emission rate in gram per total time of a cycle and (3) the emission factor in gram per cycle distance traveled. Fuel consumption exhibited is determined according to the carbon balance method and it is expressed in fuel consumed per 100 km traveled (l/100 km).

In terms of average emission rate, the results show that the value of HC varies slightly with average speed. A relatively small increase in emission rate of HC is seen in EUDC with an average speed 62.6 km/h when comparing to those of BDC and ECE with a significant low average speeds range 17–19 km/h. However, when the emission amount is considered based on the distance that the vehicle can travel or the so-called "emission factor" in g/km, there is a strong influence of the average speed on the emission factor of HC. It can be observed that the decrease in average speed of the cycle would result in the increment of emission factor of HC.

In general, CO polluted from vehicle equipped with a catalytic converter is sensitive to the acceleration variations (André and Pronello, 1996). The degree of fluctuations of the vehicle speed in the driving cycle hence would significantly influence the average emission rate of CO occurring during the cycle. With high degree of speed fluctuations prevailing in the BDC cycle, the CO emission rate is higher than those of the ECE, EUDC and EDC cycles, for which the driving at cruising mode is relatively more. The high emission rate of CO occurring in the EUDC cycle might be attributed to the extreme accelerations from low to high speed. However, when the cycle travel distance is concerned, the emission factor (g/km) of CO observed from the BDC cycle is much higher in comparisons with those of ECE, EUDC and the whole EDC cycles.

As for the NO*x* emissions, high temperature during combustion process results in increasing of NO*x* (USEPA, 1993). This high temperature can be caused from driving

Table 3 Total emissions and fuel consumption of the test vehicle under specified driving cycles

Emission	Driving cycle						
	Emission limit	BDC	ECE	EUDC	EDC (ECE + EUDC)	AUC[a]	US-FTP75[a]
HC							
Total emission (g)		0.77	0.50	0.31	0.82		
Emission rate (g/s)		0.00066	0.00065	0.00078	0.00069		
Emission factor (g/km)	0.20*	0.134	0.125	0.045	0.075	0.550	0.250
NO*x*							
Total emission (g)		3.18	1.66	3.86	5.52		
Emission rate (g/s)		0.00274	0.00212	0.00966	0.00467		
Emission factor (g/km)	0.15*	0.557	0.409	0.564	0.506	1.620	0.970
CO							
Total emission (g)		11.95	2.89	3.23	6.12		
Emission rate (g/s)		0.01030	0.00371	0.00808	0.00518		
Emission factor (g/km)	2.30*	2.093	0.714	0.470	0.561	8.560	2.980
CO_2							
Total emission (g)		1178.38	760.23	1066.73	1826.96		
Emission rate (g/s)		1.01584	0.97466	2.66682	1.54827		
Emission factor (g/km)		206.371	187.712	155.727	167.611		
Fuel consumption (l/100 km)		8.48	7.63	6.32	6.81	11.24	10.11

* Emission standard for new gasoline engine vehicle in Thailand level 7. [a] Watson, 1995.

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at high speed and extreme accelerating during driving period (Tong *et al*., 2000). The extreme acceleration occurs when the speed is suddenly changed from a low level to a significantly high level. From Fig. 3, it can be seen that the EUDC cycle, which is the last part of the driving pattern shown in each graph, contains a large portion of extreme accelerations at very high speed (V > 80 km/h). Therefore very high emission rate (g/s) of NOx under the EUDC cycle can be observed (Table 3). The lower NOx emission rate can be found in the tests under the ECE and BDC cycles as their average driving speeds are much lower than that of the EUDC cycle. However, when emission amount per travel distance is concerned, the NOx emission factor obtained from the EDC cycle is lower than that from BDC cycle. This is because the average speed of the EDC cycle is greater than that of the BDC cycle. Hence, for a given time period, the vehicle runs under the EDC cycle can travel much longer distance than it does under the BDC cycle.

The amount of CO_2 emitted from a motor vehicle is highly related to its fuel consumption rate; the more the fuel consumed, the more the CO_2 emitted. The fuel consumption rate increases with the increasing driving speed. It is clearly confirmed by the results of CO_2 emission rate analyzed for the ECE driving cycles (Table 3) that the EUDC cycle having a higher average speed of 62.6 km/h produces higher CO_2 emission rate than the ECE cycle, which has a lower average speed of 18.7 km/h. However, when the driving pattern of the cycle contains highly fluctuated driving speeds, such as the BDC cycle, higher value of CO_2 emission rate and its consequent fuel consumption rate are obtained despite it has a lower average driving speed than the ECE cycle. Similarly, when the cycle travel distance is taken into consideration, the cycle with low average vehicle speed and high variation of driving speed tends to have a high emission factor of CO_2. In the study, the BDC cycle that possesses such driving conditions produces the greatest emission factor of CO_2. The fuel consumption in terms of liters per 100 km distance travel is closely linked to the CO_2 emission factor. The higher the CO_2 emission factor, the higher the fuel consumption in l/km.

2.6 Emissions and fuel consumption comparisons

The relative increase in BDC cycle emissions and fuel consumption over the Thai currently used EDC cycle were investigated using the data in Table 3. Comparisons reveal that the emission factors of HC and CO of the BDC cycle are almost two and four times greater than those of EDC cycle respectively. For NOx emissions, although EDC cycle is suffered from the extreme accelerations at high speed driving which result in high emission rate of NOx, but because of its much less proportion of idle driving, the NOx emission factor is found smaller than that of BDC cycle by 10%. Under BDC cycle, the test vehicle needs 1.67 more liters of fuel (Table 3) or about 25% more to cover 100 km distance than it does under EDC cycle. All of these differences are mainly due to the greater proportion of idle periods and higher fluctuations of vehicle speed in BDC cycle.

Results of relative increase in Australian urban cycle (AUC) emissions and fuel consumption with the US-FTP75 cycle are also shown by Watson (1995). AUC cycle was developed using data collected from real driving in Melbourne traffic condition to replace the US-FTP75 cycle and later it became the Australian legislated cycle. Their relative differences are similar to those between BDC and EDC cycles. This indicates that higher level of emissions and fuel consumption can be measured and expected from the in-service driving cycles (BDC and AUC cycles) for urban or city areas than those from the legislated cycles (EDC and US-FTP75 cycles).

3 Conclusions

It has been found from the measurements on a test vehicle performed on a standard chassis dynamometer that the exhaust emissions and fuel consumption of the vehicle driving under BDC cycle are significantly different from those obtained from the driving under EDC cycle. The differences are resulted from the different patterns in driving. BDC consists of a series of microtrips with fluctuating speed profile collected from real driving in Bangkok traffic whereas EDC is a modal cycle with smooth acceleration and cruise profile. It can be concluded that the use of EDC as the legislative cycle for testing newly registered automobiles in Thailand may not produce realistic performance on exhaust emissions and fuel consumption of those vehicles traveling in urban areas. Therefore, careful consideration must be taken when adopting the values obtained from the tests using legislative cycle for purposes requiring realistic data of exhaust emissions and fuel consumption of vehicles in service, especially those running in cities with heavy traffic conditions. Examples of analyses requiring such information include the establishment of policy measures for controlling vehicle exhaust emissions, fuel saving and greenhouse gases emission mitigation. In these analyses, a more realistic driving cycle is needed, such as the BDC presented in this study, which is developed using the driving patterns collected from real on-road driving under prevailing traffic conditions.

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