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วิศวกรรมสารฉบับวิจัยและพัฒนา

วิศวกรรมสถานแห่งประเทศไทย ในพระบรมราชูปถัมภ์

สารบัญ

จัดพิมพ์โดย : วิศวกรรมสถานแห่งประเทศไทย ในพระบรมราชูปถัมภ์
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For the purpose of analysis it has been divided into three segments called Thonburi, Rama IV and Silom. We loosely call these "cycles". The normal term driving cycle refers to a statistically representative driving pattern which is an aggregate of many trips, rather than a single trip. In admitting that at least 20 hours driving would be desirable for the development of a representative test cycle, it is worth noting that the U.S. city cycle which has been the dominant standard for vehicle emissions system development was based on a single driver's record of about one-half hour's driving in Los Angeles(7).

5. RESULTS

5.1 Cycles and Statistics

Speed-time graphs of the cycles are displayed in fig. 3. The major parameters of each driving pattern are summarised in table 1.

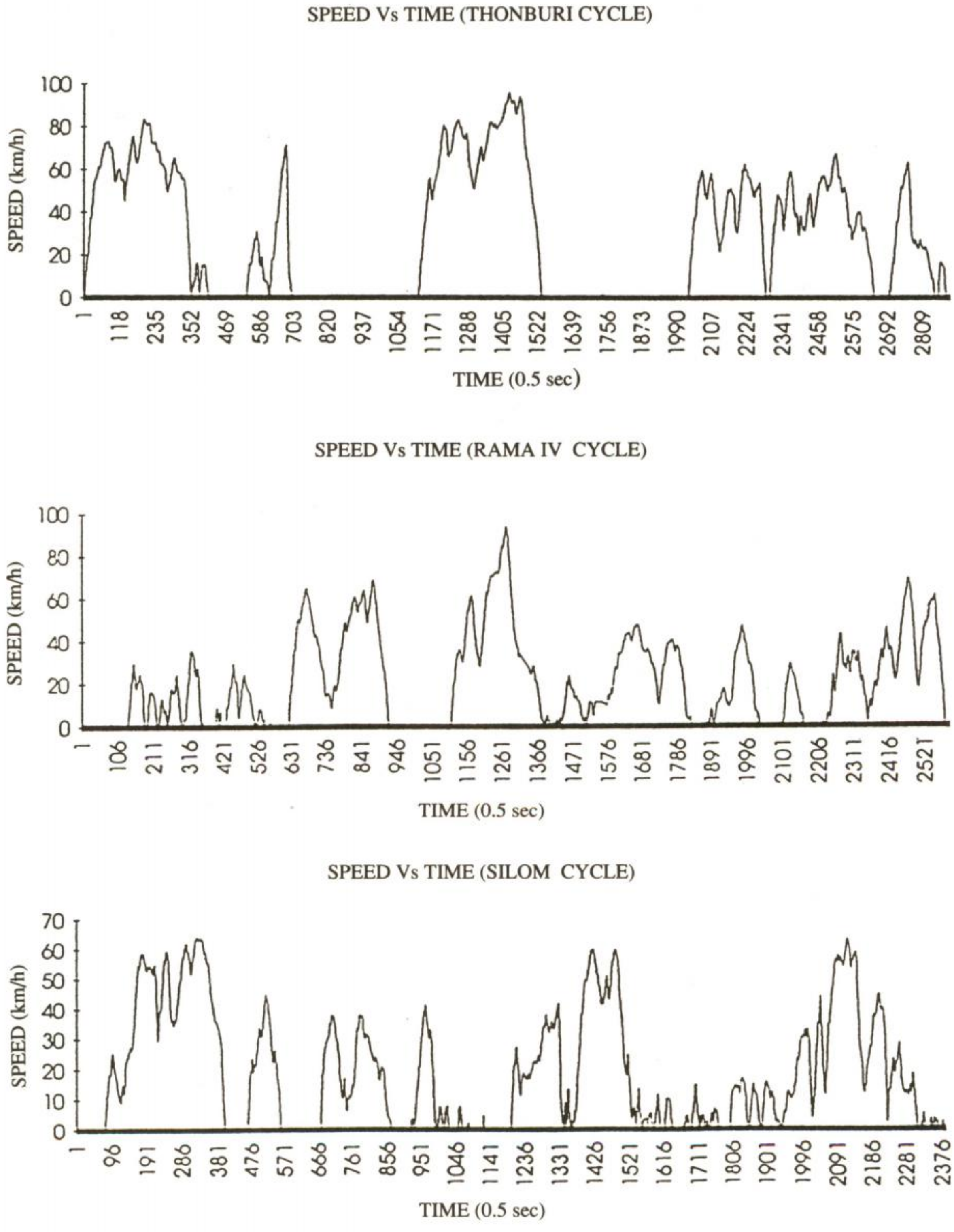


Figure 3 Speed time graphs for the three segments of the test route.

Table 1 Characteristic parameters of the driving pattern survey, preliminary Bangkok cycle and U.S. and Australian driving cycles.

Driving Cycle	TIME s	DIST m	IDLE %	STOPS/ km	Vmean km/h	Vrun km/h	Vmax km/h	PKE m/s2
THONBURI	1452	11619	39.2	0.86	28.8	40.1	96.4	0.49
RAMA IV	1313	7659	25.9	1.96	21.0	26.4	94.0	0.44
SILOM	1194	6195	26.7	4.52	18.7	23.7	63.6	0.55
BANGKOK	3915	25460	30.6	1.89	23.4	30.6	96.4	0.49
U.S.+	1172	11970	17.9	1.50	31.4	37.0	91.2	0.35
AUSTRALIAN*	1020	10710	17.8	0.93	37.8	44.5	107.5	0.56

+ BASED ON LOS ANGELES
** BASED ON SYDNEY, MELBOURNE AND BRISBANE*

These include the proportion of the total trip time whilst stopped (idle %), the stopping frequency per unit distance travelled, the mean speed (Vmean), the mean speed whilst not stopped (Vrun) and the maximum speed (Vmax) and a measure of acceleration energy requirement PKE, given by:

$$PKE = \left(\sum (V_f^2 - V_i^2)_{a>o}\right)/Dist$$

where V_f is the final speed and Vj is the initial speed in acceleration manoeuvres which form part of a trip or microtrip of distance Dist.

Those familiar with Bangkok traffic would not be surprised to note that the Thonburi cycle had 40% idle time although when the traffic moved the top speed was high at nearly 100 km/h. Whilst the vehicle was actually moving, the running speed was similar to that of U.S. and Australian conditions. The lowest average speed was found in the Silom cycle, with the maximum speed also the lowest.

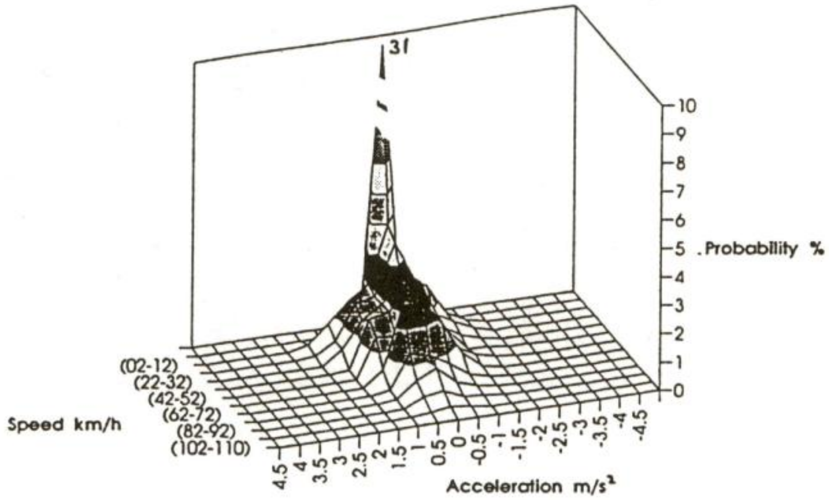
When aggregated to form a single preliminary Bangkok cycle and compared with U.S. (Los Angeles) and Australian driving, we can note that the stop (idle) time is almost twice as large. Other indicators of congestion are that the running speeds are lower although the acceleration energy term (PKE) is nearly the same as that for Australian cities(5) where the vehicles are typically more powerful than the test vehicle. This supports the observation that drivers use "foot to the floor" (maximum acceleration rates) frequently.

5.2 Frequency-VAPDFs

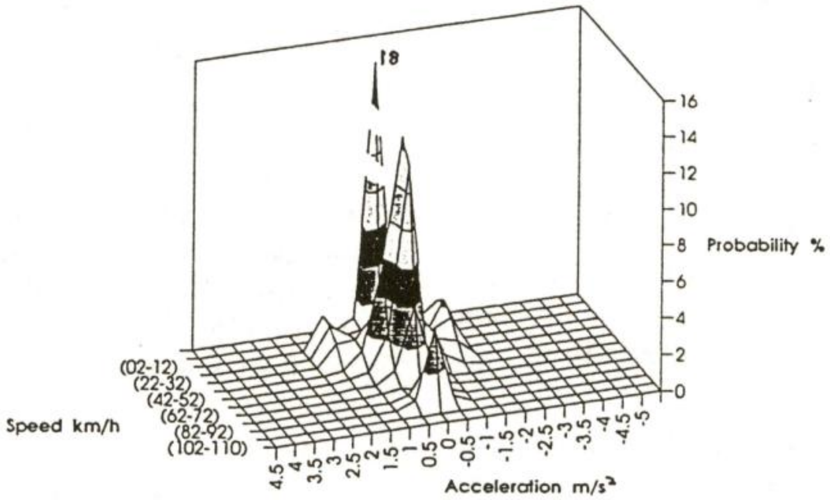
Watson and Milkins(6) for many years has represented driving cycles as bivariate frequency distributions called velocity-acceleration probability density functions (VAPDFs). Fig. 4 allows comparison of the composite VAPDF for Bangkok with U.S. and Australian city driving. The numerical frequency values are to be found in the Appendix.

The VAPDF for Bangkok identifies the absence of cruising conditions (i.e. at zero acceleration) that lower the PKE. In the U.S. there are two peaks associated with cruising close to the 30 mi/h and 55 mi/h speed limits and, although less pronounced, peaks exist in the AUC at 60 and 100 km/h corresponding with speed limits. The peaks of the U.S. cycle VAPDF, in the positive and negative accelerations, are results of data manipulation that took place to avoid wheel slip in testing cars on the 1970's vehicle testing dynamometers (8), and thus should be ignored. We can note that the accelerations in the Bangkok cycle are not as high as those of the AUC. This is thought to be an artefact of the commercial vehicle, used for the test program, which had limited acceleration capability. In most real world driving, accelerations of up to 3.5 m/s^2 are measured (8).

SPEED & ACCELERATION PROBABILITY DISTRIBUTION OF BANGKOK CYCLE



SPEED & ACCELERATION PROBABILITY DISTRIBUTION OF U.S. 72 FTP. CITY CYCLE



SPEED & ACCELERATION PROBABILITY DISTRIBUTION OF

AUSTRALIAN URBAN COLD START CYCLE

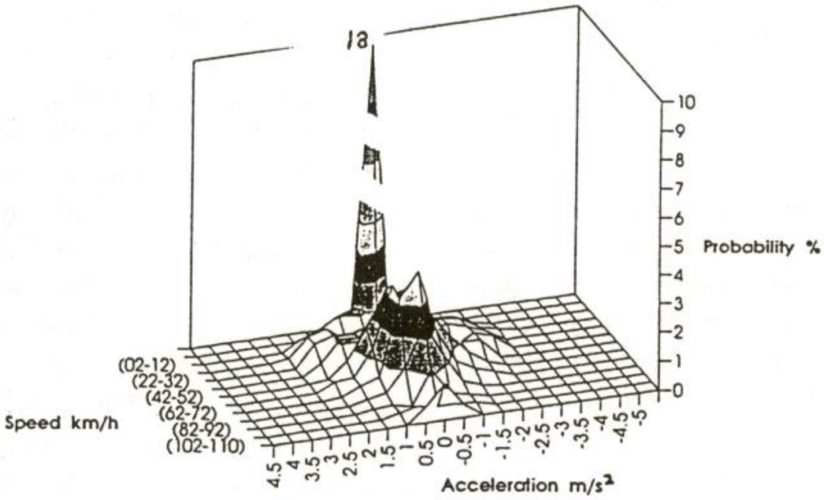


Figure 4 VAPDFs for driving in Bangkok, Los Angeles and Australian cities.

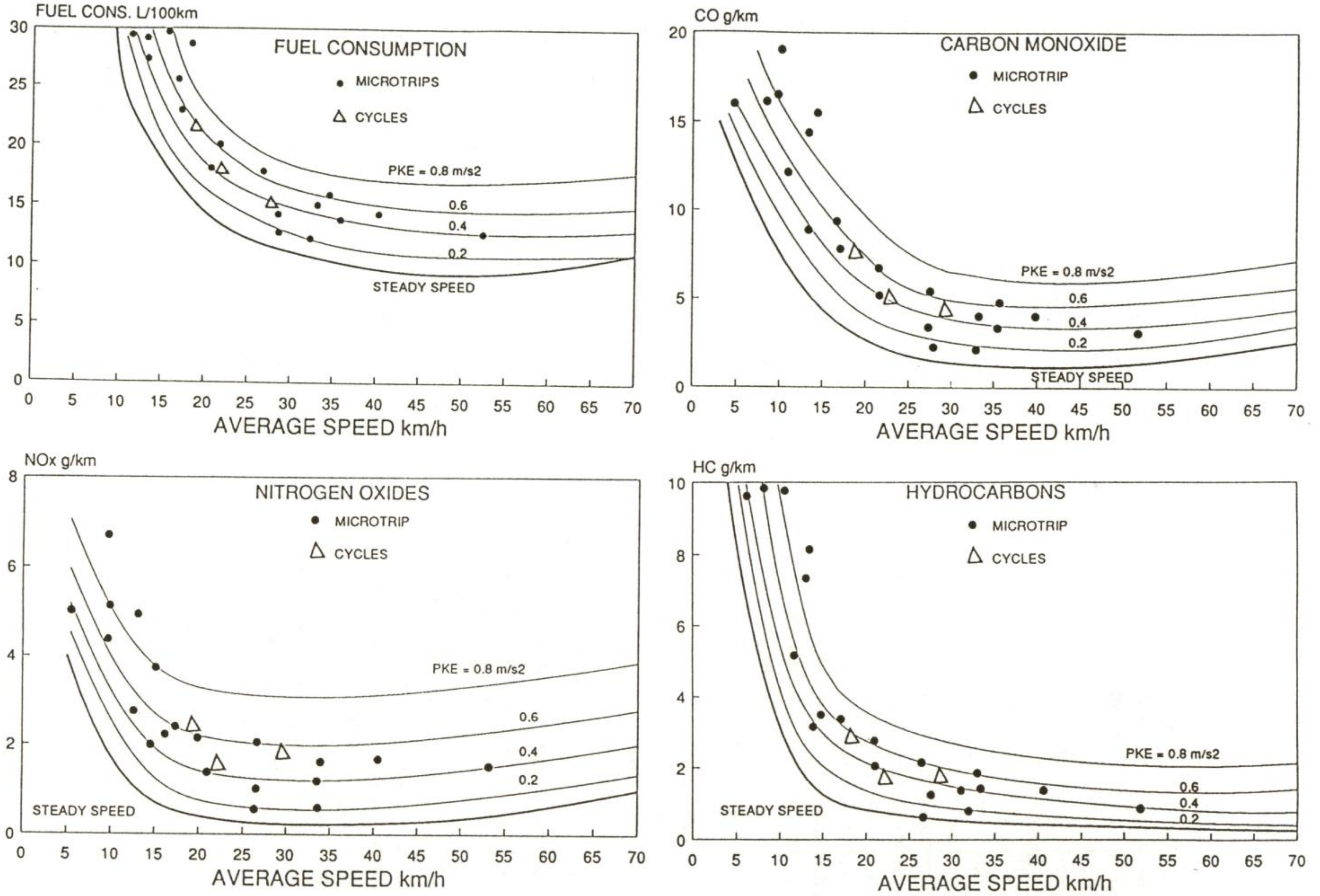


Figure 5 Warmed up fuel consumption and emissions representative of pre-catalyst vehicles but with some emission controls, estimated to be representative of Bangkok vehicles of the middle to late'80s.

6. ENERGY AND EMISSIONS

6.1 Non-Catalyst Vehicles

As identified elsewhere(10) there are a range of methods that can be applied to predict fuel consumption and emissions. The single equation speed-PKE models were initiated in the late û70s and early '80s (9, 10) and have recently been revisited in a review of predictive methods that can be applied in to find ways of reducing greenhouse gas emissions from traffic(11). These methods have also been applied to reanalyse earlier data(12) from vehicles with moderate levels of emission control as well as the latest data for vehicles with 3-way catalyst technology(1 1). On the basis that a significant number of vehicles produced in Japan, or to Japanese designs, are found in the markets of Australia and Thailand, it is reasonable to expect that emissions rates will be similar. Even if the magnitudes do differ, the trends with speed and PKE changes are unlikely to be significantly affected for a given type of emission control technology, thus allowing the plotting of the driving pattern speed and PKE as points on the emission graphs.

Fig. 5 shows the microtrips (one stop to the next stop for at least 1 00s of time) of the three driving cycles plotted on graphs for fuel consumption, HC, CO and NOx emissions for vehicles with intermediate level of emission control. These controls approximate the emissions performance equivalent to U.S. 1973 or ECE 1986 legislation. Also shown are the values for the microtrips aggregated into the three cycles. In all emissions or fuel examples, the significant increase in emissions from slow speed driving is obvious. Slow speed trips compounded with high accelerations (high PKE) lead to even worse emissions and fuel use. The corollary is that improving driving and traffic conditions to a PKE of about $0.2m/s^2$ and average speeds of 35 km/h, would reduce emissions by at least one half and fuel consumption by one third.

6.2 Catalyst Vehicles

The recent analysis of the emissions performance of a fleet of three-way catalyst cars' emissions, over microtrips found in several test cycles, has led to the production of the graphs that form the basis of fig 6(11). The work excluded the analysis of the CO data, although given resources the data exist and a CO family of graphs could be produced. The reason for excluding CO analysis is that ambient CO levels in Australian cities have been well below WHO standards of concern for many years.

The U.S. city cycle results comprise three bags of gas in the normal test method. Since only hot start results are reported here, the two hot bags for the hottransient phase of 866s duration (H866) and the hot-stabilised phase (H505) of 505s duration are shown as well as the composite city driving. In addition to the AUC, the Melbourne peak hours cycle(6)MPC is also given. The fuel consumption of these vehicles in Bangkok driving is seen to be clearly higher than that for driving in the U.S. or Australia - by more than a factor of 2 over the smooth driving of H866. Improvements in overall fuel consumption from the earlier vehicles are noted of about 20% consequent on the efficiency improvements associated with electronic engine management systems etc.

The HC emissions in fig. 6 are generally about 80% less than those found in fig 5 and the NOx are about 60% less. One might also ex[ect improvements of CO of this order. If the PKE could be improved from Silom driving to H866 driving a 50% reduction in HC and NOx emission might be achieved without any increase in travel speeds. This means that drivers would need to accelerate more smoothly and to lower cruising speeds in comgested driving conditions.

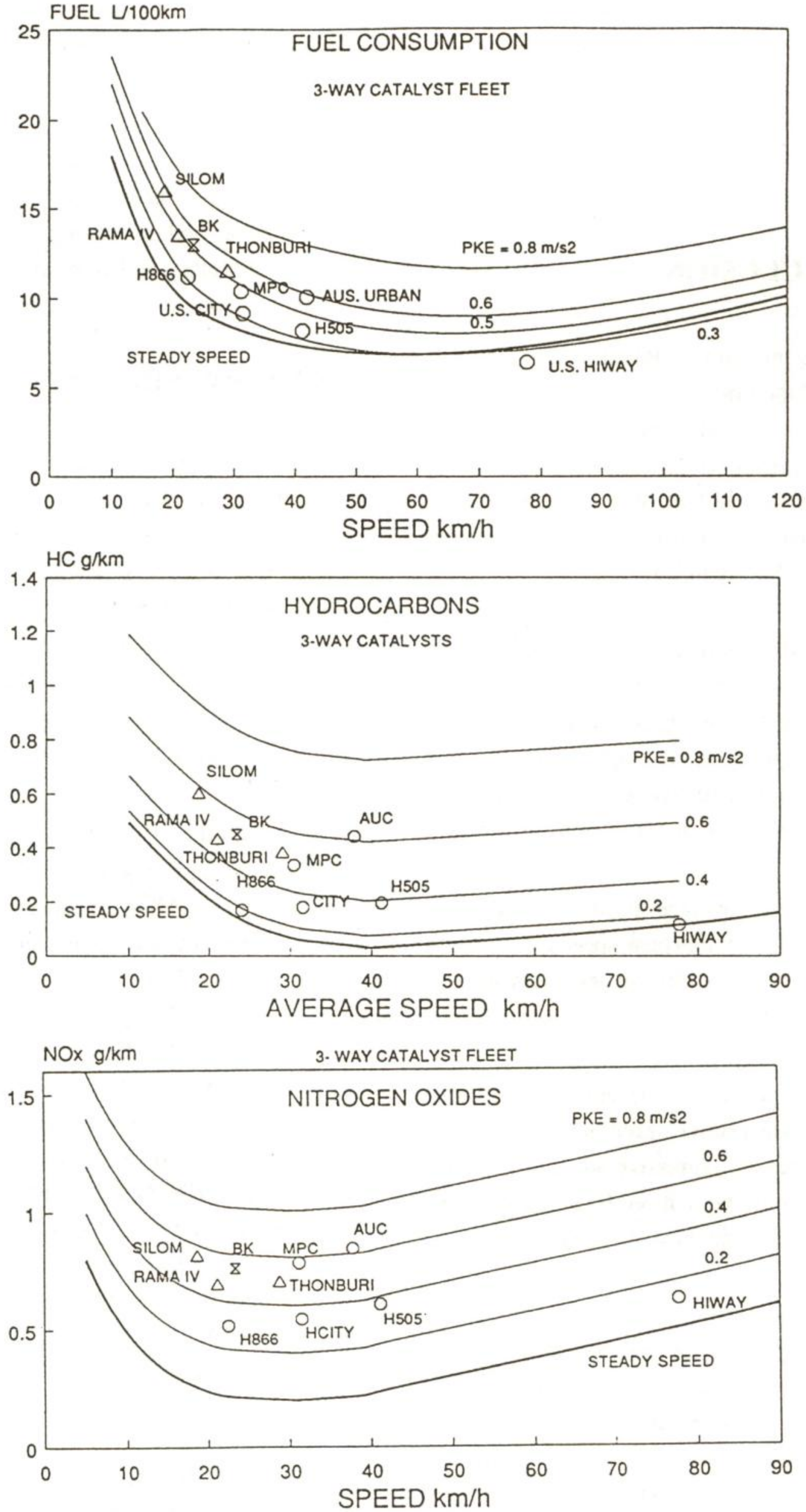


Figure 6 Hot start emissions from 3- way catalyst (unleaded petrol cars) indicating the location of driving cycles for Bangkok areas and other cities.

It should be noted that the results in figs. 5 and 6 are for fully warmed up passenger cars and derivatives. When cold started, the cars' emission levels are several times higher than those of fig. 6 until the exhaust catalyst is hot enough to be active.

7. CONCLUSIONS

The preliminary Bangkok cycle reported was developed from measuring driving patterns on one day. Although a larger data base would be desirable it is noted that the U.S. city cycle, which is the dominat standard cycle for vehicle testing, was based on a single drive's record of about one-half hours' driving in Los Angeles.

The driving patterns exhibit some characteristics of large cities elsewhere in the world, but the idle time is much greater than in those with well developed road systems such as Los Angeles, Melbourne and Sydney and consequently travel speeds are less and stopping more frequent.

The lower average speed of Bangkok driving, coupled with high peak speeds, gives higher PKE, leading to significant increases in emissions and fuel use.

From the results presented it can be deduced that irrespective of old or new vehicles, if drivers were less aggressive when accelerating, emissions could be reduced by at least one half and fuel use by one third. A challenge for driver education.

If the traffic flow can be co-ordinated to achieve higher average speeds, without increasing maximum speeds, it would be possible to reduce pollution to about one third of its present level and fuel consumption by one half. The social benefits from the improved driving and air quality have not been costed here but must be so significant that these problems should be tackled in the near future.

Plainly, more driving pattern analysis can assist in identifying regional variations in emissions sources and the driving styles that need to be emulated along with infra structure changes in a joint attack on the problem.

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APPENDIX

Frequency Tables for the VAPDF's Found in Figure 4

BANGKOK CYCLE

Accn. m/s^2	Vel. km/h	(00-02)	(02-12)	(12-22)	(22-32)	(32-42)	(42-52)	(52-62)	(62-72)	(72-82)	(82-92)	(92-102)	102-110	Accl. DBN
-4.5		0	0	0.0133	0	0.01	0.01	0	0	0	0	0	0	0.0333
-4		0	0	0	0.0133	0.01	0	0.01	0	0	0	0	0	0.0333
-3.5		0	0	0	0.01	0	0	0	0.01	0	0	0	0	0.02
-3		0	0	0.0467	0	0.0433	0	0	0	0	0	0	0	0.09
-2.5		0	0.0367	0.01	0.0133	0.0333	0.0233	0	0	0	0	0	0	0.1167
-2		0	0.1833	0.2033	0.1367	0.1367	0.11	0.0133	0.01	0	0	0	0	0.7933
-1.5		0	0.5367	0.52	0.3467	0.1633	0.2733	0.15	0.08	0.05	0.0267	0	0	2.1467
-1		0.1833	1.6567	0.9367	0.7967	0.9033	0.6233	0.7167	0.2467	0.1467	0.0967	0	0	6.3067
-0.5		0.9333	2.0733	2.3567	2.3867	2.1133	1.3267	1.82	0.7433	0.3633	0.1367	0.1067	0	14.36
0		30.57	3.9567	3.64	2.4933	2.7633	1.5067	2.75	1.1167	0.9767	0.4433	0.1733	0	50.39
0.5		0.8767	1.9933	1.8633	1.8667	1.89	1.31	2.8033	1.31	0.6233	0.3367	0.0733	0	14.947
1		0.22	1.5133	1.6967	1.3967	1.7367	1.3933	0.54	0.0967	0.0733	0.0133	0.01	0	8.69
1.5		0.0133	0.79	0.48	0.4833	0.06	0	0	0	0	0	0	0	1.8267
2		0	0.1667	0.0733	0	0	0	0	0	0	0	0	0	0.24
2.5		0	0	0	0	0	0	0	0	0	0	0	0	0
3		0	0	0	0	0	0	0	0	0	0	0	0	0
3.5		0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0
4.5		0	0	0	0	0	0	0	0	0	0	0	0	0
Vel DBN		32.797	12.907	11.84	9.9433	9.8633	6.5767	8.8033	3.6133	2.2333	1.0533	0.3633	0	99.993

U.S. 72 FTP CITY CYCLE

Accl. m/s^2	Vel. km/h	(00-02)	(02-12)	(12-22)	(22-32)	(32-42)	(42-52)	(52-62)	(62-72)	(72-82)	(82-92)	(92-102)	102-110	Accl. DBN
-5		0	0	0	0	0	0	0	0	0	0	0	0	0
-4.5		0	0	0	0	0	0	0	0	0	0	0	0	0
-4		0	0	0	0	0	0	0	0	0	0	0	0	0
-3.5		0	0	0	0	0	0	0	0	0	0	0	0	0
-3		0	0	0	0	0	0	0	0	0	0	0	0	0
-2.5		0	0	0	0	0	0	0	0	0	0	0	0	0
-2		0	0	0	0	0	0	0	0	0	0	0	0	0
-1.5		0	1.75	2.26	1.67	0.87	0.14	0	0	0	0	0	0	6.71
-1		0.43	0.87	0.36	1.16	1.16	0.72	0.07	0.07	0	0	0	0	4.89
-0.5		0.87	0.36	0.36	1.02	2.55	1.31	0.65	0.29	0.36	0.43	0	0	8.24
0		17.79	0.14	1.24	2.18	12.61	11.45	4.08	0	1.82	4.23	0	0	55.58
0.5		0.94	0.72	0.29	2.62	5.47	2.33	0.72	0.21	0.29	0.43	0	0	14.08
1		0.43	0.58	1.09	1.24	1.09	0.36	0.07	0.07	0	0	0	0	4.96
1.5		0	1.82	1.67	1.16	0.14	0.14	0.07	0	0	0	0	0	5.03
2		0	0	0	0	0	0	0	0	0	0	0	0	0
2.5		0	0	0	0	0	0	0	0	0	0	0	0	0
3		0	0	0	0	0	0	0	0	0	0	0	0	0
3.5		0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0
4.5		0	0	0	0	0	0	0	0	0	0	0	0	0
VEL DBN		20.46	13.51	7.27	11.05	23.89	16.45	5.66	0.64	2.47	5.09	0	0	100

AUSTRALIAN URBAN COLD START CYCLE

Accl. m/s^2	Velocity km/h	(00-02)	(02-12)	(12-22)	(22-32)	(32-42)	(42-52)	(52-62)	(62-72)	(72-82)	(82-92)	(92-102)	102-110	Accl. DBN
-5		0	0	0	0	0	0	0	0	0	0	0	0	0
-4.5		0	0	0	0	0	0	0	0	0	0	0	0	0
-4		0	0	0	0	0	0	0	0	0	0	0	0	0
-3.5		0	0	0	0	0	0	0	0	0	0	0	0	
-3		0	0	0.1	0	0	0	0	0	0	0	0	0	0.1
-2.5		0	0.15	0.25	0.39	0.49	0.05	0.05	0	0	0	0	0	1.37
-2		0	0.44	0.64	0.64	0.69	0.74	0.25	0.2	0	0	0	0	3.58
-1.5		0.05	0.49	0.74	0.83	0.29	0.74	0.69	0.39	0.1	0	0	0	4.31
-1		0.2	0.78	0.29	0.69	0.59	0.64	1.37	0.74	0.34	0.15	0.15	0	5.93
-0.5		0.69	1.03	0.78	0.64	2.6	2.25	2.25	1.86	1.32	0.29	0.2	0.44	14.36
0		17.99	0.78	1.37	0.83	2.5	2.21	2.11	4.07	2.45	1.18	0.2	1.27	36.96
0.5		0.93	1.18	0.69	1.18	2.16	2.94	3.38	3.14	1.08	0	0.29	0.54	17.5
1		0.1	1.03	0.49	0.98	1.08	1.67	1.27	0.54	0.29	0.15	0.15	0	7.75
1.5		0	0.64	0.93	0.98	1.13	0.64	0.34	0.34	0.15	0.1	0	0	5.25
2		0	0.39	0.74	0.78	0.39	0.1	0.29	0.05	0	0	0	0	2.75
2.5		0	0	0.1	0	0	0.05	0	0	0	0	0	0	0.15
3		0	0	0	0	0	0	0	0	0	0	0	0	0
3.5		0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0
4.5		0	0	0	0	0	0	0	0	0	0	0	0	0
VEL DBN		19.95	6.91	7.11	7.94	11.91	12.01	12.01	11.32	5.74	1.86	0.98	2.25	100