ASSESSING THE PERFORMANCE OF MODERN POLLUTANT EMISSION ABATEMENT SYSTEMS ON MOTORBIKES

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ABSTRACT

The present statutory pollutant emission limits Euro-3 for motorbikes implicates the use of modern emission abatement systems such as three-way catalytic converters. Determining the quality of implementation of these new systems in different driving situations such as real-world driving is important, since motorbikes are commonly used for personal transportation in urban areas. For this reason, a test bench series was carried out with a sample of 10 motorbikes of state-of-the-art certification category Euro-3. Emission factors of regulated pollutants and CO_2 are presented on the basis of the statutory driving cycle, the latest version of the real-world World Harmonized Motorbike Test Cycle (WMTC) and the real-world Common Artemis Driving Cycle (CADC).

It can be stated that 7 out of 10 motorbikes fail to comply with the statutory emission limits. The results of both real-world driving cycles confirm remarkable traffic situation dependent emissions of HC in urban and NO_x in motorway driving conditions. CO emissions of motorbikes with small displacement increase significantly in the urban and extra-urban cycle sections of the CADC cycle, which has a more dynamic velocity profile than the respective WMTC cycle. Although pollutant emissions of motorbikes show a marked improvement compared with earlier certification classes, they clearly exceed the emission levels of modern light gasoline passenger cars, especially for CO and HC.

Keywords: *Motorbike, pollutant, emission, real-world.*

1. INTRODUCTION

The latest tightening of statutory pollutant emission limits for motorbikes has led to the implementation of modern pollutant emission abatement systems in vehicles set into traffic within the present certification category Euro-3. This has become necessary for the first time, since previous certification directives were still achievable with classic technologies such as two-stroke engines and carburetors, resulting in poor in-use emission performance (Tsai et al., 2000), especially compared with passenger cars (Vasic et al., 2006). The relevance of this measure is evident when taking into account that motorbikes represent a common and widely used form of personal transportation in urban areas in present (Yannis, 2007) and in future, especially in emerging countries (Singh, 2006), and as such have a substantial environmental impact (Borken, 2007, Nziachristos, 2006). Investigating the quality of implementation of these pollutant emission abatement systems in different driving situations such as real-world driving cycles is thus of great interest.

Consequently an experimental investigation focusing on these issues was carried out on the basis of roller test bench measurements. A sample of 10 motorbikes of state-of-the-art certification category Euro-3 was selected, reflecting the Swiss vehicle fleet distribution. The emission performance of these vehicles was determined in the statutory driving cycle for Europe and in two different real-world driving cycles: the World Harmonized Motorbike Test Cycle (WMTC) and the Common Artemis Driving Cycle (CADC). Both these cycles are based on real-world driving behavior studies. Representative vehicle emission factors for the individual vehicles were derived for the different driving patterns reproduced in the individual cycles in order to reflect their real-world emission behavior.

2. EXPERIMENTAL PROGRAM

The main characteristics of the motorbike vehicle sample employed in the test series are summarized in ***Table 1***. The in-use vehicles were selected from private customers in order to reflect the Swiss fleet distribution with regard to mass, displacement and power at the time of the investigation. The selected vehicles were not serviced before the test runs. Note that both the displacement and the rated power of the individual vehicles are rather high and their mileage is fairly low.

Table 1: Main characteristics of the employed motorbike vehicle sample. displ.: displacement, reg.: registration, cert.: certification, m: manual, aut: automatic

	make	model	empty mass	displ.	power	gearbox	1^{st} reg.	mileage	cert. class	WMTC class
	[-]	[-]	[kg]	[cm$^{\wedge 3}$]	[kW]	[-]	[mmm jj]	[km]	[-]	[-]
B3-01	Suzuki	GSX R 1000	283	999	136.1	m6	Feb 07	2064	Euro-3	3-2
B3-02	Honda	SH 125	134	125	10.1	aut	May 05	17615	Euro-3	2-1
B3-03	Kawasaki	ER-6N	277	649	53	m6	Mar 06	15133	Euro-3	3-2
B3-04	BMW	R 1200 GS	300	1170	74	m6	Apr 06	23665	Euro-3	3-2
B3-05	Suzuki	GSX R 750	268	750	110	m6	Jul 06	7982	Euro-3	3-2
B3-06	Honda	CBR600RR	259	599	88	m6	Apr 07	10947	Euro-3	3-2
B3-07	Yamaha	FZ1	289	998	110	m6	Apr 06	26225	Euro-3	3-2
B3-08	Piaggio	X8	249	244	16	aut	Mar 06	9447	Euro-3	2-2
B3-09	Harley Davidson	FXDC	385	1584	56	m6	Mar 07	6448	Euro-3	3-2
B3-10	Piaggio	VESPA LX 125	190	124	7.65	aut	Jun 07	3306	Euro-3	1

Several driving cycles were employed in the test series in order to determine the emission behavior of the individual motorbikes. The statutory cold start driving cycle for Europe (European Council Directive 97/24/EC) was included as well as two real-world driving cycles: the latest version 9 of the World Harmonized Motorbike Test Cycle (WMTC) and the Common Artemis Driving Cycle (CADC). The cold start WMTC cycle is based on a large number of studies of real-world motorbike driving and further adapted to test bench operation (ECE/TRANS/180/Add. 2/Appendix 1/Rev 1). The final version is under development and is intended for international use for statutory purposes in future. The warm start CADC cycle was derived from car driving behavior studies within the ARTEMIS research program and represents European real-world driving behavior for cars (André, 2004).

The cycle sections representing urban, rural and motorway driving – section 1 to 3 respectively - and the velocity profile of the WMTC cycle applied for an individual motorbike are set according to a vehicle-specific classification based on the displacement of the engine and the maximum speed of the motorbike, see also Table 1. Furthermore, a gearshift calculation procedure based on the power-to-mass ratio of the individual motorbike determines its individual gear shift points to be used for the velocity profile in the WMTC cycle (ECE/TRANS/180/Add. 2/Appendix 1/Rev 1). The selection of the cycle sections and the calculation method for determining the individual gear shift points have also been applied to the real-world cycle CADC. Note that there are no prescribed vehicle-specific gearshift points for certification measurements in the case of the statutory cycle for Europe, but only defined margins for gearshifts, see Council Directive 97/24/EC. However, a compatible, speed-dependent gearshift strategy was used for the present test series for the sake of comparability of the measurement data obtained, in which up and down gear shifts were executed at 20 km h^{-1}, 35 km h^{-1}, 50 km h^{-1}, 70 km h^{-1} and 100 km h^{-1} respectively.

The roller test bench and its settings were applied according to the stipulations of Council Directive 97/24/EC. The inertia settings were chosen according to the given flywheel class and the ambient conditions of the test bench were set to 23°C temperature and 50% relative air humidity. All vehicles were operated with the same standard fuel with low sulfur content.

The exhaust was sampled with a Constant Volume Sampling (CVS) system, see ***Figure 1***. Open dilution of the exhaust was applied owing to the rather low exhaust volume flow of small displacement motorbikes with the aim of avoiding possible engine assistance by low-pressure conditions at the tailpipe. The diluted exhaust was measured online and according to the statutory procedure of storing a sample of diluted exhaust in a tedlar bag and analyzing its content offline after completion of the test run. The online signal traces were corrected with respect to time and mixing delay due to the length of the sample lines and the measuring delay time of the analyzers by applying a specifically developed methodology (Ajtay, 2006). Regulated pollutants were detected using standard vehicle exhaust analyzers as specified by Council Directive 97/24/EC.

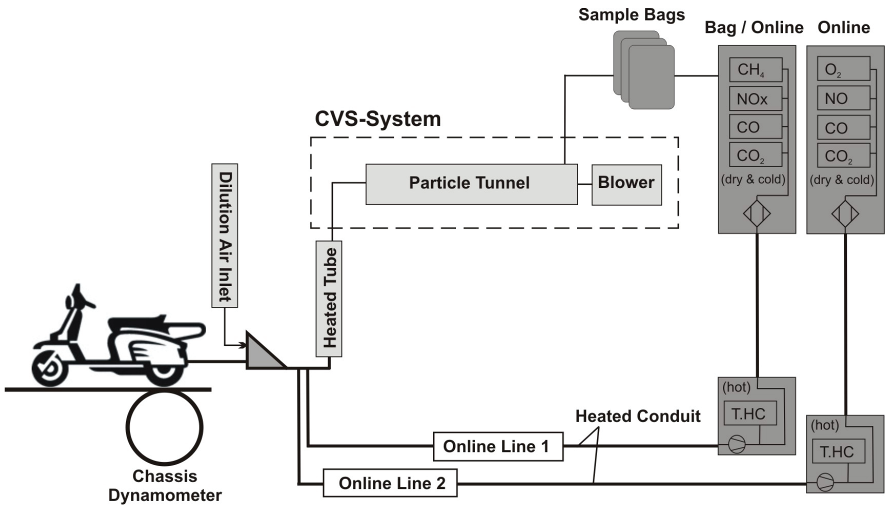

Figure 1: Schematic diagram of the test setup

3. RESULTS

Figure 2 shows the emission performance of the regulated pollutants and CO_2 of the individual motorbikes in the statutory cycle together with the respective vehicle class averages. Only three out of ten motorbikes fulfil the emission limits for all regulated pollutants. Small displacement motorbikes show increased emissions of CO that are attributable not only to the initial catalytic converter light-off, but also to incomplete combustion at high engine speeds that are no longer compensated by the catalytic converter. Note that motorbike B3-10 is not equipped with a lambda sensor upstream of the catalytic converter and uses an electric carburetor for the fuel-mixture generation. A rich air fuel mixture is thus supposed to be often provided to the combustion process of this vehicle which accounts for the very high emissions of CO observed combined with the low emission level of NO_x.

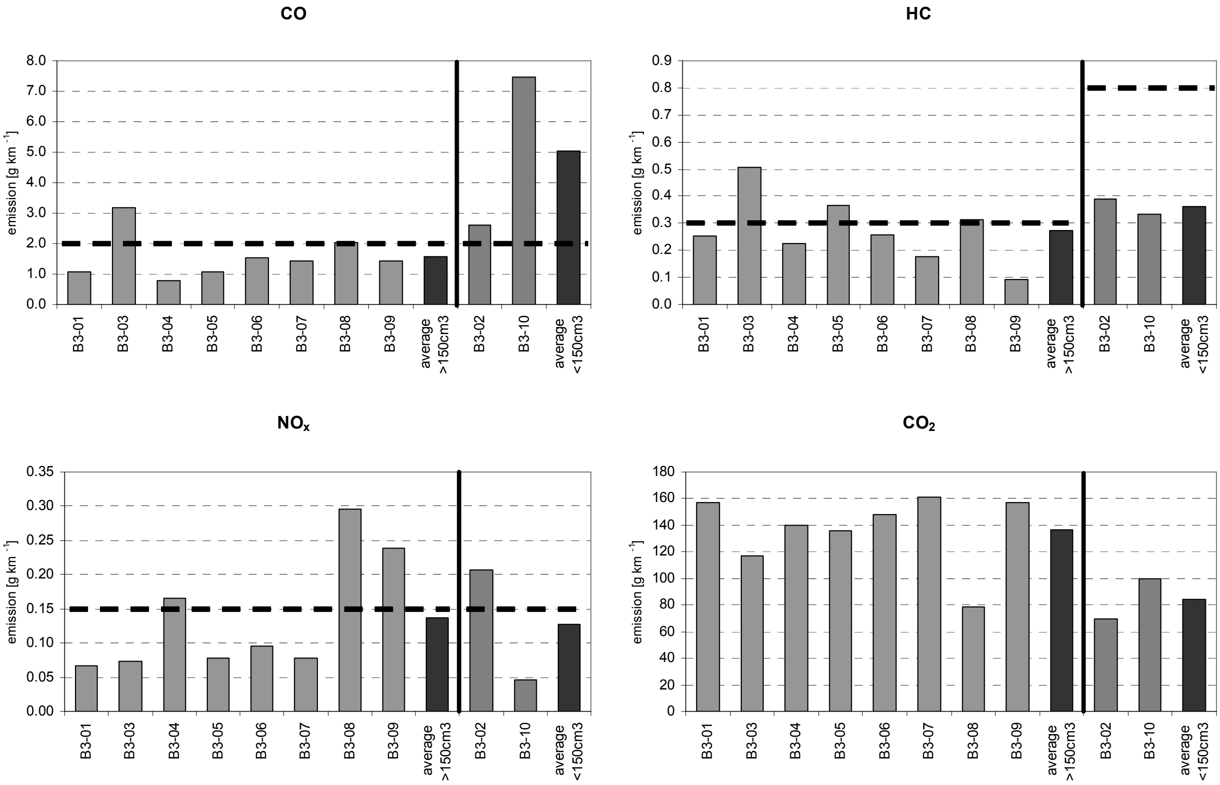

Figure 2: Emissions of regulated pollutants and CO_2 of the individual motorbikes in the statutory cycle together with the vehicle class averages. Dashed lines indicate the respective limit value

The motorbikes with large displacement generally remain within their respective CO emission limits, but show some disadvantages with regard to HC emissions. In this case it can be stated that peak HC emissions occur in most overrun fuel cut-off situations. It seems that the fuel management system and the capacity of the catalytic converter have not been designed adequately in these cases. Besides, the driving phase before catalytic converter light-off also contributes to higher HC emissions. By contrast, NO_x emissions arise at higher loads due to increased combustion temperatures that also result in exceeding of the emission limit for some motorbikes. In this case, the residence time of the exhaust in the catalytic converter may also be too short.

Figure 3 shows the emission performance of regulated pollutants and CO_2 of the individual motorbikes in the real-world cold start WMTC cycle. The vehicles are grouped according to the respective WMTC vehicle classification given in ***Table 1***. Pronounced pollutant emission levels of CO and HC occur in cycle section 1, which features an urban-like driving profile with cold start. NO_x emissions increase considerably in section 3 of the cycle, reflecting motorway driving conditions. The same observations can be made in general for the emission performance of the motorbikes in the warm start CADC cycle, see ***Figure 4***. The only difference there is the already moderate CO and HC emissions in the first cycle section, as the cycle is started with warm engine. But CO emissions of motorbikes with small displacement increase substantially in the urban and rural cycle sections of the CADC cycle, which is attributable to the more dynamic velocity profile compared with the respective WMTC cycle.

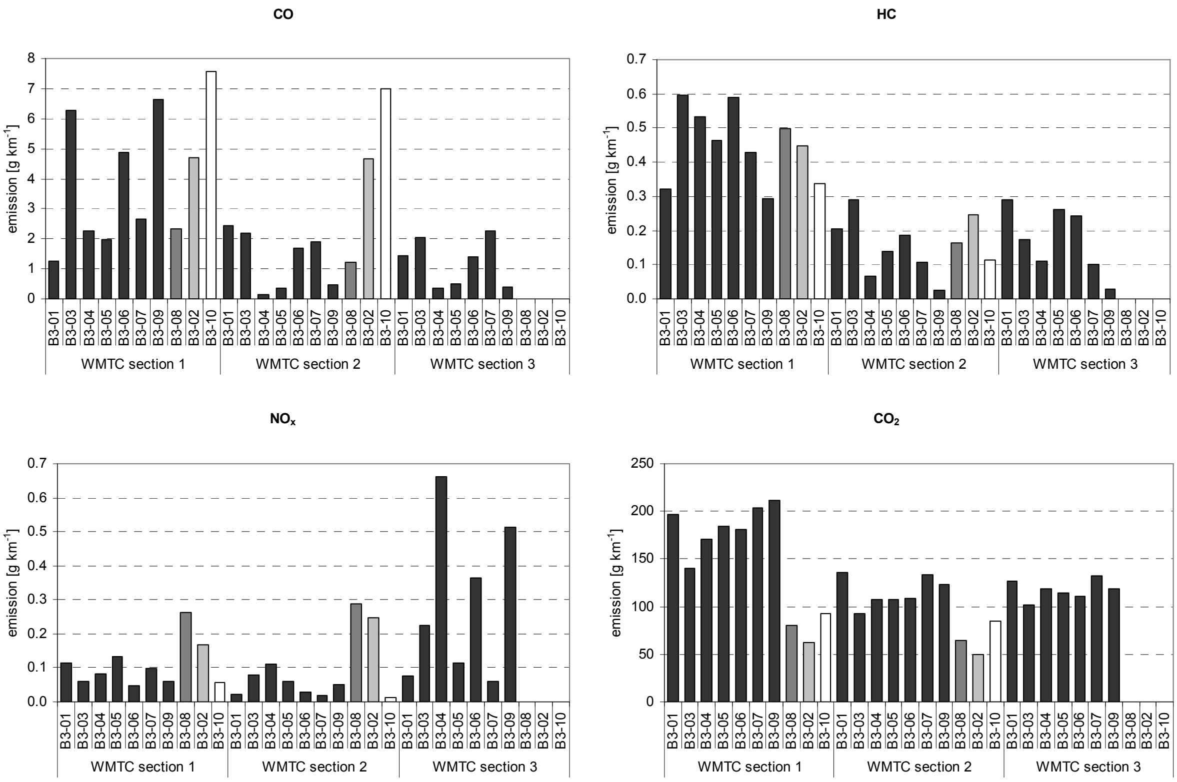

Figure 3: Emissions of regulated pollutants and CO2 of the individual motorbikes in the WMTC cycle. Vehicles are grouped according to the WMTC vehicle classification

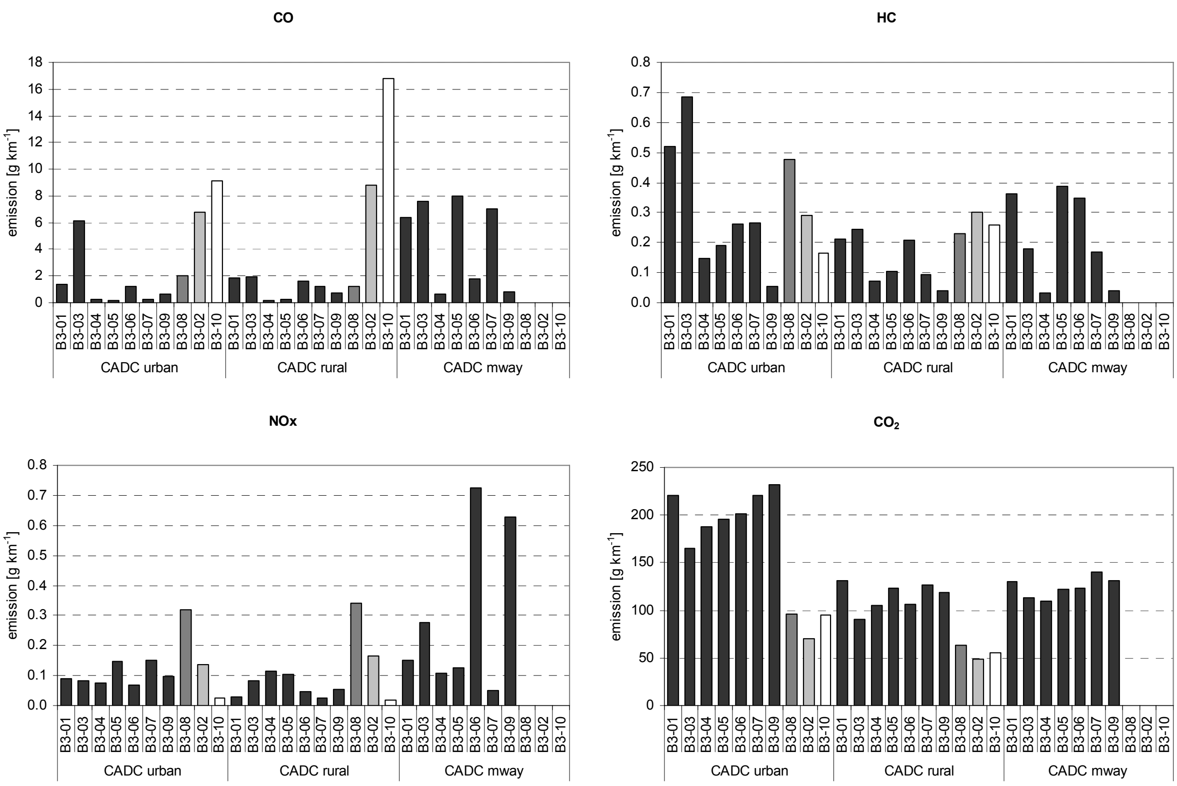

Figure 4: Emissions of regulated pollutants and CO2 of the individual motorbikes in the cycle CADC. Vehicles are grouped according to the WMTC vehicle classification

The given measurement results make it possible to draw a comparison in terms of emission performance with vehicle sample emissions of Euro-2 motorbikes (B2) (Vasic et al., 2006) and gasoline passenger cars of the present certification category Euro-4 (PC G4) (Alvarez et al., 2007) obtained in other test series, see Figure 5. The motorbike samples have been divided there according to their statutory vehicle classification. Vehicles B2-01 and B3-08 have, however, been excluded due to incompatibilities when averaging the measurement data of the CADC and WMTC cycles. Overall values for the two real-world cycles have been calculated by weighting the results for urban, rural and motorway driving with the respective percentages for Swiss driving behaviour, i.e. 33.2%, 36.1% and 30.7% (De Haan et al., 2001). Note that different statutory cycles were to be applied for the vehicle classes displayed.

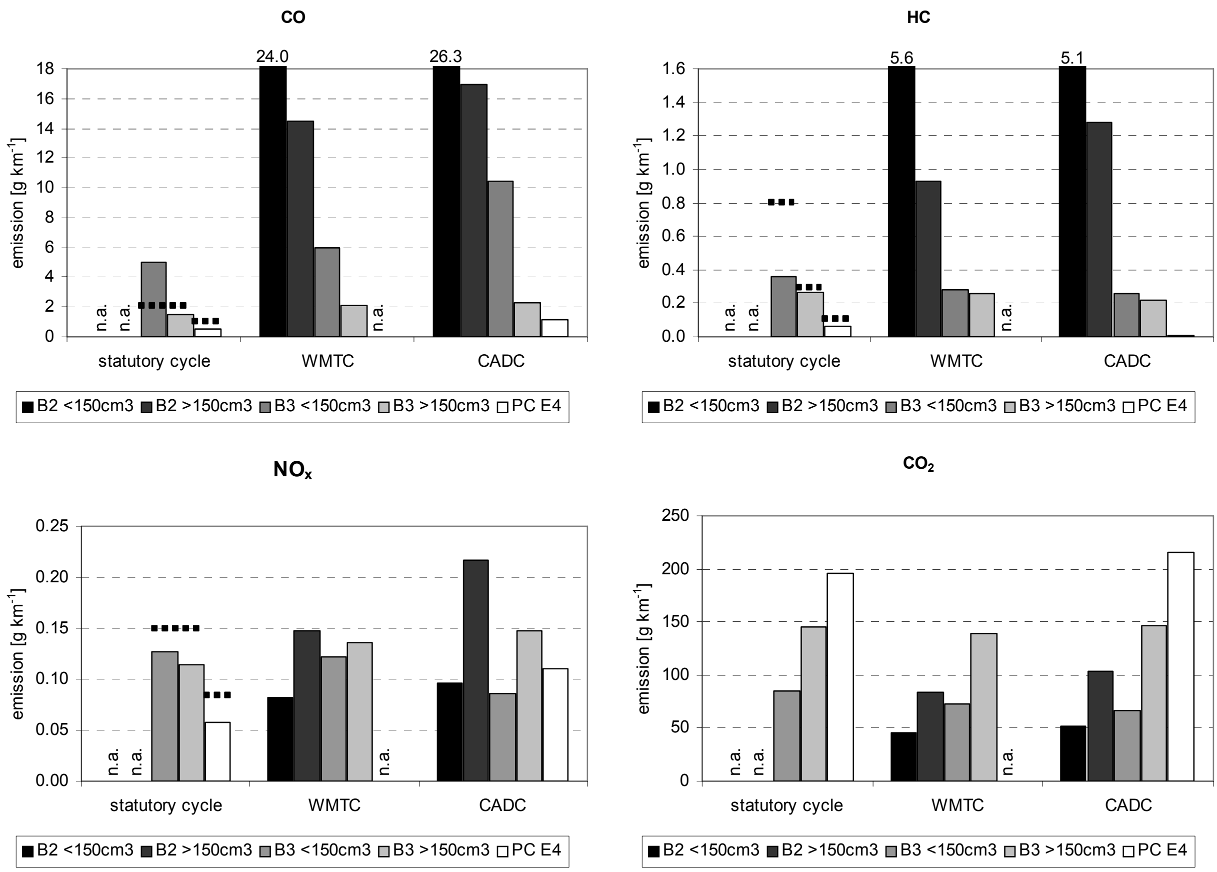

Figure 5: Comparison of reduced Euro-2 and Euro-3 motorbike sample emissions with sample emissions of gasoline Euro-4 passenger cars in real-world cycles and the respective statutory cycle (emission limits indicated by dashed lines)

Large improvements in pollutant emissions of CO and HC can be observed between the Euro-2 and the Euro-3 motorbike samples, whereas NO_x emission improves only moderately and the emission of CO_2 even increases significantly. This increase is attributable to the higher average displacement of the Euro-3 sample and particularly to the fact that it is composed exclusively of four-stroke engine powered vehicles. But emission levels of CO and HC for motorbikes of the present certification category in the CADC cycle are still massively higher than the equivalent emission levels of gasoline cars, whereas the difference in NO_x emissions is less pronounced. NO_x emissions of small displacement motorbikes are even slightly below those of passenger car emissions; however, these motorbikes were not supposed to perform the motorway driving section of the CADC cycle according to their vehicle classification. It is evident that the overall tuning of the engine management and the design of the exhaust after-treatment systems of passenger cars are still much more elaborate and thus more effective than those of modern motorbikes with regard to minimizing pollutant emissions. But in contrast to passenger cars, the overall emission levels obtained for the motorbikes in the real-world cycles are for the most part similar to those obtained in the corresponding statutory cycle.

4. SUMMARY AND CONCLUSIONS

The present experimental investigation offers varied insight into the environmental impact of modern motorbikes of certification category Euro-3. Great improvements can be seen when comparing the sample emissions obtained with the emission performance of Euro-2 motorbikes, especially for CO and HC emissions. But their compliance with statutory type approval stipulations is unsatisfactory, with only 3 out of 10 motorbikes meeting the specified Euro-3 emissions limits with an average sample mileage of around 12,200 km. In this case, excessive emissions of CO are a crucial feature of low displacement motorbikes, resulting from incomplete combustion at high engine speeds. By contrast, large displacement motorbikes show disadvantages in HC and NO_x emissions due to the formation of these substances in overrun fuel cut-off and high engine load situations respectively. However, it seems that the design potential of the exhaust after-treatment system used is not yet fully exploited. As regards real-world emission performance, it can be stated that the emission of both CO and HC in cycle sections with warm urban and rural driving patterns is pronounced, especially for low displacement motorbikes. NO_x emissions in real-world motorway driving conditions are significant as well. In general though, the overall real-world emission performance is somewhat similar to the emission performance in the statutory cycle.

From the given results, it can be deduced that the pollutant emission levels of modern motorbikes have clearly improved compared with older certification categories. For all that, comparison with the emission performance of gasoline passenger cars of the present certification category indicates that there is still considerable scope for further reducing pollutant emissions of motorbikes. In this respect, optimizing the combustion process and the systems for exhaust after-treatment are assumed to be the key issues. In fact, the urban real-world emissions of CO and HC of modern motorbikes recorded in these tests should be further reduced in order to prevent exposure to these pollutants which are harmful for human health.

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