

Methodology for the analysis of a 4-stroke moped emission behaviour

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ABSTRACT

Mopeds are popular means of transportation, particularly in southern Europe and in eastern and southern Asia. The relative importance of their emissions increases in urban environments which host large fleets of mopeds. In Naples, for example, mopeds make a considerable contribution to HC emissions (about 53%), although the percentage of mopeds (12.4%) in the total circulating fleet is lower than that of other vehicle categories [1].

This study presents a method for analysing the influence of kinematic parameters on the emission factors of mopeds during the "cold-start" and "hot" phases of elementary kinematic sequences (speed-time profiles between two successive stops). These elementary sequences were obtained through appropriate fragmentation of complex urban driving cycles. In a second step, we show how to estimate, for the whole cycle, the duration of the cold phase and the relevant time-dependence function.

The method was applied to analyse the regulated exhaust emissions (CO, HC, NO_x) of a 4-stroke moped (Euro 2) tested on a dynamometer bench. The experimental data were compared with ARTEMIS and COPERT emission factors, two of the emission models available in Europe to calculate road traffic emissions.

INTRODUCTION

Throughout eastern and southern Asia, southern Europe and particularly in Italy, mopeds (two-wheeled vehicles equipped with a less than 50 cm³ swept volume engine and built for a maximum legal speed of 45 km/h) are widely used and represent a large proportion of motorized vehicles. They are important means of

transport especially in large cities, helping to meet daily urban transport needs. In these countries, the use of mopeds is facilitated by the mild climate and is linked to several factors including parking ease, agility in traffic jams, inexpensive maintenance and in some countries the absence of any taxation on the sale or purchase of second-hand mopeds.

In Italy the size of the moped fleet is not known since they are not registered at the Automotive Public Registry (PRA). The best estimate is from the Italian Association of Motorcycle Manufacturers (ANCMA), amounting to 5058149 mopeds in 2007 [2], while their annual kilometrage is estimated between 5000 and 7500 km. Because of their prevailing use in urban environments, determination of emissions from mopeds is important for estimating their relative contribution to total emissions attributable to road transport.

Real world emissions evaluation in urban driving mode must take into account the cold start effect, since transient behaviour of the engine and after-treatment system far from optimal working points leads to significantly higher levels of pollutants than those exhausted in hot conditions. For newly sold mopeds equipped with a catalytic converter and electronic mixture control, cold-start emissions may represent an important proportion of total emissions, with an obvious repercussion on air quality. Since mopeds are mostly driven in residential areas, the cold-start influence should be taken into account in assessing CO and HC emissions from this source.

Starting from the above considerations, an experimental investigation on moped emissive behaviour is being jointly performed by Istituto Motori of the National Research Council (IM-CNR) and the Department of Mechanical Engineering for Energetics (DIME) of the

University of Naples. The first aim of this research is to evaluate moped emissions in real driving conditions. While mean emission factors from mopeds (mainly 2-stroke) measured during the type approval test cycle have been extensively documented [3,4,5,6,7,8], little is known about the emissions of 4-stroke mopeds in real-world situations. Application of the ECE-47 driving cycle to mopeds has the shortcoming of underestimating cycle dynamics; moreover, this procedure does not take into consideration the warm-up behaviour of mopeds. Therefore, the emission factors measured in such conditions might not be sufficiently representative of real-world moped riding. In order to assess the development of moped emissions in real driving conditions, measurements (and relevant statistical processing results) were then conducted on elementary driving sequences with kinematic parameters representative of urban driving patterns.

A calculation procedure to model the cold start transient behaviour of mopeds is explained in a second phase. Processing measured data allows us to quantify the cold transient duration, the emitted quantities during the cold phase and the relevant time-dependence function.

The paper also reports a summary of the current emission models available in Europe for calculating emissions from road traffic. The experimental data and the statistical processing results of this research were compared with emission factors using such estimation methods.

BACKGROUND

In 1999 the ARTEMIS project (Assessment and Reliability of Transport Emission Models and Inventory Systems) was defined within the 5th Framework Programme of the European Commission (Directorate General - Transport and Environment). The objective of the ARTEMIS project was to develop a harmonized emission model for all transport modes which aims to provide consistent emission estimates at the international (European), national and regional level. The ARTEMIS project consisted of 13 work packages of which WP 500 [9] dealt with 2-wheel vehicle emissions (powered two-wheelers).

The ARTEMIS WP500 model is based on a large number of bag and online emission results both from the ARTEMIS WP500 main measurement programme and from several other studies conducted over the years. In all, about 2700 emission results were available to serve as a basis for emission modelling which is - compared to the results that were used for previous powered two-wheeler emission models - an enormous amount of data. Therefore, the main objective of ARTEMIS WP500 was to develop a set of representative emission results for CO, HC, NO_x and CO₂ of in-use powered two-wheelers that would be the basis for the emission factor model of this vehicle category. The approach to determine emission factors for motorcycles was copied from methodology applied to update the powered two-wheelers part of the Handbuch emission model (HBEFA) [10]. The measurement data (both online and bags) were

employed to derive by regression analysis emission functions in terms of mass per time in relation to vehicle speed, for each powered two-wheeler vehicle category. The fifth order polynomial is (with v as vehicle speed in [km/h]):

$$E \text{ [g/km]} = \alpha_5 * v^5 + \alpha_4 * v^4 + \alpha_3 * v^3 + \alpha_2 * v^2 + \alpha_1 * v + \alpha_0 \quad (1)$$

By using these emission functions, emission factors can be predicted for driving patterns or test cycles for which no measurement results are available. Table 1 provides the vehicle categories that were defined for the powered two-wheelers. These eight initial categories again need another distinction with regard to legislative category: Euro 0, Euro 1, Euro 2 or Euro 3. Hence, in all 32 categories are identified for which emission factors were determined. As better explained in the next section, ARTEMIS WP500 project does not derive emission functions for the moped vehicle category since there were too few data in the emission results database.

Table 1- Vehicle categorisation for powered two-wheelers in ARTEMIS WP500

Category	Vehicle category	Swept volume [cm ³]	Engine
1	moped	vol < 50	2-stroke
2			4-stroke
3	motorcycle	vol ≤ 150	2-stroke
4			4-stroke
5	motorcycle	150 < vol ≤ 250	2-stroke
6	motorcycle		4-stroke
7	motorcycle	250 < vol ≤ 750	4-stroke
8	motorcycle	vol > 750	

EXPERIMENTAL ACTIVITY

VEHICLE

In these experimental tests, a 4-stroke 50 cm³ moped was employed. Its technical characteristics are reported in Table 2; the technologies employed on this moped to meet the latest emissive standards are the use of a catalytic converter and the secondary air injection system (SAI). A commercial gasoline conforming to European specification EN228 was employed. The moped was instrumented with two Type-K thermocouples installed upstream and downstream of the catalytic converter.

Table 2 - Technical specifications of the tested moped.

Category	moped
Engine principle	4-stroke
Cubic capacity [cm ³]	49.9
Fuel system	carburettor
Cooling system	air forced
Max power [kw] @ 8250 rpm	3,2
Maximum speed [km/h]	45
After-treatment system	catalytic converter and SAI
Legislative category	Euro 0

EXPERIMENTAL APPARATUS

In the Istituto Motori emission laboratory E4 the moped was tested on a chassis dynamometer (AVL Zollner 20" - single roller) that enables simulation of vehicle weights from small mopeds up to heavy two-wheel vehicles (range 80-450 kg) [11]. This bench is designed to simulate the road load (including vehicle inertia) and to measure the exhaust emissions during dynamic speed cycles. Using this system, it is also possible to carry out tests in constant speed mode, constant tractive force mode and constant acceleration mode.

The chassis dynamometer was set by using the running resistance table according to the procedures laid down in Directive 97/24/EC: the equivalent inertia mass was set to 170 kg, the rolling resistance of front wheel 'a' = 25 N and the aerodynamic drag coefficient 'b' = 0.0226 N/(km/h)². With these parameters set, the moped did not actually exceed its maximum on-road speed of 45 km/h (Table 2). A variable speed cooling blower was positioned in front of the moped so as to direct the cooling air in a manner which simulates actual operating conditions. The blower speed was such that, within the operating range of 10 to 45 km/h, the linear velocity of the air at the blower outlet was within ± 5 km/h of the corresponding roller speed, and at roller speeds lower than 10 km/h, air velocity was zero. Before each test in cold start conditions, the scooter was kept at a relatively constant temperature between 20 °C and 25 °C for at least 8 hours.

During the tests the exhaust gases were diluted with purified ambient air by a Mixing Unit connected to a Constant Volume Sampling with Critical Flow Venturi (AVL CFV-CVS) unit. During the tests a continuous sample flow of the mixture filled one or more bags so that concentrations (average test values) of carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NO_x) and carbon dioxide (CO₂) were determined. Average test values and continuous diluted emissions were measured with an exhaust gas analysis system (AVL AMA 4000), according to the procedures laid down in the Directive 97/24/EC.

The exhaust pollutants were collected in the dilution tunnel and analyzed at 1Hz. The signals were corrected for the time delay respect to the speed. No other compensation (i.e. mixing dynamics) or signal treatment was applied [12].

TYPE APPROVAL DRIVING CYCLE

Emissions testing was carried out according to the European driving cycle known as ECE-47. European Union Directive 97/24/EC came into force on 17th June 1999, establishing limit values and procedures to evaluate moped emissions. It provided for two phases: Euro 1 (97/24/ stage 1) and Euro 2 (97/24/ stage 2). The Directive sets limits to CO and the sum of HC and NO_x; Table 3 shows the emissions limits for Euro 1 (1999) and Euro 2 (2002) mopeds according to the type-approval driving cycle. Mopeds registered before Stage 1 of the Directive are defined as "conventional".

Table 3 - European Union emission limits for mopeds.

	CO [g/km]	HC + NO _x [g/km]
Euro 1 (1999)	6	3
Euro 2 (2002)	1	1,2

The maximum speed in this test cycle is 45 km/h. The cycle comprises eight elementary cycles (Fig. 1). Each elementary cycle lasts 112 seconds and includes an acceleration phase and a full speed phase at wide-open throttle. In the ECE-47 driving cycle, the first four elementary cycles are used to warm up the engine; the last four are used for sampling.

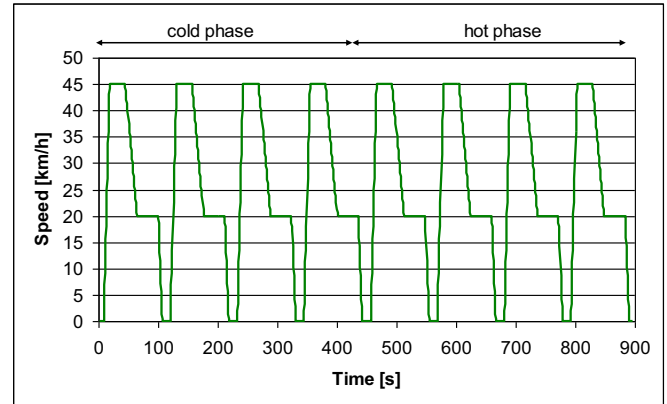


Figure 1 – ECE-47 driving cycle

Two bags were filled during this cycle: one during the conditioning phase (the first four elementary cycles) and the second during the conditioned phase (the following four elementary cycles). The second phase is used to check the technical state of the scooter and its compliance with emission standards. In this study, emission rates of CO, HC and NO_x were evaluated both during the "warming-up" phase and the "hot" phase of the ECE-47 cycle.

The results are reported as mean values of ECE-47 five test repetitions to verify compliance with Euro 2 emission limits and to evaluate the variability of tests in the laboratory. In Table 4 mean experimental emission values of each pollutant, expressed as mass emitted per kilometre travelled, are reported with the percentage variance coefficient (%CoV) for each phase (*cold* from bag 1 and *hot* from bag 2) and with the Euro 2 emission standard; the same results are displayed in Figure 2.

Table 4 - Emissions of regulated pollutants in ECE-47 phases, variability, and Euro 2 standard limits

Emissions [g/km]	CO	HC	NO _x	HC+NO _x
ECE-47 cold phase	7,75	1,17	0,29	1,46
ECE-47 hot phase	2,85	0,40	0,25	0,65
%CoV cold phase	7,75	19,92	12,80	18,15
%CoV hot phase	9,63	14,82	12,45	11,17
Euro 2 Standard	1	-	-	1,2