MEASUREMENT OF POLLUTANT EMISSIONS OF BUSES WITH DRIVING CYCLES REPRESENTATIVE OF REAL TRAFFIC CONDITIONS

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ABSTRACT

Pollutant emissions from road vehicles are closely connected to their use and functioning conditions. This study intended to link the pollutant emissions from buses to their driving conditions and to the urban context.
In a first stage, the RATP[i] bus network and the urban context were linked associating analysis of bus operating conditions and the urban characteristics collected and managed by a GIS (Geographical Information System). This work was done in the Ile de France region of France, the methodology for characterising bus network by using geographic and bus operating databases can be extrapolated to any urban zone.
Secondly, 4 bus routes representative of Paris Urban region were selected for the experimentation. Cinematic parameters of buses were measured in commercial use on these routes and used to draw 3 new specific driving cycles.
Pollutant emissions of three buses were then measured on a chassis-dynamometer. They were calculated per kilometres and for each phase of driving cycles. They changed as a function of vehicle type (engine and particle filter) and traffic conditions.
This study allowed us to associate pollutant emissions to the corresponding driving conditions and geographical areas (housing, employment, …). This can help RATP as a Public Transport Company to deploy the most environment friendly buses in the most sensitive areas. In the same objective of sustainable development, during the creation of new bus lines, RATP can choose the route that presents less emission.

Key words : pollutant emissions, bus, driving cycles, GIS, urban context, instrumentation.

INTRODUCTION AND CONTEXT OF THE STUDY

The aim of this work is to describe the operating conditions of buses in an urban context and to measure the pollutant emissions with the support of new driving cycles typical of real driving conditions. Envisaged in the case of the Ile de France region of France, this procedure constitutes a methodological basis for characterising bus networks by using geographic and bus operation databases [1]. It can be extended to any urban region described in a GIS (Geographical Information System).

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[i] RATP : Régie Autonome des Transports Parisiens - Parisian Public Transports.

CHARACTERISATION OF THE NETWORK AND SELECTION OF REPRESENTATIVE BUS LINES

The "urban context" in which the buses run was analysed by using urban characteristic data (demography, employment, road network, traffic, housing, areas crossed and served: school, stations, etc). This data was calculated for the Ile de France region divided into 225,000 units of 100x100 meters and stored in a GIS. This was completed by bus line characteristics and operating statistics (dedicated bus lanes, number and type of bus stops, commercial speed, number of passengers, fluctuations linked to congestion, accidents, specific features in passenger load, areas served and specific connections, etc).

The factorial analysis of these geographical units and classification enabled to establish a typology of areas in 12 classes. The main parameters of differentiation are density and type of housing, types of lanes, and level of traffic.

Bus routes were analysed with a similar process using the characterisation of the areas crossed and served along their itineraries. Five main categories of bus lines were then defined in the geographic zone.

I. 73 lines (34% of the network in distance) represent the first category. Buses use the main roads network with high-levels of traffic and serve dense town centres. The average speed is around 14 km/h and irregularities in the service are relatively important. Route 163, connecting Paris to the nearby Northwest suburb is representative of this group and is chosen for the experiments.

II. The second category includes 32 lines (15% of the network) connecting mixed or isolated housing areas. This class is well represented by the mixed line 206 and 207 serving the more remote suburbs of the east of Paris.

III. In the third category, 52 lines (25% of the network) serve dense mixed and individual housing areas. This category is characterised by line 319 connecting the Massy Palaiseau RER[ii] station to the International Market of Rungis in the remote southern suburb.

IV. 55 lines (21% of the network) represent the fourth category. They mainly serve Paris and high density housing areas. These lines travel with an average speed of 11 km/h. The line chosen for experimentation is line 47.

V. The last category includes 6 atypical lines (fast average speed about 28 km/h) serving airports and RER stations and using motorway. They will not be considered in this study.

The 4 lines were chosen considering on how typical the criteria are within the classes and over the areas covered by these routes in previously identified geographical zones [2].

INSTRUMENTATION OF BUSES

The parameters recorded concern: environmental parameters (temperature, weather conditions), kinetic parameters (vehicle speed and acceleration), stops (commercial or due to road junctions and congestion), vehicle load (number of passengers), engine operation (torque, engine speed and temperature, gearbox), location of the vehicle (in the urban context), and electrical and pneumatic equipment [3,4].

2 vehicles (RENAULT R312 and AGORA-type) have been instrumented. These vehicles are the most representative of the RATP's bus fleet and have very similar operating features and

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[ii] Regional Express Railway

performances (AGORA has the more recent engine specification). Each of these vehicles was successively allocated to 2 of the chosen bus lines and regularly monitored under normal commercial operating conditions for a minimum duration of 1 month, with usual driver turnaround. Drivers were unaware of the experiment.
More than 25,000 km (1,600 driving hours) were recorded in this way under real operating conditions.

CONSTRUCTION OF DRIVING CYCLES

The concept previously developed for passenger cars by M. ANDRE (INRETS[iii]) [1] was adapted to the case of buses for kinematics analysis and construction of representative cycles. 3 representative bus driving cycles were designed, structured in 11 sub-cycles corresponding to the geographical areas and the driving condition observed. One of these cycles is represented in figure 1 with the reference cycle (ADEME/RATP). Quite market contrast is observed in these cycles, from phases at 5 km/h and 73% of stops and to phases at 50 km/h. The city centre includes 2 phases at 10 and 16 km/h respectively and a stop rate that doubles from 4 to 8 stops/km. This also allows associating conditions with the places where they took place.

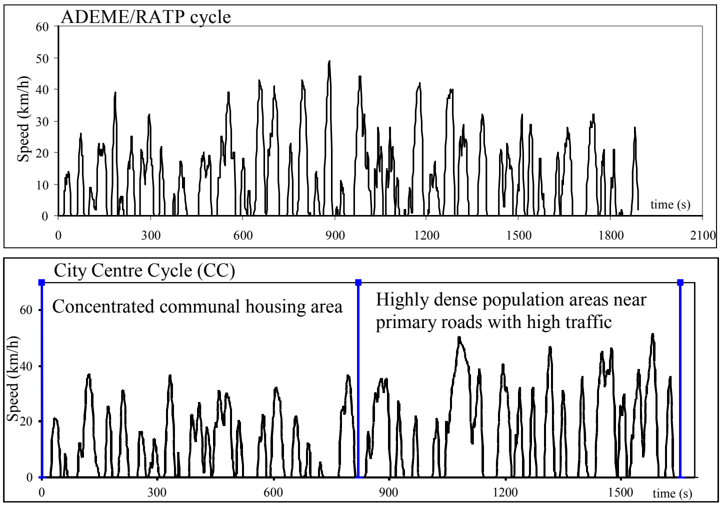


Figure 1: Reference cycle ADEME/RATP and new designed City Centre cycle

MEASUREMENTS OF POLLUTANT EMISSIONS

Emissions measurements are done using these 3 newly developed driving cycles and compared with the emissions during the ADEME/RATP cycle traditionally used since the 1990's to measure bus emissions in France.
The tests were performed in a HDV-chassis dynamometer. The 2 buses selected are representative of RATP's fleet. 3 configurations were retained: 1 bus with an Euro 2 engine fitted out with a standard exhaust system, 1 euro 3 with standard exhaust system and 1 euro 3 with a post-treatment exhaust system (Eminox particles filter).

[iii] INRETS : French National Research Institute for Transport and their Security.

The measured parameters on each configuration were: regulated pollutants (CO, HC, NO_x, PM, CO_2), volumetric fuel consumption and opacity of exhaust fumes and unburned hydrocarbons, aldehydes-cetones, N_2O, Aromatic polycyclic hydrocarbons and particle size distribution just on some configurations. In this paper, the results are not entirely presented.
Gaseous pollutant emissions were continuously measured with a ¼ min time step. This allows us to integrate and calculate emissions for each phase of cycles.

RESULTS

Regulated pollutants

The first graph (figure 2) shows the good correlation between the new designed City Centre cycle and the ADEME/RATP cycle. This one is typical of congested traffic, with an average commercial speed of 10.8 km/h. Phase 1 of CC cycle corresponds to concentrated housing area with an average speed of 9.8 km/h. It is very closed to ADEME/RATP cycle and let us see the same level of pollutant emissions. Phase 2 of CC cycle has a higher speed and less stops per kilometre than Phase 1 and ADEME/RATP cycle. Gaseous emission levels are better in this case.
Particle filter has a limited influence on emissions of nitrogen oxides and carbon dioxide but is particularly efficient on particles. Unlike gaseous emissions, the measurements of particle emissions are global for one cycle, it was not possible to recalculate it for the different phases of cycles.

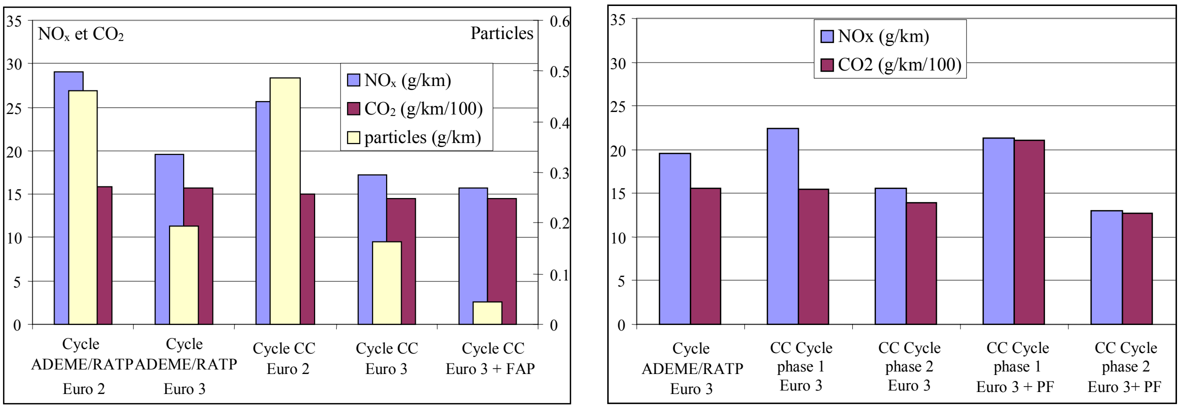


Figure 2: Emissions of nitrogen oxides, carbon dioxide and particles

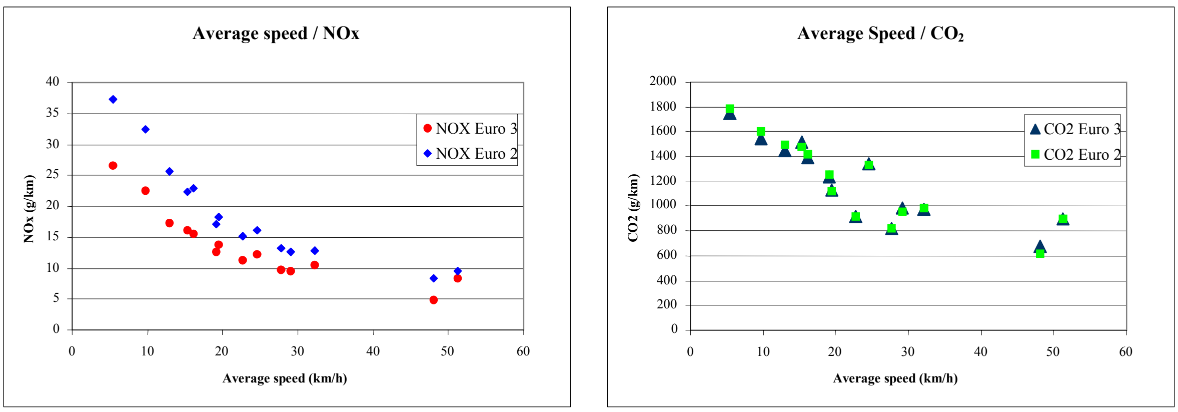


Figure 3: Influence of average speed in CO_2 and NO_x emissions (Euro 2 and Euro 3)

NO_x and particles emissions decrease significantly from Euro 2 to Euro 3, it is not the case for CO_2.
CO_2 or NO_x emissions decrease when commercial speed increase, whatever is the motor technology Euro2 or Euro3 (figure 3).
For low speeds, less than 20 km/h, an increase of 5 km/h allows a decrease of nitrogen dioxide equivalent of the gain obtained by EURO 3 / EURO 2 technology. Driving conditions of urban buses are very important in regard to pollutant emissions.

Non regulated pollutants

The post treatment system allows an important decrease of hydrocarbon emissions but has a negative effect on nitrogen oxides (figure 4).

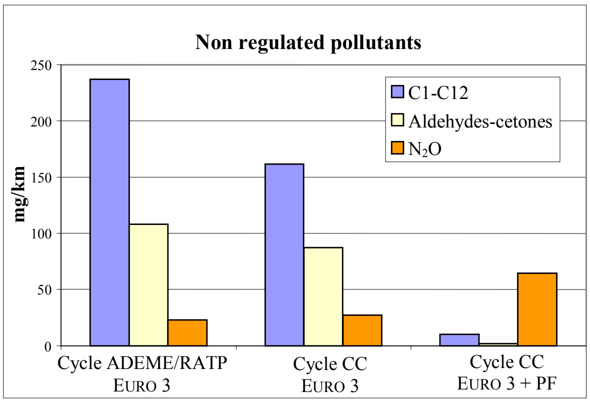
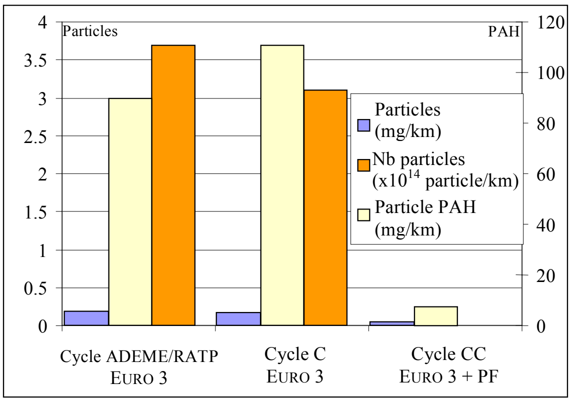


Figure 4: Gaseous pollutant emissions (mg/km)

Particles



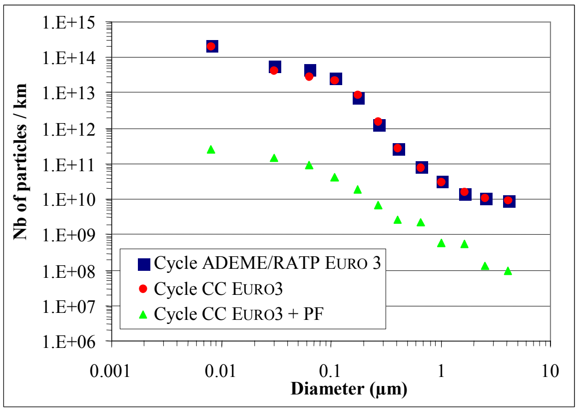


Figure 5: Particle pollutant emissions and particle size distribution (measurements - air background)

There is a low difference of particle emissions between the different cycles (figure 5) with respect to gaseous pollutants.
Particle filter can retain more than 72% of the particles' mass and 99% of the particles' number. The size distribution doesn't change with the contribution of particle filter.
Whatever the cycle considered, particle distribution and particle numbers are approximately the same. The size distribution is unimodal. Most of the particles have a size lower than

0.1 µm. These kind of particles are able to penetrate the respiratory tract system, i.e. be dangerous for health.

CONCLUSION

The first phase of the programme demonstrated the great diversity of driving conditions in the Parisian urban zone.
With the 3 driving cycles designed, this work characterised the pollutant emissions per cycle and in the case of regulated pollutants (CO, HC, NO_X and CO_2) per phase of cycles.
City centre cycle (CC) and ADEME/RATP cycle generate approximately the same quantity of pollutants and especially in the first phase of the CC cycle corresponding to a concentrated collective housing area. In typical suburb driving conditions, emissions decrease when speed increase.
Pollutant emissions from buses are strongly linked to vehicle use and operating conditions.

The driving cycles, presented in this study, enable to associate pollutant emissions with the corresponding driving conditions and geographical areas.
At a later stage, this information should enable us to predict the energy and environmental consequences linked to a given context and optimise energy reduction policies and reduce nuisances by assigning low-pollutant vehicles to the most unfavourable areas and by optimising new and actual bus routes.

Further steps in these works should enable studying the pertinence of the results and the applicability of the method to other bus networks.

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