Influence of Roof-Rack, Trailer etc. on Automobile Fuel Consumption and Exhaust Emissions, Measured on-the-road

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ABSTRACT

Fuel consumption, NO and NO_x were monitored using on board apparatus during road driving at constant speeds, for a gasoline passenger car with TWC. Exhaust gas concentrations (ppm) of nitrogen oxides were translated into mass emission values (g/km) by methods previously reported [1-4]. In addition to standard vehicle configuration, the experiments included driving with studded tyres, trailer, roof-rack and ski-box. Also, the influence of windy conditions was studied.

Generally speaking the use of extra equipment, and also higher speed, entailed raised fuel consumption. The NO_x emissions, however, did not exhibit a corresponding dependence. Calculated NO₂/NO_x ratios (v/v) varied between 0.01 and 0.03.

INTRODUCTION

Systematic studies of how environmental parameters related to the use of passenger cars are influenced by application of additional equipment is a hitherto sparsely investigated field, of vast interest in the creation of realistic emission models. Studies appearing in this area have typically concerned increased fuel consumption resulting from use of: light bars on police vehicles [5,6], different tyre types [7], roof-mounted luggage [8] or camping trailer [9].

Likewise crucial as a source of input data for emission modeling are studies during actual road driving, in realistic traffic conditions. That is because measurement and evaluation of the parameters which characterize automobile energy expenditure and exhaust emissions are traditionally performed as standardized procedures in an emission laboratory, the vehicle running on rollers in a chassis dynamometer. Studies from real traffic using on board measurement apparatus have been made at VW [2,3], at the Belgian research institute VITO [4] and at GM, Michigan [10]. Warren Spring Laboratory in England used a proportional sampler in combination with a "mini-CVS" [11,12] which can be employed for on-board sampling and subsequent analysis. At the University of Denver

Stedman *et al.* [13] have developed FEAT, a remote sensing concept for roadside monitoring of pollutant concentrations in the exhaust plumes of passing vehicles. The FEAT method has been used extensively in Sweden [14,15] and elsewhere.

EXPERIMENTAL

TEST VEHICLE AND SETUP - The vehicle used in the study was a 1992 Volvo 940 Sedan with a 2.3-l B230FB engine and three-way catalyst having an odometer reading of approximately 100 000 kilometres. The vehicle test weight was 1408 kg and the frontal area was 2.15 m².

Measuring instruments, computer, data logger and associated peripherals were fitted inside the car.

Additional equipment - Standard Michelin Energy and studded Nord Frost tyres both of dimension 185/65 R 15 were used for the tests. Roof-rack and ski-box (frontal area 0.25 m²) were common commercial products. The trailer was 4.3 m long by 2.2 m wide, designed for a maximum load of 940 kg, and exposed 1.35 by 1.75 m (2.36 m²) of frontal area to wind with a raised cover mounted.

Fuel flow metering - Fuel volume flows were registered by a Pierburg PLU 116H flow meter. The instrument has automatic corrections for fuel return flows, vapour locks and temperature differentials. The dynamic range is 0.4 - 60 litres per hour (l/h).

NO_x measurement - An Eco Physics CLD 700 instrument based on chemiluminescence was used to measure nitrogen oxides. Volume concentrations of total nitrogen oxides (NO_x) and nitrogen monoxide (NO) are monitored in parallel, enabling calculation, in a subtractive mode, of nitrogen dioxide (NO₂).

Data acquisition - The PC-based measuring system registers and stores sets of data on the computer hard disk at a frequency of 4 Hz. The following parameters were logged.

Param.   *Dim.*

- Time   s
- Accumulated dist.   m
- Accumulated fuel   l
- Fuel temp.   °C
- NO   ppm
- NO_x   ppm
- NO₂   ppm
- Oil temp.   °C
- Water temp.   °C
- Ambient temp.   °C

TEST PROGRAM - A straight, even and horizontal stretch of highway was chosen for a test track. A single experiment consisted of six successive runs, three each way, at constant speed. For each run, data were collected during at least 1 km of driving at the preset speed. The trials took place at low-traffic hours, avoiding influence from other traffic.

Particulars about the various configurations of peripheral equipment investigated are given next. All experiments were run at 70, 80 and 90 km/h.

Table 1. Details about the trials.

No wind

Test No.	Equipment
1	None (reference)
2	Tyre studs
3	Roof-rack
4	Ski-box
5	Trailer (T)
6	Trailer + Load (T+L)
7	Trailer + Cover (T+C)
8	Trailer + Load + Cover (T+L+C)

Wind

9	None (reference)
10	Tyre studs
11	Roof-rack
12	Ski-box

In experiments 6 and 8 the load applied was 564 kg, 60% of full trailer load capacity (940 kg). The empty trailer weighed 310 kg. During experiments 9 through 12 the test road was exposed to roughly 4 m/s side wind. Figures 1 through 4 picture some of the experimental configurations.

Figure 1. Experimental setup using roof-rack.

Figure 2. Experimental setup using ski-box.

Figure 3. Experimental setup using trailer.

Figure 4. Experimental setup using trailer with cover.

RESULTS AND DISCUSSION

FUEL - Fuel consumption was obtained directly as the quotient between logged accumulated values of fuel flow and distance traveled. The fuel measurement results given in Tables 2-3 are graphically presented by Figures 5-6. Labels and headings are explained by Table 1. The values are averages for six runs (three in each direction) of approximately 1200 m distance.

Table 2. Fuel consumption (l/km) using trailer in different configurations. No wind.

	Ref.	Trailer	T+L	T+C	T+L+C
70 km/h	0.0696	0.0924	0.0952	0.1105	0.1181
80 km/h	0.0737	0.1006	0.1016	0.1249	0.1328
90 km/h	0.0787	0.1125	0.1141	0.1379	0.1437

Table 3. Fuel consumption (l/km) using various equipment. Windy conditions.

	Ref.	Studs	Roof-rack	Ski-box
70 km/h	0.0689	0.0688	0.0707	0.0758
80 km/h	0.0745	0.0758	0.0760	0.0826
90 km/h	0.0790	0.0786	0.0799	0.0887

It can be deduced that all types of additional equipment investigated brought about raised fuel consumption for the tested vehicle. Likewise increased speed, in the interval 70-90 km/h, entailed raised fuel consumption. The increase is seen to be insignificant using studded tyres, 1-3% for an empty roof-rack, around 10% for a ski-box, 30-50% with a trailer and 60-80% in configurations including a raised covered trailer. The effect from increased speed exhibited a similar sequence, a speed raise from 70 km/h to 90 km/h giving 13% higher fuel consumption in the reference case (no additional equipment) while, with the inclusion of a covered trailer, an increase of 25% in fuel consumption occurred when speed was increased from 70 km/h to 90 km/h.

Tests in moderate (4 m/s) side wind did not disclose any significant changes in fuel expenditure, when the results of corresponding wind/no wind experiments were compared.

It appears, not unexpectedly, that the trailer cover, implying considerably increased air resistance, and the trailer itself, which involves an additional wheel axle, cause the largest fuel consumption increases. The addition of weight in the form of extra load seems to be less important.

NITROGEN OXIDES - NO_x and NO mass emissions (g/km) were derived from the respective measured exhaust volume concentrations (ppm) and the known facts about fuel consumption, fuel composition and combustion stoichiometry [1] ($\lambda = 1$ was presumed).

Figure 5. Fuel consumption (l/km) at different speeds using various equipment. No wind.

287 Figure 6. Fuel consumption (l/km) at different speeds using various equipment. Windy conditions.

Nitrogen dioxide ratios NO_2/NO_x (v/v) were determined as $([\text{NO}_2]-[\text{NO}])/[\text{NO}_x]$, square brackets designating volume concentrations in the gas phase. Total nitrogen oxides NO_x (g/km) and NO_2/NO_x volume fractions covering the same set of experimental conditions as before, are given by Tables 4-7 and Figures 7-8. Estimated standard deviations (+/-%) on 95% significance level are given in parentheses for NO_2/NO_x (Tables 5 and 7).

Table 4. NO_x emissions (g/km), using trailer in different configurations. No wind.

	Ref.	Trailer	T+L	T+C	T+L+C
70 km/h	0.326	0.449	0.354	0.499	0.289
80 km/h	0.320	0.276	0.327	0.258	0.335
90 km/h	0.292	0.266	0.337	0.443	0.475

Table 5. NO_2/NO_x fractions (v/v), using trailer in different configurations. No wind. ESDs in %.

	Ref.	Trailer	T+L	T+C	T+L+C
70 km/h	0.027(16)	0.025(24)	0.023(43)	0.026(31)	0.016(19)
80 km/h	0.025(20)	0.025(36)	0.023(43)	0.026(27)	0.017(41)
90 km/h	0.025(20)	0.022(40)	0.022(40)	0.025(36)	0.016(25)

Table 6. NO_x emissions (g/km) at different speeds using various equipment. Windy conditions.

	Ref.	Studs	Roof-rack	Ski-box
70 km/h	0.323	0.299	0.302	0.362
80 km/h	0.323	0.299	0.347	0.379
90 km/h	0.340	0.350	0.305	0.297

Table 7. NO_2/NO_x fractions (v/v) at different speeds using various equipment. Windy conditions. ESDs in %.

	Ref.	Studs	Roof-rack	Ski-box
70 km/h	0.011(18)	0.012(24)	0.010(30)	0.019(16)
80 km/h	0.009(22)	0.013(38)	0.012(17)	0.020(25)
90 km/h	0.011(27)	0.013(38)	0.013(31)	0.020(35)

The test vehicle had been certified according to the Swedish A12 Regulation [16], allowing emission of 0.62 g/km of NO_x during the Urban Driving Cycle (UDC) of the FTP, and 0.76 g/km NO_x during highway driving.

Although exhaust gas NO_x concentrations vary considerably in the course of a test at constant speed, the average mass emission values calculated for different cases are mostly close to 0.35 g/km of NO_x , and seem to respond quite randomly or be indifferent to changes in speed as well as in additional equipment.

The nitrogen dioxide fraction of NO_x emitted by traffic is an important parameter to atmospheric pollution in urban areas [17,18]. The NO_2/NO_x ratios cited in Tables 5 and 7 are in accord with values expected from a passenger car with TWC [19].

Figure 7. NO_x emissions (g/km) at different speeds using various equipment. No wind.

Figure 8. NO_x emissions (g/km) at different speeds using various equipment. Windy conditions.

SUMMARY

Fuel consumption and nitrogen oxides emissions for a passenger car were measured with on board instrumentation, at constant speeds on-the-road. Effects of using various kinds of peripheral equipment were studied.

Increased fuel consumption resulting from use of extra equipment was for roof-rack 1-3%, for ski-box 10%, for trailer 30-50% and for trailer with raised cover 60-80%. Fuel consumption also rose with increased speed from 70 km/h to 90 km/h, between 13% in the reference case (no extra equipment) and 25% (covered trailer with load). The use of tyre studs did not entail any significant change in fuel consumption, nor did occurrence of side wind (4 m/s) during an experiment.

It was concluded that trailer (one extra wheel axle) and trailer cover (increased air resistance) cause the largest increases in fuel consumption. The addition of extra load has less effect.

Nitrogen oxides emissions did not relate in any systematic manner either to speed variations or to application of different kinds of extra equipment. Measured values for NO_x mass emissions averaged 0.35 g/km and ranged from 0.25 g/km to 0.5 g/km. No trends in NO_x emission due to use of trailer etc can be derived from the data. Calculated NO₂/NO_x volume fractions were in the range 0.01-0.03, and although these values should be viewed with caution, due to the uncertainty introduced by subtraction ($[\text{NO}_2]/[\text{NO}] = [\text{NO}_2]$) of two similar numbers, they agree well with previous findings.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

CVS	Constant Volume Sampler
ESD	Estimated Standard Deviation
FEAT	Fuel Efficiency Automobile Test
FTP	Federal Test Procedure
GM	General Motors
NO	Nitrogen monoxide
NO ₂	Nitrogen dioxide
NO _x	"Nitrogen oxides" (NO + NO ₂)
TWC	Three-Way Catalyst
UDC	Urban Driving Cycle
VITO	Flemish Institute for Technological Research, Belgium
VW	Volkswagen

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