meteorological conditions and averaging time periods, can help planners and decision makers in planning, appraisal and selection stages of different land-use and transport alternatives. The application of the model to the inner suburb of Ultimo-Pyrmont in the Sydney region to evaluate arterial management options enables decision-makers to identify the most beneficial options with respect to air pollution: the Area-Wide Environmental Deficiency Index gives a summary measure of performance of each option. The likely future changes in vehicle, engine, petrol, and post combustion devices, and their impact on the basic relationship between total travel activities and air pollution concentrations, require more research work in the on-going development of the AWEC models.

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INFLUENCE OF URBAN DRIVING CONDITIONS ON ON-ROAD EXHAUST EMISSIONS AND FUEL CONSUMPTION OF GASOLINE CAR

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ABSTRACT

The paper presents results of on-road measurements of vehicle fuel consumption and exhaust emissions during city center driving. Gasoline-powered cars of various types relevant to the Israeli vehicle fleet were tested. All experiments were performed on the same driving route, selected earlier as representative of Israeli city center driving pattern. Today's average traffic speed was determined and compared to that found in 1980.

On-road fuel consumption and mass emissions of CO, HC, NO_x and CO_2 were measured and compared at different average speeds with and without AC system operation.

1. INTRODUCTION

The severity of air pollution from mobile sources is becoming more and more serious worldwide. In Israel the situation is worsened by a very rapid growing of motorization rate (one of the highest in the industrialized countries) which is not accompanied by a proportional increase in road infrastructure, [1]. As previously noted in [2], from 1960 the number of vehicles on Israel's roads rose about 20 times.

It is well known, that emissions from road transport have a major impact on urban air pollution. The situation is evidently more severe in urban business centers, where traffic is generally more congested and average speeds are low, which results in increased levels of fuel consumption and pollutant emissions. Obviously, emissions during city center driving are an important contributor to a total air pollution inventory from motor vehicles.

Different driving cycles are commonly used in order to simulate realistic vehicle driving patterns under various traffic conditions. Typical city center driving pattern in Israel was found in 1980, [3]. It was concluded at that time that the Israeli urban driving pattern was quite similar to that of ECE15, especially in the most important parameters, namely average speed (21.8 km/h vs. 18.8 for ECE 15) and percentage of standstill time (27.40 vs. 28.7%). Because of the above mentioned reasons, it may be reasonable to assume that today's urban center driving pattern is substantially different from that of 1980, and emission estimations according to ECE15 may not be justified. Clarifying this issue was one of the main goals of the present work. Additionally, it is important and interesting to evaluate, in real traffic situations, how such changes in driving patterns (if they indeed occur) affect real-world vehicle fuel consumption and exhaust emissions. Published data on related subjects (for example [4, 5]) are still limited and it is difficult to apply them to different driving conditions. Switching-on the air conditioning (AC) system is an integral part of urban driving under Israeli climatic conditions over long periods of time during the year. It is evident that AC system operation leads to fuel consumption penalties, but to date there is scarcely any information regarding quantitative values of AC system effects on vehicle fuel economy and exhaust emissions in real traffic situations.

2. MEASUREMENT SYSTEM

As mentioned above, vehicle fuel consumption and emissions of the gaseous pollutants CO, HC, NO_x and CO_2 were measured during real urban driving.

Fuel consumption was evaluated by a gravimetric method. The engine feeding and return fuel pipes were reconnected with an additional fuel pump to a special fuel tank, which was precisely weighed before and after the test with accuracy of ± 1g. The accuracy of the fuel consumption measurement is estimated as better than 0.5%.

Exhaust gases emitted during each test were sampled on-board through appropriate filters and valves, into a special bag intended for exhaust gases collection. After the test, CO, HC and CO_2 contents in the bag and also λ were measured by a standard Non-Dispersive Infrared (NDIR) gas analyzer, usually used for inspection/maintenance (I/M) tests. The accuracy of the measurement is standard for such equipment. The NO_x content in the sample bag was measured by the Griess-Saltzmann method, explained in detail in [6].

Mass emissions of CO, HC, CO_2 and NO_x were calculated based on the mass flow rate of the exhaust gases (G_{ex}), according to the following formulae:

$$G_{ex} = G_{fuel}(1 + \lambda \cdot L_o),$$

$$CO_{mass} = 9.66 \times 10^{-3} \times CO_{conc} \times G_{ex}, \quad g/km$$

$$HC_{mass} = 2.868 \times 10^{-6} \times HC_{conc} \times G_{ex}, \quad g/km \text{ of } C_1H_{1.85}$$

$$CO_{2\,mass} = 1.519 \times 10^{-2} \times CO_{2\,conc} \times G_{ex}, \quad g/km$$

$$NO_{x\,mass} = 1.587 \times 10^{-6} \times NO_{x\,conc} \times K_H \times G_{ex}, \quad g/km$$

where: G_{fuel} - measured fuel consumption, g/km.
L_o - air quantity needed for stoechiometric fuel combustion
(it was assumed in this work that $L_o = 14.7$ kg/kg, constant for all experiments).
λ - real air-to-stoechiometric air ratio, measured in sample bag.
K_H - humidity correction factor.
$NO_{x\,conc}$ - as measured in ppm vol.
CO_{conc} and $CO_{2\,conc}$ - as measured in % vol.
HC_{conc} - as measured in ppm vol of C_6.

3. TEST PROGRAM

The first part of the test program was devoted to the determination of the present Israeli city center driving pattern compared to that found in 1980, [3]. It is known that driving pattern can generally be characterized by parameters such as average speed, average net speed, mean acceleration, mean deceleration, idling time, etc. [3, 7, 8]. Among them, the average speed is the simplest to measure, and it is most frequently used to present emissions and fuel economy variations vs. changes in driving pattern. This parameter was used in order to compare the current city center driving pattern with that previously found. For this aim, about 60 tests were performed during all working days of the week from 7:00 AM until 7:00 PM. Ten different cars with engine displacements from 770 up to 2000 cc participated in this stage of the work.

Three gasoline vehicles representing the most popular types in the Israeli fleet were selected for fuel economy and emission tests. Some of their technical data are presented in Table 1.

Table 1. Vehicles used for emissions tests.

Vehicle No.	Vehicle Type	Production Year	Traveled Distance, km	Engine Displacement, cc	Type of Fuel System	TWC* availability
1	Pick-up	1996	12,000	1400	fuel injection	yes
2	Passenger car	1994	42,000	1400	fuel injection	yes
3.	Passenger car	1992	67,000	1600	carburetor	no

* TWC - Three way catalyst, e.g. catalytic converter simultaneously reducing CO, HC and NO_x emissions.

All the vehicles were properly maintained and tuned-up (if needed) before starting the experiments. The vehicles were driven within the whole range of possible average speed values, as measured in the first stage of the work. Series of measurements were repeated with and without switching on the vehicle's AC system.

All experiments with the same vehicle were carried out by the same driver and all vehicles were filled with unleaded gasoline RON95 from the same batch. A "normal driving behavior", [4], was "selected" for all the tests. All fuel economy and emissions measurements were performed with fully warmed-up engines and catalysts.

4. RESULTS AND DISCUSSION

The distribution of the weekly mean values of vehicle average speed between 7:00 AM and 7:00 PM is given in Figure 1. The overall mean value of vehicle average speed for current city center driving pattern can be calculated, taking into account the number of vehicles passing the route at various times of the day:

$$\overline{V} = \frac{\Sigma \overline{V}_i \times n_i}{\Sigma n_i},$$

where V_i and n_i are the weekly mean values of vehicle average speed and number of vehicles passing the route for the time interval "i" of the day.

Because accurate values of n_i were not available, it was assumed that the n_i is oppositely proportional to vehicle average speed $\overline{V}_i$. In this manner the overall mean value of vehicle average speed was calculated. It was found, that $\overline{V}$ of today's city center driving pattern is 15.3 km/h, 30% lower than in 1980 (21.8 km/h). This result correlates well with another one (15.4 km/h), obtained on the basis of preliminary data from [9] about the number of vehicles passing the route. During the day, the average speed values change from a minimum of about 10 km/h to a maximum of about 20 km/h. In this range of vehicle average speeds, measurements of fuel consumption and emissions were carried out.

The results of the fuel consumption measurements at various speeds are presented in Figure 2. As can be seen from the Figure, and as was anticipated, the fuel economy of the vehicles becomes worse when average speed decreases. Reduction of the latter from 18-19 km/h to 10-11 km/h leads to 34 - 38% increase in vehicle fuel consumption.

Based on the results obtained here about the reduction of average speed in Israel from 21.8 in 1980 to the current value of 15.4 km/h, it may be estimated that the fuel economy penalties due to traffic congestion are above 15%.

Figure 3 illustrates the results of CO_2 (greenhouse gas) mass emissions at different vehicle average speeds. As can be seen, CO_2 emission performance is quite similar to that of fuel consumption. Average speed reduction from 18-19 to 10-11 km/h leads to rise of CO_2 emissions by about 40%.

The results obtained for the emissions of the other pollutants - CO, HC and NO_x at various average speeds, are much less conclusive and it is impossible at this stage to derive from them definite conclusions.

Figure 4 shows the changes in vehicle fuel economy and pollutants emission with air conditioning in operation. It was found that the use of AC during city center driving leads to 13 - 28% increase in vehicle fuel consumption and generally the penalty is higher for lower average speeds. This follows from the higher relative power increase due to AC operation at lower engine loads.

The CO_2 emission changes, as noted above, are generally similar to those of fuel consumption: AC switching-on leads to the rise of CO_2 mass emissions by 15 - 34%. Operation of the AC system puts an additional load on the engine, which leads to an associated rise of NO_x emissions. An increase by a factor of up to two in NO_x mass emissions has been observed in the tests described here (see Fig. 4). As for the changes in CO and HC mass emissions with AC system in operation, the results, as can be seen from Fig. 4, are inconclusive (different changes in opposite directions have been observed).

The results do not show any significant differences between TWC equipped and non-catalyst vehicle responses to average speed change and AC system switching-on. CO, HC and NO_x emissions of TWC vehicles were, as expected, much lower than those of a carburetor non-catalyst car. The observed reductions of pollutants mass emissions were about 80% for CO and NO_x, and 85% for HC.

5. CONCLUSIONS

Based on the results obtained in the tests, the following conclusions have been reached. The average speed of the current Israeli city center driving pattern is about 15.4 km/h and it is 30% lower compared to that in the year 1980. During a work day, average speed values change from a minimum of about 10km/h to a maximum of about 20km/h.

The fuel consumption of vehicles increases with the average speed drop. A 34 to 38% rise of fuel consumption was observed with average speed reduction from 18 - 19 to 10 -11 km/h. Based on these results, it may be estimated that the fuel economy penalties caused by 30% reduction of average traffic speed from 1980 to 1997 amount to approximately 15%.

Use of air conditioning during city center driving leads to the 13-28% increase in vehicle fuel consumption and generally the penalty is higher for lower average speed.

CO_2 emission changes are generally similar to those of fuel consumption. AC switching-on leads to the rise of CO_2 mass emissions by 15 - 34%. Operation of the AC system puts an additional load on the vehicle's engine and therefore leads to a corresponding rise in NO_x emissions. An increase by a factor of up to two in NO_x mass emissions has been found with AC system operation.

No significant differences were observed between TWC and non-catalyst vehicle responses to average speed change and AC operation. CO, HC and NO_x emissions of TWC vehicles were much lower than those of a carburetor non-catalyst car. The observed reductions of pollutants mass emissions were about 80% for CO and NO_x, and 85% for HC.

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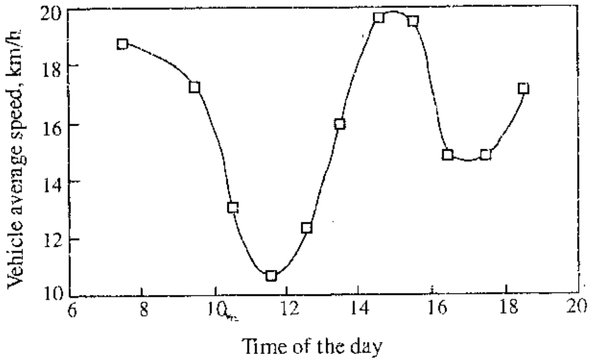

Figure 1. Vehicle average speed distribution within a day.

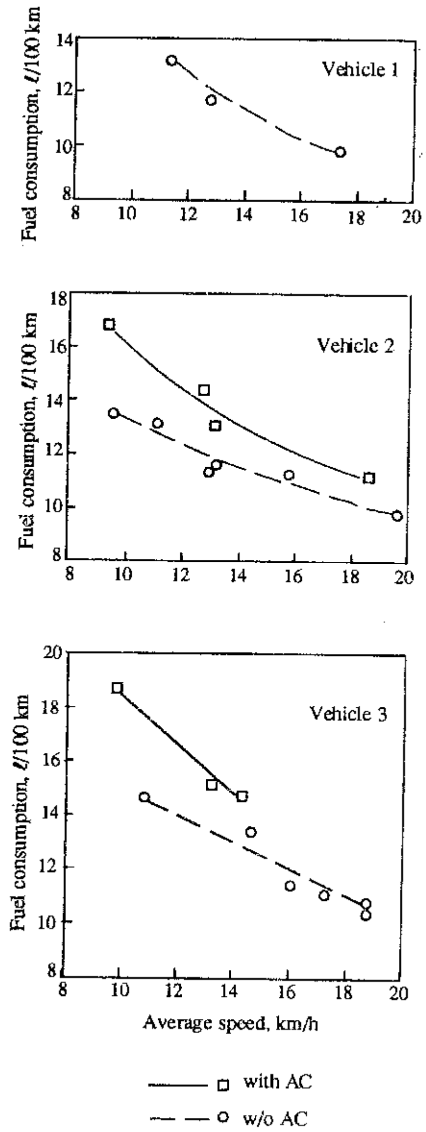

Figure 2. Vehicle fuel consumption vs average speed (city center driving).

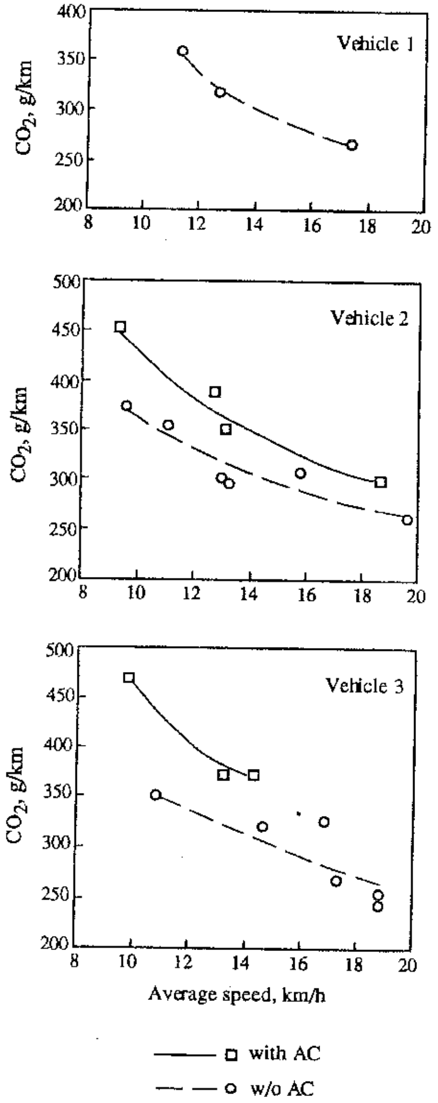

Figure 3. Mass CO_2 emissions vs vehicle average speed (city center driving).

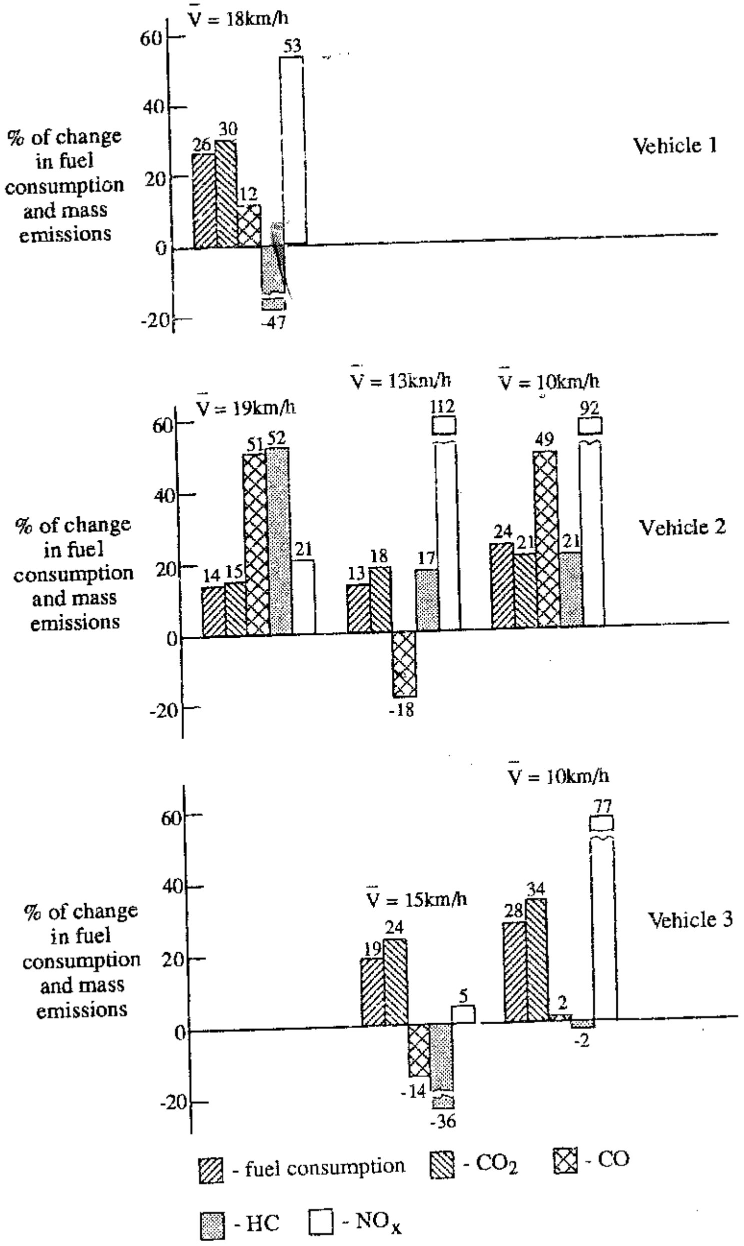

Figure 4. Effects of air conditioning operation on vehicle fuel consumption and emissions.

A REVERSE FLOW CONVERTER FOR DIESEL FUEL ENGINES

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ABSTRACT

Diesel dual fuel engines operate by compression ignition of diesel fuel injected into a mixture of air and gaseous fuel, commonly natural gas. The very efficient combustion process results in exhaust gases that are of relatively low temperature, equal to or less than those from a diesel engine. The exhaust gases contain methane and other hydrocarbons which should be removed. Conventional converters do not effectively destroy hydrocarbons because the exhaust temperature is too low for oxidation catalysts to stay ignited. This paper presents a novel converter concept that uses periodic reversal of gas flow through the catalyst monolith. This allows maintenance of the high temperature oxidation process when the input temperature is as low as ambient. Inclusion of an adsorbent in the reverse-flow converter (RFC) allows effective treatment of start up emissions from internal combustion engines. Computer simulation showed that the RFC provides for complete removal of methane along with other hydrocarbons and CO. The paper discusses the mathematical model of the converter and the results of converter simulation under different operating modes of a diesel dual fuel engine.

INTRODUCTION

Heavy duty diesel engines are significant contributors to local air quality and to global warming. Today there are over 100 million heavy duty diesel engines in operation with an annual production of over 10 million additional new heavy duty diesel engines added to world fleets each year.

A typical diesel bus engine produces about 100 tonnes of CO_2 per year. Vast amounts of CO_2 emitted from all diesel engines are largely unavoidable. This emission can be reduced by about 15 % by using fuel with a lower carbon to hydrogen ratio, such as in the multipoint diesel dual fuel engine [1].

The multipoint diesel dual fuel engine uses a fuel management control system to accurately meter and time separate diesel and natural gas injections into each cylinder so that the benefits of diesel compression ignition are maintained while natural gas fuel is used for power. Diesel-like performance can be achieved with fuel efficiency, power, and torque remaining similar whether operating on diesel or dual fuel. In fact, switching between diesel and dual fuel operation is easily done under load, and is a major advantage when natural gas fueling infrastructure is not available.

One major benefit of dual fuel operation is the cleanliness of natural gas fuel and its impact on lubricating oils, exhaust temperature, and emissions. One drawback of dual fuel operation is the lesser effectiveness of exhaust gas aftertreatment of methane gas due to low exhaust temperature.

This problem can be solved using the reverse flow converter (RFC) concept, pioneered by Matros [2], and widely used today in such catalytic processes as oxidation of SO_2 to SO_3, VOC oxidation in industrial exhaust gases, and selective catalytic reduction of nitrogen oxides [3].

A typical RFC (Fig. 1) operation involves passing a cold inlet flow directly into the preheated bed of catalyst. When the gas flow enters the catalyst or inert packing bed, it picks up heat from the preheated solid material, while the solid material cools down. When the gas temperature increases to levels where the catalyst is active, a catalytic reaction occurs. In the case of an exothermic reaction, the reaction heat is released. After the reaction zone, the gas enters the cooling zone where it gives up its heat energy to cooler solid material. Then it leaves the converter.