an investigation into evaporative hydrocarbon emissions from european vehicles

Prepared by the CONCAWE Automotive Emissions Management Group's Special Task Force No. 1 (AE/STF-1)

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ABSTRACT

The report covers an experimental programme to determine evaporative hydrocarbon emission levels from a range of modern European cars, and the effects of various fuel and vehicle parameters on them. The results are used to estimate an inventory of evaporative hydrocarbon emissions in Europe. These are set in context with the other sources of hydrocarbon emissions. The control options for evaporative and refuelling emissions are compared and the high levels of efficiency for carbon canister controls are shown.

Detailed descriptions of the laboratory test procedures are given and tables are included to record the results of the evaporative emissions tests and to show the methodology used to calculate the overall emission inventory. Figures describe the fuel systems, their large impact on evaporative emissions and demonstrate the effectiveness of various emission control options.

The report reaches conclusions and makes recommendations on the need to alert legislators of the effectiveness of carbon canisters and identifies further areas for investigation. A management style summary is included at the beginning of the report.

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SUMMARY

This report describes a programme carried out by CONCAWE to determine typical hydrocarbon evaporative emission levels from modern European cars, and the effects of various fuel and vehicle parameters on these levels. Ten cars were tested covering a range of engine sizes from 1.1 to 2.5 litres, including carburetted, fuel injected and turbo-charged models. In addition three cars were tested which were equipped with catalysts and evaporative emission control systems to meet current US emission limits, and which closely matched three of the European vehicles tested.

The cars were tested using a modified SHED (Sealed Housing for Evaporative Determination) test procedure developed by the CEC CF-11 group. This procedure requires that the vehicle is warmed up over four ECE-15 test cycles. In addition four of the cars were tested using three other warm-up procedures (US Federal cycle, 90 km/h for 30 minutes, 90% max speed for 30 minutes) to assess the effect of test severity on evaporative emissions. A very wide variation in emissions between different vehicles was found. Using the standard test procedure, emissions varied between 4-16 g/test on a typical European summer fuel and from 9-24 g/test on a more volatile winter grade fuel. The emission controlled cars gave much lower levels, 1-3 g/test on the winter fuel, showing an 85% reduction compared to their equivalent European specification cars. As expected increasing test severity of the warm-up cycle caused a significant increase in emission levels. For the four cars tested, average emissions increased from 15 g/test over the ECE cycle to 48 g/test after 30 minutes at 90% maximum speed.

The effect of gasoline volatility was determined using a set of seven fuels whose volatility parameters were independently varied. Three oxygenated fuels were also tested whose volatilities were closely matched to two of the hydrocarbon fuels. RVP was found to be the only significant volatility parameter to affect emissions. Using the ECE-15 warm-up procedure the effect was linear, and over the range tested a 10 kPa reduction in RVP reduced evaporative emissions by 23%. After 30 minutes warm-up at 90 km/h, a logarithmic correlation between emissions and RVP was found to give a better fit. Oxygenated fuels gave similar or lower emission levels compared to hydrocarbon fuels of equivalent RVP. A MTBE blend in particular produced significantly lower emissions.

A few measurements of true diurnal emissions were made by leaving vehicles in the SHED over a 24 hour period. Results suggest that diurnal losses are significant for uncontrolled cars, although they are not currently included in the CEC test procedure. Analysis of vapour samples taken from the SHED showed that the vapour consisted essentially of C4 to C6 hydrocarbons. A significantly higher proportion of olefins was found in the vapour than in the base fuel.

Exhaust hydrocarbon emissions levels were shown to increase with reducing gasoline volatility. In this case E100 was found to be the only significant parameter; however, for normal commercial fuels there is a general correlation between RVP and E100 levels. Thus, reducing RVP will tend to increase exhaust emission levels.

Using the results of this programme, an estimate has been made of the total inventory of evaporative hydrocarbon emissions in Europe, taking into account variation in climate, fuel volatility, car population and driving patterns. The resulting figure of 1 million tonnes per annum make evaporative emissions the third largest source of man-made hydrocarbons in the atmosphere, after solvent evaporation (4 million tonnes/a) and vehicle exhaust emissions (2.5 million tonnes/a). Refuelling emissions were estimated at only 0.18 million tonnes, less than 2% of the total man-made hydrocarbon emissions. The most effective way of reducing evaporative emissions is clearly to fit carbon canister control systems to all vehicles.

1. INTRODUCTION

It is now some eleven years since the introduction of unleaded gasoline (ULG) and catalysts to control exhaust emissions in the USA and Japan. In Europe exhaust emission levels have also been reduced during this period, but at a more moderate pace without requiring ULG or catalysts. However increasing environmental concern, especially relating to European forests, has led to proposals for more stringent exhaust emission limits. Once these limits are in place, legislators will undoubtedly turn their attention to other automotive emissions, including evaporative hydrocarbon emissions.

Evaporative emissions consist mainly of light hydrocarbons emitted by a vehicle as a result of fuel evaporation through vents open to the atmosphere. They are known to depend on three major factors:

- vehicle and fuel system design;
- ambient temperature and pressure;
- gasoline volatility.

The subject has been studied in some detail in the past, and is discussed in more detail in the next section. Evaporative emission limits are applied in the USA, Japan and Australia, but not as yet in Europe. Control technology has been developed based on the use of adsorbent charcoal canisters to trap the vapours, which are subsequently burned in the engine.

In 1985 CONCAWE set up a task force (AE/STF-1) to study the question of evaporative emissions as related to the European scene. Initially a literature survey was carried out which showed that although much data were available for US cars in the 60's and 70's, there was little recent information, and essentially no data for modern European cars. The major conclusions of the literature survey were:

(i) vehicle design factors have the greatest effect on evaporative emissions and show a spread of up to 5:1 between different designs of uncontrolled vehicles (i.e. without either catalytic converters or evaporative emission controls);

(ii) control technology is available to minimise evaporative emissions from vehicles. In the USA a 90% reduction was achieved from uncontrolled levels;

(iii) based on very limited data on uncontrolled European vehicles, evaporative losses currently contribute approximately 50% of the total vehicle hydrocarbon emissions;

(iv) for uncontrolled US vehicles evaporative emissions have been shown to correlate best with the gasoline volatility parameters RVP and E70. However, for current European vehicles higher distillation points such as E100 may be important;

(v) US data indicate that gasoline volatility has a smaller effect than vehicle design features on evaporative emissions at moderate ambient temperatures;

(vi) gasolines containing alcohols can cause an increase in evaporative emissions due to increased front-end volatility. At matched volatility levels the resultant effect of alcohol fuels on evaporative emissions is still uncertain;

(vii) increasing ambient temperature increases evaporative emissions particularly with high volatility gasolines.

On this basis, and especially in view of the conclusion (iii), the STF-1 task force proposed that a test programme be carried out to determine typical evaporative emission levels from a range of modern European cars, and to quantify the effects of gasoline volatility and oxygenate content. This report presents and discusses the results of this work, carried out by CONCAWE at Esso Research Centre, Abingdon U.K., during June-July 1986.

2. BACKGROUND INFORMATION

Atmospheric hydrocarbon emissions can contribute, via complex chemical reactions with NO_x in the presence of sunlight, to the formation of photochemical smog (ozone). This is a major problem in certain cities, for example Los Angeles and Tokyo and has led to the introduction of severe emission limits in the USA and Japan. In Europe the problem is very much less severe and has only been observed occasionally.

Automotive emissions contribute to total atmospheric HC emissions and arise from two major sources, exhaust emissions and evaporative losses from the vehicles fuel system. This report is mainly concerned with evaporative emissions and the impact on them of changes in fuel volatility, vehicle design and operating conditions.

Vehicle evaporative emissions can be divided into three categories and the relative importance of each depends upon vehicle design and operating conditions.

RUNNING LOSSES

These are defined as losses which occur while the vehicle is being driven.

DIURNAL LOSSES

These occur while a vehicle is stationary with engine off and are due to the expansion and emission of vapour mainly from the fuel tank (tank breathing) as a result of the normal temperature changes which occur over a 24 hour period.

HOT SOAK LOSSES

These occur when a fully warmed-up vehicle is stationary and the engine stopped. Engine heat is then dissipated into the fuel system causing evaporation of the fuel mainly from the carburettor bowl and tank. The major factors which influence the amount of fuel lost during a hot-soak are:

- peak temperatures of the carburettor bowl and fuel tank;
- fuel system design features such as liquid surface area, presence of a fuel tank pressure relief valve and carburettor venting system etc.;
- quantity of fuel in the carburettor bowl and fuel tank;
- volatility characteristics and composition of the fuel.

A number of test procedures have been developed for measuring vehicle evaporative emissions which are discussed in more detail in Section 3.4.

Hydrocarbon losses also arise during vehicle refuelling due to displacement of vapour from the fuel tank. However these are normally much smaller than evaporative emissions.

Evaporative emission control standards have been instituted in the USA, Japan and Australia. To meet these standards, vehicle evaporative emission control systems were first introduced in California in 1970, extended to the rest of USA in 1971, and subsequently adopted by Japan and Australia.

Evaporative emissions can be reduced considerably by relatively simple mechanical modifications such as:

- pressurised fuel tanks with vapour relief valves;
- sealing leaks;
- venting of carburettor float-bowl into the air-cleaner;
- venting of fuel tanks into the crankcase.

Some of these techniques were adequate to meet the initial US emission standards of 6 g/test in 1970-71, but were not sufficient as the limit was progressively tightened in later years. The technique now universally adopted to meet these more severe limits employs canisters filled with activated carbon to which all fuel system vents are connected. Any diurnal or hot soak hydrocarbon vapour emissions will thus be adsorbed by the carbon and retained in the canister, which must be large enough to adsorb some 30-40 grams of hydrocarbon vapour. The carbon is purged of hydrocarbons during normal driving by drawing air back through the canister and into the engine where it is burnt. A typical example of this type of system is given in Fig. 1.

In EEC countries there are currently no evaporative emission limits, and consequently carbon canisters are not normally fitted. However in some countries European and Japanese cars certified to US emission standards are available, which consequently are equipped with carbon canisters.

Currently only the State of California has instituted gasoline volatility limits to control evaporative emissions (9 psi/62 kPa RVP during summer). Recent US Environmental Protection Agency (EPA) studies have shown that many vehicles in service exceed the 2 g/test evaporative emission limit. There are a number of reasons for this, one of which is that vehicles are certified on a reference fuel of RVP 62 kPa, while typical volatility of marketed fuel is now 76 to 90 kPa. Another reason is that the certification procedure permits new carbon canisters to be used without preconditioning which is unrealistic as the initial performance of a carbon canister deteriorates quickly to a stable condition. Consequently the carbon canisters can become overloaded with vapour from the more volatile fuels leading to vapour 'breakthrough' and significantly increased emissions. The

EPA has recently proposed legislation which will require all new vehicles to be fitted with larger carbon canisters to control both evaporative and refuelling emissions. Gasoline volatility restrictions will also progressively be imposed.

If the latter is adopted, it will of course establish a precedent for other countries to follow. The EEC are known to be studying the subject of evaporative emissions, with a view to legislation on the subject. If legislation to control gasoline volatility were introduced in Europe, it would have a major adverse economic impact on oil refining.

3. TEST PROGRAMME

3.1 OBJECTIVES AND STRATEGY

The overall objective of the test work was to obtain information on typical hydrocarbon evaporative emission levels from European vehicles and to establish the relative effectiveness of different control strategies.

The detailed terms of reference as agreed by CONCAWE, together with the programme of work designed to cover each separate aspect, are summarised below:

(a) establish the range of evaporative losses that occur in a representative selection of recent model European vehicles by testing ten cars using two fuels with the CEC evaporative loss test procedure (SHED test) as defined by the CEC CF-11 group. The fuels represent averages of the highest and lowest marketed RVP's in Europe during summer and winter. Criteria for selection of cars are given in Section 3.3;

(b) identify the important gasoline volatility parameters that control vehicle evaporative emissions by testing four of the ten vehicles with seven fuels in which RVP, E70, E100 and E150 are independently varied. The ECE 15 test will be used to warm-up the vehicle as required by the standard procedure. In addition, a more severe procedure that should give higher fuel system temperatures, will be used on three of the cars.

The cars selected for this more detailed investigation will represent a range of engine designs and will show a spread of evaporative emissions as indicated by the tests in (a) above. The effect of severity of the warm-up procedure i.e. of the importance of driving conditions, will be checked using four cars and three additional warm-up procedures i.e. the Federal test procedure, 90 km/h for 30 minutes and 90% of the maximum speed (or 130 km/h, whichever is the lower) for 30 minutes;

(c) establish the impact that oxygenated fuels will have on evaporative emissions by including three fuels containing oxygenates in the test work covered in paragraph (b) above. These will be blended to match specific hydrocarbon fuels, as discussed in Section 3.2;

(d) compare the effect of on-board automotive evaporative control equipment with that of reducing gasoline volatility by testing three cars certified to US standards fitted with control systems and comparing the results with those from the corresponding European versions. The two fuels used in paragraph (a) above will also be used in this work;

(e) establish the importance of diurnal losses, which are measured in the US procedure but not in the European procedure, by carrying out limited tests on selected vehicles.

3.2 FUELS MATRIX

The test fuels were chosen to cover as wide a range of inspection properties as would be representative of European markets. These fuels have been blended from the Intercompany (1) range of cold weather driveability fuels (Intercompany fuels being readily available). Table 1 shows comparative volatility data for some fourteen European countries where the RVP has been selected as the critical inspection property (2). The averages of the lowest and highest marketed RVP's for Europe are 65.8 kPa in Summer and 86.6 kPa in Winter. Two fuels with volatilities close to these levels (coded 357 and 125) were therefore included in the total fuels matrix as shown in Table 2. The correlation matrix is also given in Table 2 showing that the important volatility parameters RVP, E70, E100 and E150 are uncorrelated at the 95% confidence level in this fuel set, and hence the important properties which control evaporative emissions can be independently identified.

Gasolines containing alcohols can cause an increase in evaporative emissions due to increased front end volatility (3), however, the effect of alcohol fuels on evaporative emissions at matched volatility levels is uncertain. Three oxygenated fuels were defined, two containing 3% Methanol/2% TBA and one containing 15% MTBE. The volatilities were matched throughout the distillation range with fuels 125 and 357, European summer and winter grades respectively, as can be seen in Table 3. The data in Tables 2 and 3 represent mean values determined in 3 separate laboratories.

3.3 TEST VEHICLES

In order to meet the objectives of this test work, a wide range of vehicle types and fuel systems was selected. The criteria used for selection were:

- vehicle type: They should be representative of European models;
- engine displacement: Vehicles were selected from each of three categories: below 1.4 litres, 1.4 to 2.0 litres and above 2.0 litres, since these represent small, medium and large vehicles and exhaust emission legislation is related to these categories;

- air/fuel mixture preparation: A range of carburetted, fuel injected and fuel injected plus turbocharged vehicles were selected;

- fuel recirculation: Vehicles with and without fuel recirculation systems were selected;

- cooling fan operation: Cars with fans that are mechanically driven and with electric thermostatic control were chosen.

Ten vehicles were selected using these criteria. In addition three vehicles fitted with evaporative emission control systems were chosen which matched three of the uncontrolled vehicles i.e. same make, model and engine size. These emission-controlled cars were fitted with catalysts and evaporative control canisters to meet US emission limits. Detailed vehicle descriptions are given in Table 4.

Prior to testing in this programme all cars were equipped with thermocouples to enable tank and fuel system temperatures to be recorded. Most of the vehicles had accumulated at least 8000 km, but if a car had a lower mileage it was steam cleaned and soaked for at least one hour at 40°C prior to testing.

The evaporative control systems used on the three controlled vehicles are described in Appendix 1.

3.4 TEST PROCEDURES

One of the difficulties that faced CONCAWE when planning this test programme was to select which test procedure to use as a basis for the work. The only procedure which had official acceptance at the time was the ECE test method TRANS/SCN/WP29/R.205 which involved the use of carbon canisters fitted at strategic points on the car's fuel system to adsorb potential hydrocarbon losses. However, the CEC group CF-11 has developed a European version of the US SHED test procedure. Their position paper reference RDF-72-83, shows that the SHED technique has better repeatability and that test data indicated that the carbon canister procedure can underestimate evaporative losses by up to 87%. This was thought to be mainly due to losses from fuel sources where it is not possible to attach a canister, e.g., throttle spindles and fuel hoses. They also point out that even small leaks in the fuel system, which would barely show up on a pressure test, can result in large hydrocarbon losses. This procedure is given in detail in Appendix 2.
A further criticism is that the canisters themselves can cause a restriction to the natural flow of vapours and therefore artificially reduce losses. For these reasons, it was decided to use the CEC test procedure which utilises four ECE 15 cycles to warm up the vehicle, and the use of a sealed housing (SHED) to allow total losses to be measured.

An alternative considered was use of the US Federal test procedure - but there are very significant differences between this and the CEC procedure, as shown below.

	US Test	CEC CF-11 Test Procedure
Running losses	Not measured but procedure being reviewed	Measured by canisters
Diurnal losses	Simulated by 1 hour test when fuel temperature increased by 13°C	Not measured
Test cycle	Federal test procedure 23 min. "road" cycle 10 mins. soak 8 mins. "road" cycle	4 ECE-15 cycles 13 mins.
Hot soak losses	1 hour in SHED	2 hours in SHED

Considering each of the four elements in turn, it will be seen that running losses are measured in the CEC CF-11 procedure by the use of carbon canisters but not in the Federal procedure. Diurnal losses are measured in the US test, but were considered unlikely to be of great importance in the European procedure and therefore were not included.
The US diurnal procedure involves increasing the tank fuel temperature by 13°C by means of a heater - this increase in temperature has been estimated as a typical diurnal temperature change in the USA. However in Europe the average diurnal change is only about 8°C (see Table 11), and so the use of the US procedure here would be rather misleading. In the event, it was decided to investigate true diurnal emissions separately from the main programme to establish typical levels that are likely to occur in practice.
The test cycle itself is very different for the Federal and the CEC CF-11 test procedure, not least because the Federal test is longer and has a higher average speed and the fuel probably becomes hotter, leading to higher losses. There is also a 10-minute "soak" during the Federal test, which would have some influence on losses. Finally, the hot soak part of the test lasts for only one hour in the Federal test, versus two hours for the CEC CF-11 test procedure.
In view of the fact that some European countries have effectively accepted the US Federal test procedure, it was decided that it was important to obtain data using this method. However for the data to be comparable to the CEC CF-11 test procedure, it was considered necessary to use results including running losses, but ignoring the diurnal part of the cycle, and by leaving the vehicle in the SHED for two hours as in the CEC CF-11 test procedure.
Another reason for including the Federal procedure in the test programme was to show the effect that changing the warm-up cycle has on the hot soak emissions. Since both the Federal and the ECE 15 procedures are relatively mild, two other warm-up

procedures were also investigated - 90 km/h for 30 minutes and 90% of the vehicle's maximum speed for 30 minutes.

Thus in summary, the SHED procedure developed by CEC CF-11 was used but four warm-up procedures were investigated:

1. four ECE-15 cycles as specified by CF-11;

2. EPA Federal Test Procedure FTP/75;

3. 90 km/h for 30 minutes;

4. 90% of maximum speed or 130 km/h for 30 minutes, whichever is the lower.

In all four cases, running losses were measured by attaching oversized carbon canisters to the points at which evaporation was expected. A hydrocarbon detector was used to ensure that there were no significant leaks. To conserve fuel, in the preconditioning phase only, 10 litres of fuel rather than 40% of tank capacity as required by the procedure, was used. This was considered to be justified since the prime purpose of the preconditioning phase is to ensure that test fuel is in the carburettor/injector system during the test phase. Limited testing using 40% of tank capacity versus 10 litres showed no significant differences.

Exhaust emissions were measured over the ECE 15 and Federal test cycles. In the ECE test, two bags were taken, the first representing the first two ECE 15 cycles (i.e. while the vehicle was warming up) and the second representing ECE 15 cycles 3 and 4 (i.e. when the car is expected to be fully warmed up).

Diurnal tests were carried out in a number of different ways and these are described in Section 4.7. No standard procedure is available for European testing, so that the aim was to estimate the total evaporative emissions likely over a 24 hour period. The data obtained would help to establish the need for such a test in Europe and, if so, to obtain some preliminary information that would assist in the definition of such a test.

4. RESULTS AND DISCUSSION

All the data obtained in the test programme are summarised in Appendix 3.

4.1 PRECISION OF TESTING

The test programme was designed to include a number of duplicate determinations in order to make an estimate of test precision. Since all test results have been obtained in one laboratory, it is only possible to estimate repeatability (i.e. not reproducibility).

The following precision data were generated for four test vehicles (VW Jetta, Toyota Corolla, Alfa Romeo, Ford Fiesta) using seven test fuels using the European ECE-15 warm-up driving procedure only. The standard deviation and coefficient of variance was calculated for each pair of repeat tests and averaged. Statistical procedures (such as Cochrans or Dixons tests) were not employed to remove outlying results as only limited repeat data were obtained on each vehicle.

Test	Min	Max	Mean	Average Standard Deviation	Coefficient of variance (Std. Dev) / (mean)
	g/test				
Evaporative Emissions					
Running Losses	0.0	9.5	2.6	0.72	0.47
Hot Soak Losses	3.5	28.6	11.6	1.33	0.11
Total Evap. Losses	3.5	33.7	14.3	1.57	0.11
Exhaust Emissions					
Bag 1	2.8	21.6	7.6	0.90	0.09
Bag 2	2.7	11.0	5.9	0.44	0.06
Total	5.5	32.6	13.5	1.20	0.07

The quoted repeatability data should only be used as a guide to the precision of the test work as insufficient repeat data were generated to enable a true statistical statement to be made.

4.2 RANGE OF EVAPORATIVE LOSSES FOUND IN CURRENT EUROPEAN CARS

The ten European cars summarised in Section 3.3 and Table 4 were each tested using two fuels, one representing a European winter fuel (coded 357), and the other a European summer fuel (coded 125). Results using the ECE warm-up procedure are given in Appendix 3, Table 1A and shown as a bar chart in Fig. 2. From these results it can be seen:

- vehicle design has a very large influence on evaporative emissions. The range of hydrocarbon losses from 9.3 to 24.5 g on winter fuel, and from 4.0 to 16.0 g on the lower volatility summer fuel, represents a very wide spread;
- reducing RVP by 21 kPa (3 psi) reduced test evaporative emissions by 45% for the median car;
- on average for these ten European cars for both the summer and winter fuels, the running losses represented 16.7% and the hot soak 83.3% of the total measured evaporative losses.

4.3 INFLUENCE OF TEST PROCEDURE ON EVAPORATIVE LOSSES

Four of the ten uncontrolled vehicles were selected to evaluate the effect of changing the warm-up part of the test on evaporative emissions as described in Section 3.4.

The averaged results of tests on the four cars (Ford Fiesta, VW Jetta, Alfa Romeo 2.5, and Toyota Corolla) using a winter grade fuel (coded 357) are summarised in the table below and illustrated in Fig. 3.

	Averages of 4 cars (g/test)			%	%
Procedure	Running losses	Hot soak	Total	Running losses	Hot soak
1) ECE 15	2.70	12.01	14.71	18.4	81.6
2) Federal	12.33	13.45	25.78	47.8	52.2
3) 90 km/h	15.73	20.40	36.13	43.5	56.4
4) 90% V max	20.83	27.67	48.50	43.0	57.0

From these average results it can be seen that:

- hot soak losses over two hours are similar for the Federal and ECE warm-up procedures, but increase as the driving cycle becomes progressively more severe;
- the running losses for the Federal procedure, however, are much higher than for the ECE 15 procedure, due to the much longer period that the car is actually running on the chassis dynamometer (losses during the 10 minute soak in the Federal Procedure have been ignored);
- the running losses become progressively greater as one goes from ECE to Federal to 90 km/h to 90% of the maximum speed;

- the contribution that running losses make to the total is between 40 and 50% for all the procedures except the ECE, where it is only 18%. This figure is consistent with the figure of 16.7% determined for all ten cars as given in Section 4.2;

The European cycle adopted by the CEC CF-11 committee was designed to be representative of European urban driving conditions, hence this procedure should give a good indication of the evaporative losses to be expected in practice under these conditions - ignoring diurnal losses which are discussed later.

Although the Federal test requires only a one hour soak in the SHED, as stated earlier it was decided to run for two hours in order to make the results comparable with the other three procedures. A continuous trace of hydrocarbons versus time was taken and from this it was possible to determine the hydrocarbon concentration after one hour. Analysis of these test results showed the two hour hydrocarbon concentration is 30% higher, on average, than the one hour figure (it varied from 15% to 45% higher for individual cases). After two hours the rate of evaporation is much slower and reasonably constant. To convert the reported Federal results to a true Federal test, but without diurnal losses, one would need to omit the running losses and multiply the total two hour hot soak losses by 0.77. A two-hour soak gives a better (but higher) representation of the true hot soak losses than a one-hour soak since they have by then stabilised to a constant rate.

4.4 INFLUENCE OF ON-BOARD CONTROL SYSTEMS ON EVAPORATIVE LOSSES

As has already been indicated, three pairs of vehicles were tested in which one of each pair was fitted with an evaporative control system to enable it to meet US Federal regulations. These vehicles were the Honda Civic, the Alfa Romeo, and the Opel Ascona (which was matched with a Vauxhall Cavalier of the same engine size etc.).
These six vehicles were tested (ECE procedure) using the winter and summer grade fuels with the following results:

Evaporative losses (g/test)

Fuel 125 (summer grade RVP = 62 kPa/9 psi)

Car	Evap. control System	Running losses	Hot soak losses	Total evap. losses
Opel Ascona/Vauxhall Cavalier	Yes	0	1.8	1.8
" " " "	No	1.3	3.0	4.3
Honda Civic	Yes	0	1.3	1.3
" "	No	0	4.0	4.0
Alfa Romeo	Yes	0	2.0	2.0
" "	No	0.9	7.3	8.2

Evaporative losses (g/test)

Fuel 357 (winter grade RVP = 83 kPa/12psi)

Car	Evap. control System	Running losses	Hot soak losses	Total evap. losses
Opel Ascona/Vauxhall Cavalier	Yes	0	1.4	1.4
" " " "	No	3.8	11.1	14.9
Honda Civic	Yes	0	1.2	1.2
" "	No	2.7	8.0	10.7
Alfa Romeo	Yes	0	3.2	3.2
" "	No	0.8	12.3	13.1

These results are illustrated in the form of a bar chart in Fig. 4, and are compared with all of the European versions in Fig. 5.
It can be seen that all the controlled vehicles would probably meet the Federal Regulations (2.0 g/test max) when tested on fuel 125 - which has the same RVP as the standard Federal test fuel. This is particularly so when account is taken of the shorter time required in the SHED by the Federal test which would reduce the total losses (there are no running losses) by a factor of 0.77. The Honda Civic was supplied from the USA for this test work and had been fully tested prior to its despatch. It showed a total of 1.3 g/test, using the Federal cycle and including diurnal losses. The uncontrolled cars, on the other hand, showed total emissions between two and four times higher than the controlled versions on this fuel.
Similarly, all the controlled vehicles gave extremely low results on the winter grade fuel (357), although the Alfa Romeo was somewhat higher than the other two. The uncontrolled versions gave total emissions between four and ten times greater than the controlled vehicles.
If the averages of the total losses are considered, then control systems reduced the total evaporative losses by 64% on the summer grade fuel, and by 85% on the higher volatility winter grade fuel.

4.5 INFLUENCE OF FUEL VOLATILITY ON EVAPORATIVE LOSSES

It was considered essential to determine which fuel volatility parameters influenced evaporative losses from European vehicles. As shown in Section 3.2, the inspection properties RVP, E70, E100, E150 of the seven fuels used in this work are uncorrelated. Thus in this test programme the relative contribution that each fuel parameter makes could be accurately assessed. The mean temperature in the SHED was also included as a variable, since this could have an influence over and above that of gasoline volatility, even though it varied over a comparatively narrow range. Four cars (Ford Fiesta, Alfa Romeo, VW Jetta, and Toyota Corolla) were tested with these seven fuels, using the ECE 15 procedure. Three cars (the Alfa Romeo was omitted) were tested using the 90 km/h for 30 minutes warm-up procedure to establish if this more severe driving condition changed the fuel parameters which control evaporative emissions.

Considering first the tests using the ECE procedure; linear regression equations were developed using the evaporative losses as the dependent variable and volatility parameters as the independent variables. This was done for each of the four cars in turn and then for all four cars together, but using car model as a dummy variable. The equations were computed in a step-wise fashion, firstly with a single variable and then with pairs of variables, three variables, and so on. Only variables with t values greater than 2.0 were accepted as significant. Table 5 shows, for total evaporative emissions (TEV), Hot Soak (HS) and Running Losses (RL), the coefficients determined, the t values obtained for each coefficient (provided they are greater than 2.0), and the correlation coefficient (R^2) for each equation. The equations for total evaporative losses show that RVP is the only parameter which is consistently significant and accounts for most of the variability. In individual cases other terms can be significant when used together with RVP (e.g., mean SHED temperature with the Alfa, E70 with the Corolla), but there is no consistent pattern. When all the results are put together using vehicle model as a dummy variable, the only term in addition to RVP which is consistently significant is SHED temperature which, of course, is not a fuel variable.
For hot soak a somewhat similar pattern emerges as would be expected, with the only equation of interest being the one with RVP and SHED temperature. Also for running losses, RVP was the only significant parameter that gave a high R^2 value, although for the Corolla the addition of both E70 and SHED temperature improved the prediction. However when all the results were considered, the only equations with all the variables significant and with acceptable R^2 values were those containing RVP alone. Thus it is clear that RVP is the only significant volatility parameter which influences total evaporative emissions, hot soak losses, and running losses, when the car is driven using the ECE test procedure. The high R^2 values indicate that it is a linear effect since linear regression equations give a good fit, and this is confirmed by plots of the data (Figs. 6 to 9).

Turning to the situation when the vehicles were warmed up using 90 km/h for 30 minutes prior to putting them in the SHED, the equations developed are summarised in Table 6. For this work only three cars were used (Alfa Romeo omitted). Linear regression equations were developed which again showed reasonably good correlations with RVP for all the cars, but other terms only occasionally appear as significant.

A plot of the data of TEV against RVP alone (Figs. 6 to 9), suggests that although linear regression lines give reasonable R^2 values, the influence of RVP is, in fact, non-linear under this more severe driving regime.
The use of a logarithmic term was then investigated which gave a significantly better correlation (higher R^2 values) as demonstrated in the following table:

Vehicle	Total Evaporative Losses (TEV) R^2 values for dependent variable	
	TEV	ln TEV
Ford Fiesta	.51	.57
Toyota Corolla	.82	.89
VW Jetta	.83	.99
All cars	.73	.79

The equations for hot soak and running losses were similar, with RVP clearly the only meaningful parameter. This RVP effect was also non-linear as indicated below by the improvement in R^2 values for the logarithmic versus linear equations.

Vehicle	Running losses (RL) R^2 values using as dependent variable:		Hot soak losses (HS) R^2 values using as dependent variable:	
	RL	ln RL	HS	ln HS
Ford Fiesta	.37	.98	.56	.63
Toyota Corolla	.73	.81	.86	.90
VW Jetta	.92	.98	.40	.95

It can be seen that ln RL gives an extremely good correlation with running losses for all three cars, and the non-linearity is particularly important in the Fiesta. Similarly, for hot soak there is a dramatic improvement in R^2 by using the non-linear equation for the Jetta.

In summary it can be said that for urban driving conditions, (as used in the ECE procedure), evaporative emissions are linearly related to RVP levels, i.e. for the four cars tested:

$$TEV_{ECE} = -14.8 + 0.42\ RVP\ (kPa)$$

$$RL_{ECE} = -3.1 + 0.10\ RVP\ (kPa)$$

$$HS_{ECE} = -11.2 + 0.32\ RVP\ (kPa)$$

For more severe driving conditions, as represented by 90 km/h for 30 minutes, the following equations would apply for the three cars tested:

$$\ln TEV_{90km/h} = 1.5 + 0.03\ RVP\ (kPa)$$

$$\text{i.e., } TEV_{90km/h} = e^{(1.5 + 0.03\ RVP)}$$

and similarly $\ln RL = 0.4 + 0.03\ RVP\ (kPa)$

and $\ln HS = 1.1 + 0.02\ RVP\ (kPa)$

4.6 INFLUENCE OF FUELS CONTAINING OXYGENATES ON EVAPORATIVE LOSSES

Three oxygenated fuels were specially blended with volatilities matched, as closely as possible, to either fuel 357 or 125. Table 3 summarises the volatility of these 3 fuels and compares them with the corresponding hydrocarbon fuel. RVP's for the oxygenated fuels were measured using a dry test method. As can be seen there is excellent agreement between the corresponding fuels, the only significant deviation being the RVP of fuel 15A versus fuel 125. However, as has been shown in Section 4.5, it is only RVP that influences evaporative losses and under the conditions of the ECE test this RVP effect is linear. Thus it is relatively easy to correct the results for the hydrocarbon fuels to the same RVP level as the oxygenated fuels.

Three cars were tested with the three oxygenated fuels using the ECE-15 warm-up test procedure. The following table summarises the average results for each car on hydrocarbon fuels 357 and 125 (two tests were carried out on each car with each fuel) and single results on fuels 35A, 35E and 15A. Results are also given for hydrocarbon fuels adjusted by interpolation to the same RVP levels as the oxygenated fuels.

	TOTAL EVAPORATIVE EMISSIONS (g/test)								
Fuel	WINTER FUEL			WINTER FUEL			SUMMER FUEL		
Fuel Code	35A	357	357 corrected to 81.1	35E	357	357 corrected to 82.4	15A	125	125 corrected to 66.0
RVP (kPa)	81.1	82.2		82.4	82.2		66.0	61.6	
Ford Fiesta	11.2	11.2	10.9	8.0	11.2	11.2	5.6	4.8	6.2
Alfa Romeo	12.6	14.0	13.7	9.4	14.0	14.0	8.8	8.2	9.4
VW Jetta	18.5	19.8	19.3	18.2	19.8	19.8	10.8	9.4	11.7

From these data it can be seen that in most cases the total evaporative emissions are lower for oxygenated fuels than for hydrocarbon fuels of the same volatility. The percentage reductions are summarised below and the data are shown in bar-chart form in Fig. 10.

	% Change in total Evap. Emissions - Oxygenated vs HC fuel		
Type Oxygenate	Winter 3% MeOH + 2% TBA	Winter 15% MTBE	Summer 3% MeOH + 2% TBA
Ford Fiesta	+3%	-29%	-10%
Alfa Romeo	-8%	-33%	-8%
VW Jetta	-4%	-8%	-6%

The average reduction in evaporative emissions when 3% methanol plus 2% TBA is used in both winter and summer fuels, is 5.5% but this is not a significant difference. However, 15% MTBE shows a much larger average reduction (23%). This may be significant, but a much larger test programme would be necessary to establish the difference with a high level of confidence.

In summary it can be said that oxygenated fuels do not increase evaporative emissions as compared with hydrocarbon fuels, provided they are blended to the same RVP, and they may even reduce them.

It is recognised that oxygenates can reduce the FID response. Previous work (4) has used a correction factor of 1.05 to account for this effect. Such a correction would not be significant in the limited tests of this project and no corrections have been applied.

It should be stressed that these results were obtained on vehicles without evaporative control systems. There have been suggestions in the USA that alcohols may be preferentially adsorbed in the carbon, and not fully desorbed during the purge mode, thus reducing the capacity of the canister. It is conceivable that the canisters used to measure running losses could have been affected, but these had a very large capacity so it is unlikely they would have become saturated.

4.7 DIURNAL EVAPORATIVE LOSSES

As has already been stated diurnal losses are estimated in the Federal procedure by applying heat to the tank of the vehicle over a period of one hour, so that the fuel temperature is increased by 13°C, and measuring the total evaporative emissions using the SHED.

This technique was not used in the CONCAWE study since it would have required special heating blankets, and it was considered that in this initial work the diurnal losses should be measured under more realistic conditions. A series of tests was therefore carried out in which the vehicle was allowed to stand in the SHED for 24 hours, so that the ambient temperature within the SHED changed to some extent in accordance with the outside conditions. Mostly the vehicle was pushed into the SHED while it was cold, i.e., it had been pre-conditioned to ensure the correct fuel was in the fuel system, allowed to soak for at least six hours at normal ambient temperature, and then the tank filled to 40% capacity with test fuel prior to putting the vehicle into the SHED.

In one case the vehicle was left in the SHED following a hot soak, and the emissions, fuel and ambient temperatures were recorded over a period of several days. However, in most of the experiments the hydrocarbon level was only checked at the beginning and at the end of each 24-hour period, although a continuous record of ambient and fuel temperatures was always made.

It should be mentioned that the fuel was normally introduced at a temperature of about 15°C and since the ambient temperature was generally in the range 22-30°C while the test work was in progress, there was normally a significant fuel temperature change of up to 13°C. However, probably because of the insulating effect of the SHED, ambient temperature changes were relatively small - often only a few degrees.

Tables 7A and 8A in Appendix 3 summarise the results of the diurnal tests carried out and Figs. 11 - 14 show temperature profiles of all the tests.

A more detailed programme of tests was also carried out using the VW Jetta, in which a number of different parameters were varied so that the factors responsible for diurnal losses could be identified.

Comparing measured diurnal losses with total evaporative losses, and ignoring variations that might have occurred during the diurnal testing, the following data were obtained with a fuel of 62 kPa RVP:

Vehicle	Diurnal losses (g/test)	Total evaporative losses (g/test)
VW Jetta	9.1, 15.7	8.1
Alfa Romeo	21.4	8.2
Toyota Corolla	7.4	9.4
Ford Fiesta	18.9	4.9

These results show that the diurnal losses can be several times greater than total evaporative losses. The difference in two results for diurnal losses for the VW Jetta also indicates that

other factors such as fuel or ambient temperature may have a large effect.
In order to try and identify those factors that influence diurnal losses, the data obtained on the Jetta using two different fuels, and a range of temperature changes, etc., were subjected to linear regression analysis. A number of factors were investigated, but the parameters which gave the best equations were:

DT = Sum of increases in fuel temperature over the 24-hour period

TM = Maximum fuel temperature in degrees centigrade

RVP = RVP of fuel in kPa

The following equation was obtained for this vehicle:

Diurnal losses = 0.51 DT + 0.62 TM + 0.22 RVP - 24.89

Each of the parameters in the above regression equation had a t value greater than 2 (indicating significance at the 95% level), and the R^2 value (indicating degree of correlation) for the overall equation was 0.99.
Using this equation, and taking DT = 8°C, TM = 30°C maximum, and fuel RVP = 83 kPa, then a reduction in RVP of 21 kPa would give rise to about a 30% reduction in diurnal losses. By comparison, a lower maximum fuel temperature of 25°C would give a 20% reduction in diurnal losses.
Increases in temperature of the fuel appear in these tests to have a much lower influence than the other two factors, for example temperature increase to 16°C instead of 8°C would only increase emissions by 25%.
To establish the influence of evaporative emission controls on diurnal losses, the three vehicles fitted with control systems were also tested, using the 62 kPa fuel. The results, compared with one corresponding European version, are as follows:

	Controlled vehicles			Uncontrolled
	Honda Civic	Opel Ascona	Alfa Romeo	Alfa Romeo
Diurnal losses (g/test)	4.1, 3.2	2.6	4.7	21.4
Total evaporative losses (g/test)	1.3	1.8	2.0	8.2

The above results have not been corrected in any way for different levels of ambient temperature or fuel temperature increase, but all have been tested on the same fuel (fuel 125, i.e., summer grade).

From these results we can conclude:

- control systems have a very large effect on reducing diurnal emissions - on the Alfa Romeo the reduction is 80% (versus 30% for reducing RVP by 21 kPa on the Jetta);
- diurnal emissions are clearly important and should not be ignored as is the case with the CEC CF-11 test procedure;
- a new test to determine diurnal losses is needed, which does not rely on uncontrolled ambient conditions, or on artificially heating the tank. Preferably it needs to be much shorter than 24 hours.

4.8 COMPOSITION OF VAPOUR BY EVAPORATION

A limited number of tests were carried out in which small bag samples were taken from the SHED atmosphere at the end of the two hour period, and subjected to GC analysis. The full results are given in Table 9A of Appendix 3 which includes the GC analysis of the fuel itself.

There was poor agreement between the total hydrocarbon figures determined by the GC and by the SHED FID. The ratio of GC/FID for each test is given in Table 9A Appendix 3, and if the highest and lowest values are discarded ratios range from 0.67 to 1.18, average 0.85. This suggests that loss of hydrocarbons when sampling for GC analysis may be the major problem.

As might be expected, the evaporated vapour consisted mainly of light C4 and C5 hydrocarbons. As the composition of the base fuel varied widely, Table 9A in Appendix 3 shows the ratio of hydrocarbons in the vapour phase to that in the fuel. Although there is considerable variation on average the following relationships were found:

	Ratio HC in vapour/fuel (wt)
C4 hydrocarbons	5.5:1
C5 "	3.3:1
C6 "	2.2:1
C7 "	1.5:1
C7+ "	0.1:1

The results in Table 9A also show that the ratio was significantly higher for C4 and C5 olefins than for saturates. Again there is considerable variation, but the average figures are:

	Ratio of HC in vapour/fuel (wt)
C4 Saturates	4.7
C4 Olefins	6.3
C5 Saturates	2.4
C5 Olefins	4.2

For C6 compounds there was too much variation to draw conclusions. For example benzene (C6 aromatic) ratios varied from 0.6 to 6.9, although with one notable exception benzene concentration in the vapour was not above five per cent weight.

Measurements of MTBE content in the vapour showed similar levels to its concentration in the fuel. However, methanol vapour levels were in fact much lower than the fuel concentrations.

In view of the limited number of analyses undertaken and the wide variability of the results, it is felt that no firm conclusions can be drawn, and a more detailed programme would be needed to fully investigate these aspects.

4.9 EXHAUST EMISSIONS

It was considered important to measure exhaust emissions at the same time as the evaporative emissions so that a direct comparison could be made. All results obtained are given in Appendix 3 and summarised in Fig. 15.

The fuel parameters that influence exhaust hydrocarbon emissions were determined for each of the four vehicles tested on all of the seven test fuels using the ECE procedure (Ford Fiesta, Toyota Corolla, VW Jetta and Alfa Romeo). Equations were derived for three cases:

- Bag 1, i.e. the hydrocarbon emissions obtained during ECE cycles 1 and 2 during which the vehicle is warming up and the choke is in operation for at least some of the time;
- Bag 2, i.e. hydrocarbon emissions during ECE 15 cycles 3 and 4 when the vehicle should be warmed up;
- Total HC i.e. the sum of the hydrocarbon emissions in Bags 1 and 2.

Table 7 summarises the equations obtained when the t value for individual coefficients is 2.0 or more. This means that only coefficients which are significant at the 95% confidence level have been considered.

The Alfa Romeo did not yield any equations in which the coefficients were significant. However the other three vehicles all gave satisfactory equations although the overall correlation coefficients (R^2 values) were lower than found for evaporative losses equations.

For the three vehicles giving acceptable equations, E100 is the only fuel parameter that is consistently significant. It is always negative, which indicates that as the volatility increases, hydrocarbon emissions are reduced. The VW Jetta also showed RVP (positive coefficient) and E70 (negative coefficient) as significant for Bag 1 and Total HC. The combined effect of RVP and E70 tend to cancel each other for this one vehicle. The Toyota Corolla also showed RVP as being significant for Bag 1, but it was negative and coupled with a negative coefficient for E150. However the preferred equation for this car, i.e. the one having the highest R^2 value, for Bag 1 would be the one having only E100 as the only significant fuel variable.

It appears that RVP has little or no direct effect on exhaust hydrocarbon emissions, but it is E100 that is the most important fuel variable. However for commercial fuels RVP is correlated with E70 and E100, so that it is true for most cases that increasing RVP reduces exhaust hydrocarbon emissions. The fuel matrix used in this work was carefully designed to eliminate such intecorrelations and the fuels are not typical of commercial fuels.

The general conclusion that can be drawn from these results is that for typical commercial fuels, hydrocarbon exhaust emissions tend to decrease as fuel volatility increases.

4.10 RELATIVE CONTRIBUTION OF EXHAUST AND EVAPORATIVE EMISSIONS TO TOTAL HYDROCARBONS EMISSIONS FROM VEHICLES

As explained in Section 2, hydrocarbon emissions from gasoline engined vehicles arise from the following sources:

- evaporative losses from the vehicle fuel system:
  - hot soak losses;
  - running losses;
  - diurnal losses;
- vapour losses during refuelling;
- exhaust hydrocarbon emissions;

Hydrocarbon emissions from paint, tyres etc. have not been considered in detail in this report due to their low contribution to overall evaporative emissions.

In order to compare the relative contribution of these various sources to total hydrocarbon emissions, it is necessary to relate results from standard emission test cycles to normal road usage. Exhaust and evaporative emissions will not generally occur at the same time, therefore it is necessary to consider emissions over a fixed time period, such as one day or one year, taking into account average driving patterns. Emission factors can be developed in terms of gHC/km or gHC/kg fuel, which can provide a reasonable comparison of relative contributions to total emissions.

4.10.1 Driving patterns

Official EEC data (5) on the current European car population in terms of vehicle size, annual mileage and fuel consumption are given in Table 8.

Data on the relative proportions of different types of driving (i.e. motorway, urban etc.) are scarce, however some recent UK and German data are available (6) (7) as shown in Table 9.

4.10.2 Evaporative emissions

To calculate the total evaporative emissions for a vehicle over one day, the average number of journeys per day (hot soaks) and the average km/day (running losses) must be known. An early US survey (8) quotes 3.3 journeys and 47 km/day, and a UK survey quotes 3.4 journeys and 39 km. For our purposes we will use a figure of 3.4 journeys/day and take average mileage from Table 8.

Emissions can then be calculated as follows, per day:

- hot soak
  - 3.4 x measured hot soak;
- running losses
  - K/4 times measured running losses where K is km/day, and 4 km is the distance for 4 ECE cycles;
- diurnal
  - 3.4 hot soaks and running losses account for 8 hours, so remaining 16 are covered by 0.66 x measured diurnal losses.

Evaporative emissions will obviously vary with ambient temperature and fuel volatility, therefore in order to estimate total emissions in Europe, these parameters must be taken into account. To do this we have split Europe into seven climatic regions and taken the average temperature for each month based on published meteorological data (9). Average volatility levels were estimated for each region based on published data (Octel survey) or national specification. Table 10 shows this data together with figures for the total car population in each region (10).

Typical diurnal temperature variations were also estimated from climatic data as shown in Table 11.

All the CONCAWE data were obtained at temperatures of 26-30°C as specified in the test procedures, with a range of fuel volatilities. To estimate emissions at lower temperatures and other volatilities, the following procedure was used.

The only published data on the effect of temperatures on evaporative emissions from uncontrolled cars are that of Eccleston and Hurn (15) (16) (see Appendix 4). Their data on the effect of RVP at various temperatures is shown in Fig. 1A, Appendix 4. This data is replotted against RVP in Fig. 16, together with the CONCAWE figures. Clearly the general shape of the curves is similar which suggests that it is reasonable to extrapolate the CONCAWE data based on the relationships established by Eccleston and Hurn. Fig. 17 shows some of their data split up into "full size" and "compact" US cars, with logarithmic curves fitted to the data points.

The CONCAWE data can also be split into large and small cars (above/below 1.4 litres) as below, but there was no significant difference between cars above 2.0 litres and between 1.4-2.0 litres.

The CONCAWE figures for 62 kPa fuel are also plotted on Fig. 17, and fall very close to the US data. Consequently we have taken the curve for US "compact" cars and drawn similar curves through CONCAWE data points at different RVP levels to extrapolate emissions over the required range of temperatures and volatilities.

Average evaporative emissions - g/test

	RVP-62 kPa		RVP-82 kPa	
	Running losses	Hot soak	Running losses	Hot soak
Large cars >1.4 l	1.6	8.0	3.1	16.2
Small cars <1.4 l	0.9	5.0	2.2	9.0

The average ratio of RL/HS is 17/83 (see Section 4.2), so we have extrapolated total emissions and calculated RL and HS based on the above ratio. Diurnal losses were based on the following equation, determined for only one vehicle, as discussed in Section 4.7.

Diurnal losses = $-25 + 0.51\ DT + 0.62\ TM + 0.22\ RVP$

To reduce complexity, an average value for DT was assumed for each temperature zone as below, based on the figures in Table 11.

Zone	TM °C	DT °C
A	-7.5	5
B	-2.5	5
C	2.5	6
D	7.5	8
E	12.5	9
F	17.5	10
G	22.5	11
H	27.5	12

Using the techniques described above, running losses, hot soak and diurnal losses figures were calculated for combinations of ambient temperature and volatility, as shown in Table 12. Combining these figures with those given in Table 10, and using traffic statistics from Tables 8 and 9, the mass evaporative emissions for each region and period were calculated and summed to give a total annual figure for evaporative emissions in Europe of 1,010,000 tonnes.

To investigate the sensitivity of these calculations to changes in gasoline RVP, another calculation was made assuming that RVP was limited to 60 kPa during the summer period only (May-September inclusive). This resulted in a figure of 909,000 tonnes, a reduction of only 10%.

4.10.3 Refuelling emissions

Refuelling losses have been studied in some detail. in the USA recently. Work by the EPA (10) gave values between 4 and 7 g/US gal, an Exxon (11) study showed 6 g/US gal for a 63 kPa fuel., and Mobil (12) quoted 5 g/US gal. An average figure of 5 g/US gal (1.3 g/1) agrees well with figures generated in a previous CONCAWE study. Refuelling emissions can now be calculated for the three vehicle size classes, using fuel consumption and car population data from Table 8, as shown below:

Refuelling losses

Vehicle Type	Fuel consumed 1/year	Refuelling emissions g/car-year	European car population millions	Total emissions tonnes	Total fuel consumed million tonnes
<1.4 1	880	1,144	68.6	78,498	45.3
1.4-2.0 1	1,315	1,710	40.4	69,016	39.8
>2.0 1	2,075	2,700	7.3	19,791	11.3
Total				167,305	96.4

The above EEC data gives total European gasoline consumption of 96.4 million tonnes. True consumption for 1985 was 108 million tonnes, so the total emissions figure must be scaled up to include non-automotive uses etc. This gives total refuelling emissions of 187,400 tonnes.

4.10.4 Exhaust emissions

To estimate exhaust HC emissions it is of course possible to take measured ECE 15 figures and calculate emission factors based on the cycle length of 4 km. However, this is a very low duty cycle and emissions are relatively high, so doing this will tend to exaggerate exhaust emissions.

The UK Warren Spring Laboratory has, however, derived emission factors (6) for in-use vehicles based on average speed. This work quotes a range of emission factors covering 18 vehicles tested, and we have used the median of this range. Unfortunately, no correlation with engine size is available.

The emission factors vary with speed, so composite factors taking into account average speeds and driving patterns given in Table 9 were derived. These factors are as below:

Driving Type	Speed km/h	Emission factors min.	max.	g/km median	Driving pct.
Motorway	115	0.319	1.40	0.860	10.4
Highway (1)	95	0.331	1.40	0.865	4.0
Highway (2)	75	0.455	1.396	0.925	36.2
Urban	25	1.578	3.631	2.605	49.4
Composite				1.745	100

(1) Dual carriage-way
(2) Single carriage-way

Table 13 shows total exhaust emissions for each region, giving an overall total for Europe of 2,470,000 tonnes.

4.10.5 Overall contribution

These total emission figures are CONCAWE best estimates and should be viewed in the context of a total hydrocarbon (or VOC) inventory for Europe, as shown in Table 14. This has been compiled from other CONCAWE reports and data from other task forces, and was first published in Ref. 14.
From this table it can be seen that the major sources of man-made VOC emissions in Europe are:

- solvent evaporation (40%);
- gasoline vehicle exhaust emissions (25%);
- vehicle evaporative losses (10%).

Vehicle refuelling emissions in Europe contribute less than 2% to man-made VOC.

5. CONCLUSIONS

- The major sources of man-made volatile organic compounds (VOC) emissions in Europe are:
  - solvent evaporation (40%)
  - gasoline vehicle exhaust emissions (25%)
  - vehicle evaporative losses (10%).
- Vehicle and fuel system design has the greatest influence on automotive evaporative emissions. Fuel volatility has a significant, but on average smaller effect. The hydrocarbon losses range from 9 to 24 g/test on winter fuel, and from 4 to 16 g/test on the lower volatility summer fuel.
- Under standard test conditions (as defined by CEC CF-11 test procedure) carbon canister control systems reduce evaporative emissions by over 85% on average for a 83 kPa fuel, while a reduction in RVP of 10 kPa would reduce emissions by 23%.
- Clearly the use of onboard canisters is the most effective way of controlling evaporative emissions. This technology has been used in the USA and Japan for over 10 years, and can easily be modified to control refuelling emissions as well.
- Exhaust hydrocarbon emissions decrease with increasing fuel volatility, due to improved engine warm-up. E100 is the gasoline parameter which correlates best with exhaust HC emissions.
- Evaporative losses increase with increasing warm-up cycle severity, from an average of 14.7 g for 4 ECE-15 cycles to 48.5 g after 30 minutes at 130 km/h.
- Hot soak losses are similar for the CEC CF-11 and US Federal warm-up procedures, even though the soak times are different. However running losses were much higher in the Federal test.
- True diurnal emissions are important and should not be ignored; however, carbon canisters are very effective for reducing them. A revised test procedure to include measurement of diurnal losses is needed.
- RVP is the only statistically significant fuel parameter influencing evaporative losses.
- The effect of RVP on evaporative losses is linear under urban driving conditions but is non-linear under more severe driving conditions.

- For gasolines of closely matched volatility, which are not typical of commercial practice, the use of oxygenated components does not increase evaporative emissions and may give a small reduction compared to hydrocarbon only gasolines.

6. RECOMMENDATIONS

- Since this work clearly shows that the use of "on-board" canisters is the most effective method of controlling evaporative emissions from vehicles, every effort should be made to bring this to the attention of legislators.

- A test procedure should be developed that predicts diurnal losses from vehicles.

- The effectiveness of MTBE in reducing evaporative emissions should be further investigated.

- The effect of ambient temperature on evaporative emissions should be determined for modern European cars.

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Table 1 Comparative volatility data for commercially-available European premium gasolines (from Ref. 2)

Reid vapour pressure, kPa Observed in market				
	Winter		Summer	
Country	Highest	Lowest	Highest	Lowest
Austria	86	-	75	-
Belgium	84	75	69	-
Great Britain	107	78	86	69
Denmark	93	80	85	76
Finland	91	88	85	77
France	84	76	69	57
Federal Republic of Germany	99	72	80	65
Netherlands	84	77	77	65
Italy	74	52	68	51
Norway	110	93	81	77
Portugal	65	56	62	58
Switzerland	85	78	76	74
Spain	60	48	60	49
Sweden	91	84	87	71
European Average	86.6	73.6	75.7	65.8

Table 2 Analyses of fuels used for evaporative emissions work

CODE	RVP kPa	E70 %	E100 %	E150 %
3	91.1	43.0	56.8	71.0
4	91.8	24.5	72.0	80.5
125	61.6	32.0	58.8	87.5
16	55.2	19.5	41.3	77.2
357	82.2	36.2	57.3	81.0
42	71.7	24.5	62.8	84.2
71	79.8	27.0	43.3	81.5

CORRELATION MATRIX - Correlation coefficient

	RVP	E70	E100	E150
RVP	1.0	0.51	0.51	-0.56
E70		1.0	0.18	-0.38
E100			1.0	0.22
E150				1.0

Table 3 Properties of specially blended oxygenated fuels compared with corresponding hydrocarbon fuels

	Winter Fuel Alcohol	Winter Fuel Base	Winter Fuel Ether	Winter Fuel Base	Summer Fuel Alcohol	Summer Fuel Base
Code	35A	357	35E	357	15A	125
Oxygenate	3% MeOH 2% TBA	none	15% MTBE	none	3% MeOH 2% TBA	none
RVP kPa	81.1	82.2	82.4	82.2	66.0	61.6
E70 % v	41.9	36.2	42.0	36.2	34.6	32.0
E100 % v	59.8	57.3	61.4	57.3	57.6	58.8
E150 % v	83.7	81.0	85.7	81.0	88.1	87.5

Table 4 Test vehicle description

Test vehicle code	A	B	C	D	E
Make	Ford	Toyota	Renault	Ford	Austin
Model	Fiesta 1.1	Corolla	9	Scorpio 1.8	Montego 1.6
Model year	1986	1983	1985	1986	1984
Country of origin	U.K.	Japan	France	U.K.	U.K.
Displacement, cc	1117	1296	1397	1796	1598
Number/arrangem.	IL-4	IL-4	IL-4	IL-4	IL-4
of cylinders	front	front	front	front	front
Compression ratio	9.5:1	9.3:1	9.25:1	9.5:1	9.7:1
Rated power, kW/RPM	37/5000	50.5/6000	44/5250	66/5400	63/5600
Carburettor/ fuel injection system	Ford VW carb.	Downdraft 2 stage carb.	SOLEX 32 BIS downdraft	Pierburg downdraft 2 stage carb.	carburettor
Turbo charger	no	no	no	no	no
Transmission/number of gears	M 4	M 5	M 5	M 5	M 5
Driven axle	front	front	front	rear	front
Max. speed, km/h	142	160	153	179	154
Tank capacity, litres	34	50	47	70	50
Cooling fan	electric	electric	mechanical	multi-blade viscous coupling	electric
Fuel recirculation	no	yes	yes	yes	no
Exhaust gas treating system	no	no	no	no	no
Carbon canister	no	no	no	no	no

Table 4 (cont.'d)

Test vehicle code	F	G	H	I
Make	VW	Fiat	Alfa Romeo	Alfa Romeo
Model	Jetta 1.8	Uno Turbo	GTV 2.5	GTV 2.5 Cat.
Model year	1986	1986	1985	1985
Country of origin	Germany	Italy	Italy	Italy
Displacement, cc	1781	1301	2492	2492
Number/arrangem.	IL-4	IL-4	V-6	V-6
of cylinders	front	front	front	front
Compression ratio	10.0:1	8.0:1	9.0:1	9.0:1
Rated power, kW/RPM	82.5/5500	77/5750	117.5/5600	115/5500
Carburettor/	Bosch	Bosch	Bosch	Bosch
fuel injection system	K-Jetronic	LE2-Jetronic	L-Jetronic	L-Jetronic
Turbo charger	no	IHI VL-2	no	no
Transmission/number of gears	M 5	M 5	M 5	M 5
Driven axle	front	front	rear	rear
Max. speed, km/h	189	200	205	205
Tank capacity, litres	55	50	75	75
Cooling fan	electric	electric	electric	electric
Fuel recirculation	yes	yes	yes	yes
Exhaust gas treating system	no	no	no	3-way-cat.
Carbon canister	no	no	no	yes

Table 4 (cont.'d)

Test vehicle code	K	L	M	N
Make	Vauxhall	Opel	Honda	Honda
Model	Cavalier	Ascona 1.8i Cat.	Civic	Civic Cat.
Model year	1985	1985	1984	1986
Country of origin	U.K.	Germany	Japan	Japan
Displacement, cc	1796	1796	1342	1342
Number/arrangem.	IL-4	IL-4	IL-4	IL-4
of cylinders	front	front	front	front
Compression ratio	9.5:1	8.9:1	8.7:1	8.7:1
Rated power, kW/RPM	8.45/5800	73.5/5800	52/6000	45/5500
Carburettor/	Bosch	Bosch	Downdraft	Downdraft
fuel injection system	LE-Jetronic	LU-Jetronic	2 stage carb.	2 stage carb.
Turbo charger	no	no	no	no
Transmission/number of gears	M 5	M 5	M 5	M 5
Driven axle	front	front	front	front
Max. speed, km/h	187	180	157	157
Tank capacity, litres	61	61	46	46
Cooling fan	electric	electric	electric	yes
Fuel recirculation	yes	yes	yes	yes
Exhaust gas treating system	no	3-way-cat.	no	oxidation
Carbon canister	no	yes	no	yes

Table 5 Evaporative emission equations with t values >2.0 (represent significance at the 95% confidence level)

ECE 15 warm-up test cycle

Vehicle	Dependent Variable	RVP (kPa) Coefficient	t	E70 Coefficient	t	E100 Coefficient	t	E150 Coefficient	t	SHED Temp. Coefficient	t	Intercept	t	Correlation Coefficient (R^2)
Ford Fiesta	TEV	0.28	9.97									-12.121	-5.48	0.89
						0.229	2.45					-3.229	-0.61	0.33
		0.26	8.13			0.052	1.21					-13.495	-5.52	0.90
Alfa Romeo	TEV	0.36	5.45									-12.690	-2.48	0.66
		0.37	7.34							1.14	3.36	45.83	-4.31	0.81
VW Jetta	TEV	0.49	12.05									-21.452	-6.82	0.92
				0.49	2.29							1.434	0.22	0.30
						0.33	2.01					-2.913	-0.31	0.25
Toyota Corolla	TEV	0.54	7.42									-24.015	-4.27	0.82
		0.62	8.20	0.27	2.04							-22.12	-4.35	0.87
Ford Fiesta	HS	0.24	11.68									-9.79	-6.13	0.92
						0.174	2.15					-1.78	-0.26	0.28
Alfa Romeo	HS	0.27	4.70									-8.08	-1.82	0.60
		0.28	6.11							0.937	3.05	-35.18	-3.67	0.76
VW Jetta	HS	0.37	10.4									-15.39	-5.54	0.90
				0.40	2.5							1.20	0.25	0.34
						0.26	2.05					-1.64	-0.22	0.26
Toyota Corolla	HS	0.4	6.67									-17.55	-3.81	0.79
Ford Fiesta	RL	0.04	2.58									-2.34	-1.78	0.36
						0.054	2.38					-2.05	-1.58	0.32
Alfa Romeo	RL	0.09	3.85									-4.61	-2.52	0.50
								-0.19	-2.49			17.55	2.87	0.29
VW Jetta	RL	0.12	8.44									-6.06	-5.68	0.86
								-0.18	-2.19			17.38	2.62	0.29
Toyota Corolla	RL	0.14	5.14									-6.46	-3.01	0.69
										-0.89	-2.13	29.24	2.51	0.27
		0.15	5.15	-0.14	-2.43					-0.66	-1.95	15.74	1.40	0.81
All	TEV	0.42	14.08									-14.81	-6.45	0.78
				0.307	3.06							7.96	2.59	0.14
						0.268	3.66					2.09	0.50	0.19
		0.43	14.73							0.567	2.42	-31.57	-4.37	0.80
All	HS	0.32	13.33									-11.24	-6.07	0.76
				0.241	3.10							5.97	2.52	0.14
						0.191	3.31					2.46	0.75	0.16
		0.33	14.41							0.552	3.01	-27.34	-4.84	0.79
All	RL	0.1	8.76									-3.10	-3.57	0.57
				0.067	2.37							2.42	2.79	0.09
						0.078	3.94					0.06	0.05	0.21

Table 6 Evaporative emission equations with t values >2.0 (represent significance at the 95% level)

90 km/h warm-up test cycle

Vehicle	Dependent Variable	RVP Coefficient	RVP t	E70 Coefficient	E70 t	E100 Coefficient	E100 t	E150 Coefficient	E150 t	SHED Temp Coefficient	SHED Temp t	Intercept	Intercept t	Correlation Coefficient (R^2)
Ford Fiesta	TEV	0.70	2.7									-35.69	-1.74	0.51
										3.91	1.94	-89.53	-1.60	0.35
		0.57	2.3							2.66	1.59	-99.42	-2.25	0.66
VW Jetta	TEV	1.47	5.0									-65.32	-2.86	0.83
Toyota Corolla	TEV	1.18	6.12									-58.24	-3.79	0.82
		1.33	8.27	-0.71	-2.52							-49.37	-3.98	0.91
Ford Fiesta	HS	0.34	2.96									-15.36	-1.67	0.56
						0.43	2.27					-12.39	-1.16	0.42
VW Jetta	HS	0.46	1.83									-11.68	-0.60	0.40
						0.65	2.06					12.83	-0.71	0.46
		0.65	2.72					1.95	1.96	8.97	1.91	-430.6	-2.10	0.75
Toyota Corolla	HS	0.38	7.13									-16.54	-3.89	0.86
		0.40	11.04							2.39	3.30	-81.69	-4.10	0.95
Ford Fiesta	RL	0.35	2.07									-20.33	-1.50	0.38
				0.54	2.00							-9.81	-1.11	0.36
										2.95	3.07	-74.38	-2.79	0.57
		0.24	1.83							2.43	2.77	-78.75	-3.39	0.73
VW Jetta	RL	1.01	7.44									-53.63	-5.09	0.92
		1.13	15.31	-0.60	-3.84					4.48	4.22	-168.85	-6.01	0.99
Toyota Corolla	RL	0.80	4.67									-41.70	-3.05	0.73
		0.95	7.70	-0.71	-3.29							-32.8	-3.44	0.89
All	TEV	1.15	7.97									-45.27	-3.96	0.73
						0.874	2.88					-4.46	-0.26	0.26
All	HS	0.46	7.81									-14.62	-3.17	0.72
				0.359	2.14							10.07	1.93	0.16
						0.359	3.01					0.72	0.11	0.27
All	RL	0.70	6.77									-30.66	-3.76	0.66
						0.515	2.60					5.13	-0.46	0.22
								-0.858	-2.00			92.57	2.69	0.14
		0.79	7.30	-0.429	-2.20							-84.19	-3.26	0.74

<u>Table 7</u> Exhaust emission equations with t values >2.0 (represent significance at the 95% level)

ECE 15 test cycle

Vehicle	Dependent Variable	RVP Coefficient	RVP t	E70 Coefficient	E70 t	E100 Coefficient	E100 t	E150 Coefficient	E150 t	SHED Temp Coefficient	SHED Temp t	Intercept	Intercept t	Correlation Coefficient (R^2)
Ford Fiesta	Bag 1					-0.278	-2.42					27 87	4.27	0.33
	Bag 2					-0.105	-3.17					14.42	7.63	0.46
	Total HC					-3.83	-2.65					42.29	5.14	0.37
VW Jetta	Bag 1	0.04	2.70	-0.066	-2.57	-0.053	-2.85					6.65	6.07	0.60
	Bag 2							-0.08	-2.56			10.87	4.48	0.37
				-0.045	-2.14			-0.10	-3.36			13.98	4.75	0.60
	Total HC	0 08	2.37	-0.10	-2.03	-0.093	-2.58					12.20	5.76	0.52
Toyota Corolla	Bag 1					-0.054	-3.17					8 45	8.74	0.48
		-0.03	-1.99					-0.096	-2.10			15.65	3.67	0.39
	Bag 2					-0.025	-3.62					6 07	15.71	0.54
		0 01	1.61	-0.018	-1.99	-0.027	-4.09			0 08	2.22	3.65	2.97	0.79
	Total HC					-0.079	-3.90					14.52	12.68	0.58
		0.03	1.50	-0.068	-2.32	-0.092	-4.21					14.83	12.31	0.74
Alfa Romeo	Bag 1	No significant correlation												
	Bag 2	No significant correlation												
	Total HC	No significant correlation												
All Cars		No significant correlation												

Notes:

- Bag 1 relates to ECE 15 cycles 1 and 2 i.e. during period when vehicle is warming up;
- Bag 2 relates to ECE 15 cycles 3 and 4 i.e. when vehicle is warmed up;
- Total HC is the sum of Bags 1 and 2.

Table 8 Car population, mileage and fuel consumption in Europe

Country	Engine Capacity	Car Parc %	Mileage 1,000 km/yr	Mileage %	Fuel Consumption l/100 km	Fuel Consumption %
W. Germany	>2.0	12.3	14.5	14.3	12.5	19.3
	1.4-2.0	50.4	13.0	52.7	9.2	52.2
	<1.4	37.3	11.0	33.0	8.0	28.4
France	>2.0	3.1	20.0	1.5	12.5	7.4
	1.4-2.0	29.7	15.0	35.7	9.2	37.9
	<1.4	67.2	11.0	59.2	8.0	54.7
Italy	>2.0	0.5	16.0	0.9	12.5	1.3
	1.4-2.0	15.8	12.0	19.4	9.2	21.5
	<1.4	83.7	9.5	79.7	8.0	77.1
UK	>2.0	7.8	19.0	9.8	12.5	13.6
	1.4-2.0	41.7	16.5	45.2	9.2	46.3
	<1.4	50.5	13.5	45.0	8.0	40.2
Total EC	>2.0	6.3	16.6	8.4	12.5	11.8
	1.4-2.0	34.7	14.3	39.7	9.2	41.2
	<1.4	59.0	11.0	51.9	8.0	46.9

Table 9 Road traffic activity for gasoline vehicles in the UK and Germany

Year	Motorways			Highways			Urban		
	Mill. km	%	Av. Speed km/h	Mill. km	%	Av. Speed km/h	Mill. km	%	Av. Speed km/h
UK 1983	25,097	10.4	115	96,598	40.2	77*	118,903	49.4	40
Germany 1985	-	27	115	-	43	75	-	30	-

* Comprises 10 per cent Divided Highway (95 km/h), 90 per cent Single (75 km/h)

Table 10 Average temperatures and volatility levels in various regions

REGION		JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL CARS x 10^6
FRANCE/ BELGIUM	Temp	C	C	D	D/E	E	F	F	F	F	E	D	C	24.1
	RVP	80	80	80	80	65	65	65	65	65	80	80	80	
SPAIN/ PORTUGAL	Temp	C/D	D	D/E	E	F	F/G	G	G/H	F/G	E/F	D/E	C/D	10.0
	RVP	70	70	60	60	60	60	60	60	60	70	70	70	
ITALY/ GREECE	Temp	D	D	D/E	E	F	F/G	G	G/H	F/G	E/F	D/E	C/D	22.1
	RVP	85	85	85	85	70	70	70	70	70	85	85	85	
UK	Temp	C	C	D	D	E	E	E/F	E/F	E	D/E	D	C	17.3
	RVP	120	120	120	90	90	80	80	80	90	90	120	120	
SCANDINAVIA	Temp	A	A	B	B/C	D	E	E/F	E	D/E	C/D	B/C	A/B	6.0
	RVP	100	100	100	100	85	85	85	85	100	100	100	100	
SWITZERLAND/ AUSTRIA	Temp	B/A	B	C	C/D	E	E	F	E	E	D	C	A/B	5.0
	RVP	90	90	90	80	70	70	70	70	70	80	90	90	
GERMANY/ DK/NL	Temp	B	B/C	C	D	E	F	F	F	E	D	C/D	B/C	31.8
	RVP	90	90	90	70	70	70	70	70	70	90	90	90	

Key: RVP in kPa. Temperatures Deg. C.
Temperature Zones, A −10 to −5 B −5 to 0 C 0 to 5
D 5 to 10 E 10 to 15 F 15 to 20
G 20 to 25 H 25 to 30

Table 11 Average diurnal temperature variations (°C) in Europe

	January	April	July	October
France/Belgium	7	9	11	7
Spain/Portugal	6	11	12	9
Italy/Greece	5	9	11	9
UK	5	8	8	7
Scandinavia	5	7	8	5
Switzerland/Austria	5	10	11	7
Germany/NL/DK	4	10	10	8

Table 12 Evaporative emissions in g/day for various temperature and volatility levels

Temp. Region	Car Size	60 kPa RL	60 kPa HS	60 kPa DL	70 kPa RL	70 kPa HS	70 kPa DL	80 kPa RL	80 kPa HS	80 kPa DL	90 kPa RL	90 kPa HS	90 kPa DL	100 kPa RL	100 kPa HS	100 kPa DL	120 kPa RL	120 kPa HS	120 kPa DL
A	Large										1.0	5.0	1.0	1.2	6.0	1.0	1.7	8.3	1.0
	Small										0.5	2.6		0.7	3.4		1.1	5.4	
B	Large										1.0	5.0	1.0	1.4	6.6	1.0	2.0	10.0	2.4
	Small										0.5	2.8		0.7	3.5		1.2	5.6	
C	Large				0.6	2.7	1.0	0.8	4.2	1.0	1.2	5.8	1.0	1.5	7.5	1.5	2.5	12.0	5.9
	Small				0.3	1.4		0.4	2.2		0.6	2.8		0.8	3.7		1.3	6.1	
D	Large				0.6	2.9	1.0	0.9	4.6	1.1	1.3	6.4	3.3	1.7	8.5	5.5	3.1	14.4	9.9
	Small				0.3	1.5		0.5	2.3		0.6	3.0		0.8	4.2		1.4	7.0	
E	Large	0.6	3.0	1.0	0.7	3.3	2.4	1.1	5.3	4.6	1.6	7.8	6.8						
	Small	0.3	1.7		0.4	1.8		0.5	2.7		0.7	3.5							
F	Large	0.7	3.9	3.7	0.9	4.4	5.9	1.4	6.8	8.1									
	Small	0.5	2.4		0.5	2.4		0.7	3.5										
G	Large	1.0	5.4	7.2	1.4	6.6	9.4	2.0	10.0	11.6									
	Small	0.7	3.3		0.8	3.8		1.1	5.4										
H	Large	1.5	7.5	10.7	2.2	10.8	12.8	2.9	15.1	14.5									
	Small	0.8	4.7		1.2	6.6		2.1	8.4										

Table 13 Hydrocarbon exhaust emissions

Region		No. of cars million	Average km/yr '000	Total car km/yr x10^{9}	Total HC '000 tonnes
UK	large small	8.7 8.7	16.9 13.5	147.0 117.5	463
(France/ (Belgium	large small	7.9 16.2	15.5 11.0	122.2 178.2	527
(Spain/ (Portugal	large small	1.6 8.4	12.1 9.5	19.4 79.8	175
(Italy/ (Greece	large small	3.6 18.5	12.1 9.5	43.6 175.8	382
Scandinavia	large small	3.0 3.0	13.3 11.0	39.9 33.0	127
(Switzerland/ (Austria	large small	3.1 1.9	13.3 11.0	41.2 20.9	108
(Germany/ (DK/NL	large small	19.9 11.9	13.3 11.0	264.7 130.9	688
Total					2470

Table 14 Emissions of volatile organic compounds in Western Europe (OECD)

		(Tonnes x 10^3)	(%)
Mobile sources			
Gasoline vehicles	- Evaporative emissions	1010	10.1
	- Refuelling	180	1.8
	- Exhaust	2500	25.0
	Subtotal	3690	36.9
Diesel vehicles		300	3.0
Aircraft		40	0.4
Railways		40	0.4
Coastal and inland shipping		10	0.1
	Subtotal	4080	40.8
Oil industry			
Production		20	0.2
Marine transport and crude terminals		150	1.5
Refineries		170	1.7
Gasoline distribution		310	3.1
	Subtotal	650	6.5
Solvents		4020	40.2
Manufacturing industry		410	4.1
Natural gas (non-methane)		650	6.5
Solid waste disposal		110	1.1
Stationary combustion		90	0.9
	Total Anthropogenic	10,010	100
	Natural (Trees, etc.)	10,000	
	Grand Total	20,010	

Note All values exclude methane

Fig. 1

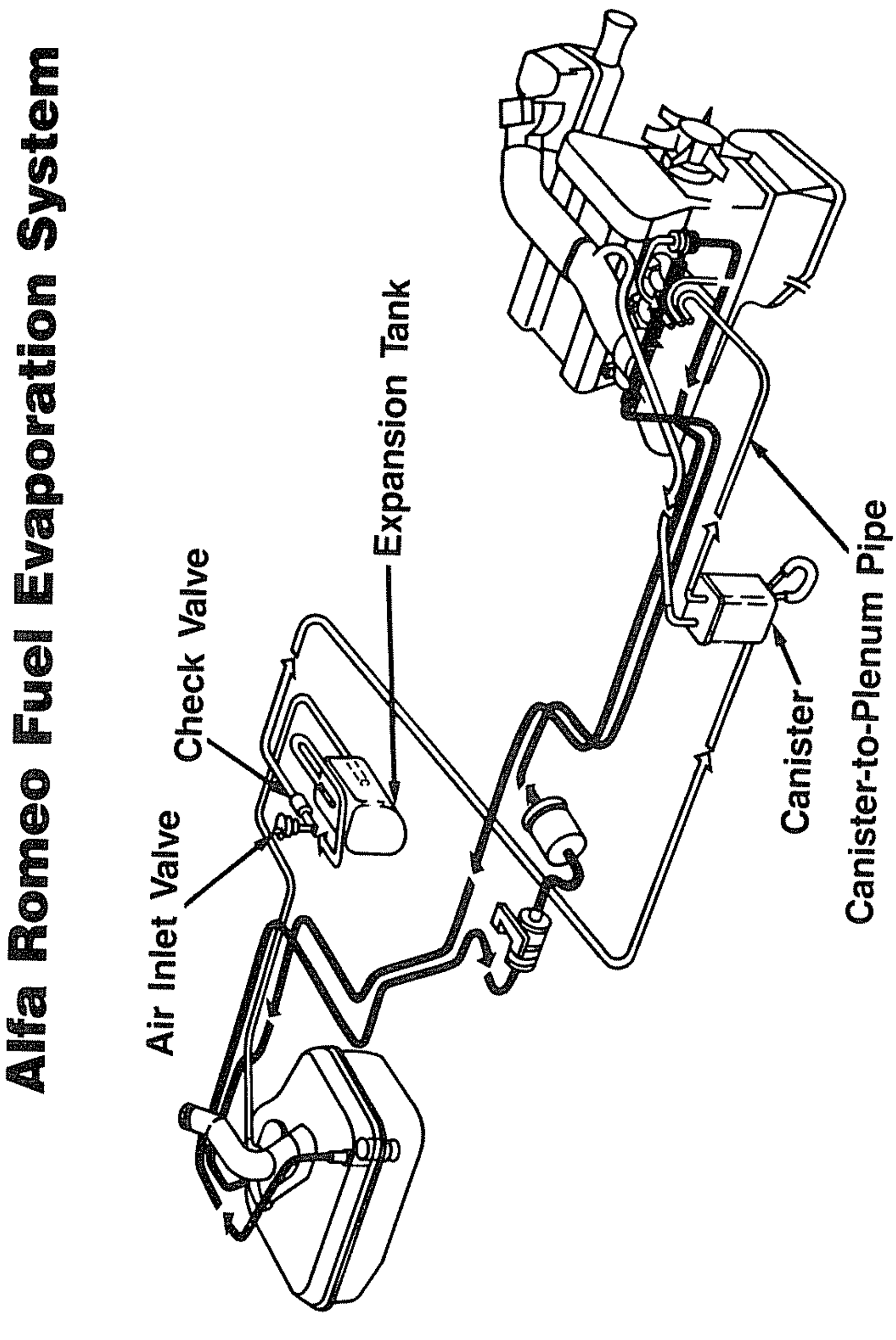

Alfa Romeo Fuel Evaporation System
Air Inlet Valve
Check Valve
Expansion Tank
Canister
Canister-to-Plenum Pipe

Fig. 2

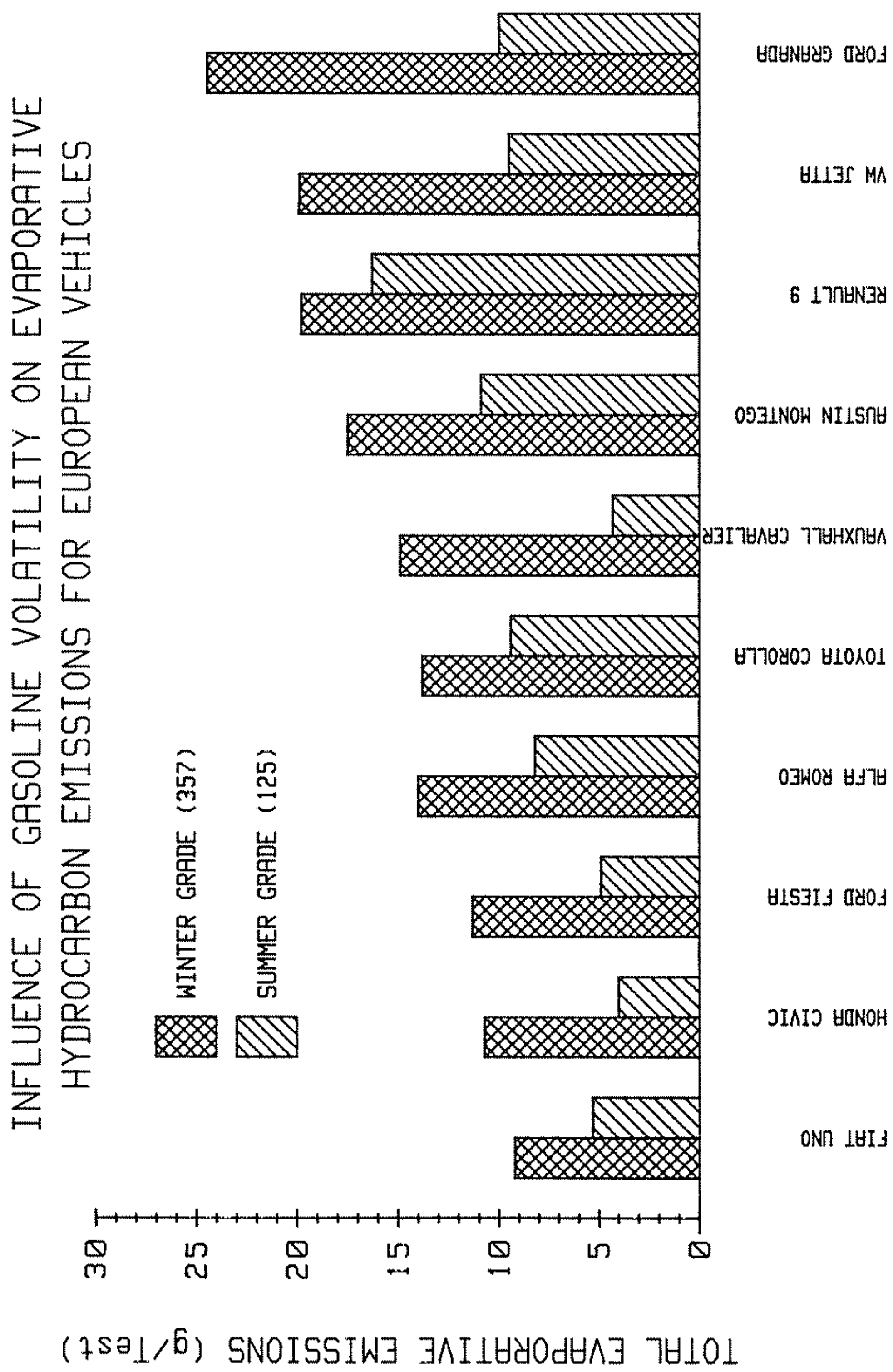

INFLUENCE OF GASOLINE VOLATILITY ON EVAPORATIVE
HYDROCARBON EMISSIONS FOR EUROPEAN VEHICLES
WINTER GRADE (357)
SUMMER GRADE (125)
FORD GRANADA
VW JETTA
RENAULT 9
AUSTIN MONTEGO
VAUXHALL CAVALIER
TOYOTA COROLLA
ALFA ROMEO
FORD FIESTA
HONDA CIVIC
FIAT UNO
30
25
20
15
10
5
0
TOTAL EVAPORATIVE EMISSIONS (g/Test)

Fig. 3

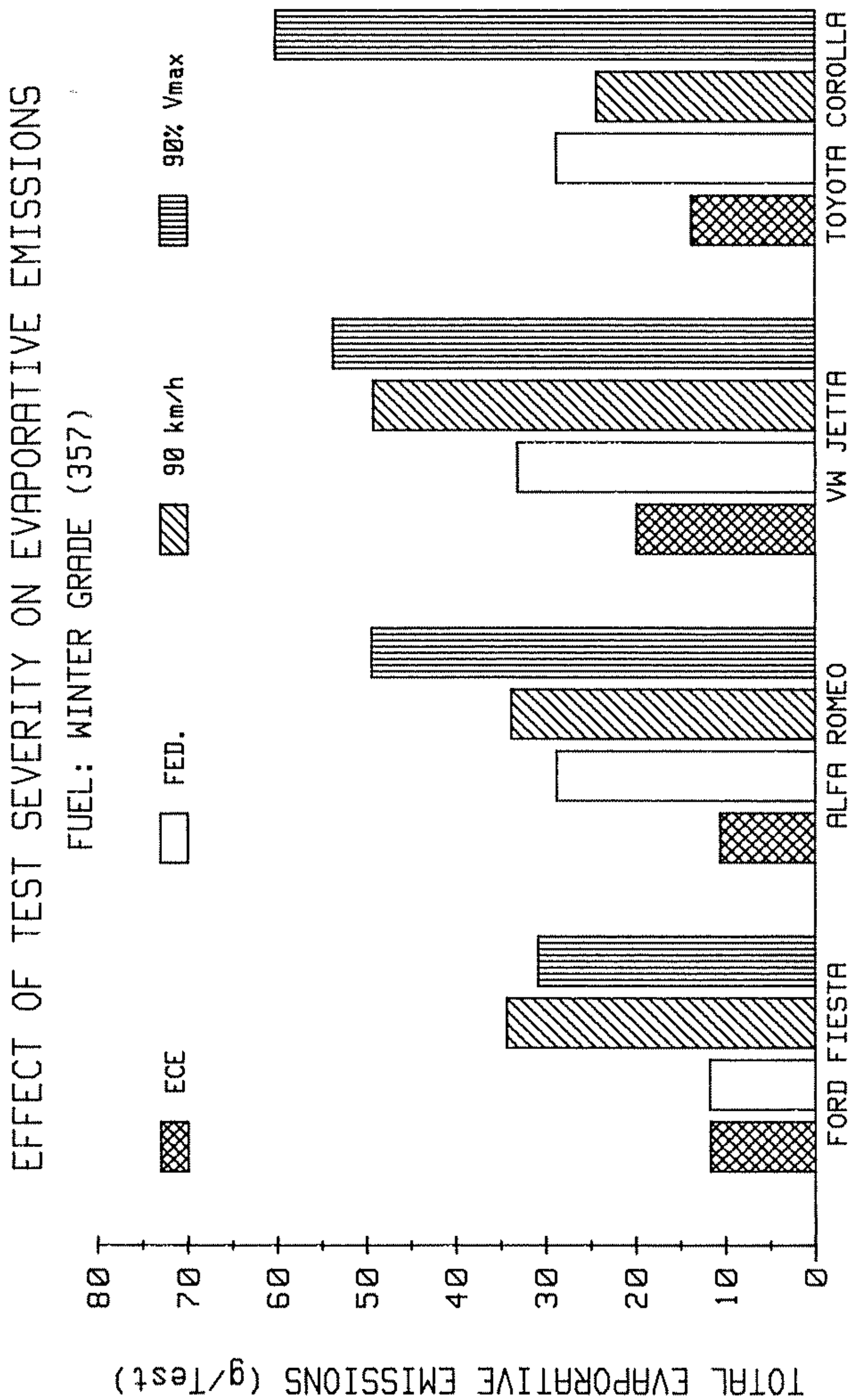

EFFECT OF TEST SEVERITY ON EVAPORATIVE EMISSIONS
FUEL: WINTER GRADE (357)
ECE
FED.
90 km/h
90% Vmax
FORD FIESTA
ALFA ROMEO
VW JETTA
TOYOTA COROLLA
0
10
20
30
40
50
60
70
80
TOTAL EVAPORATIVE EMISSIONS (g/Test)

Fig. 4

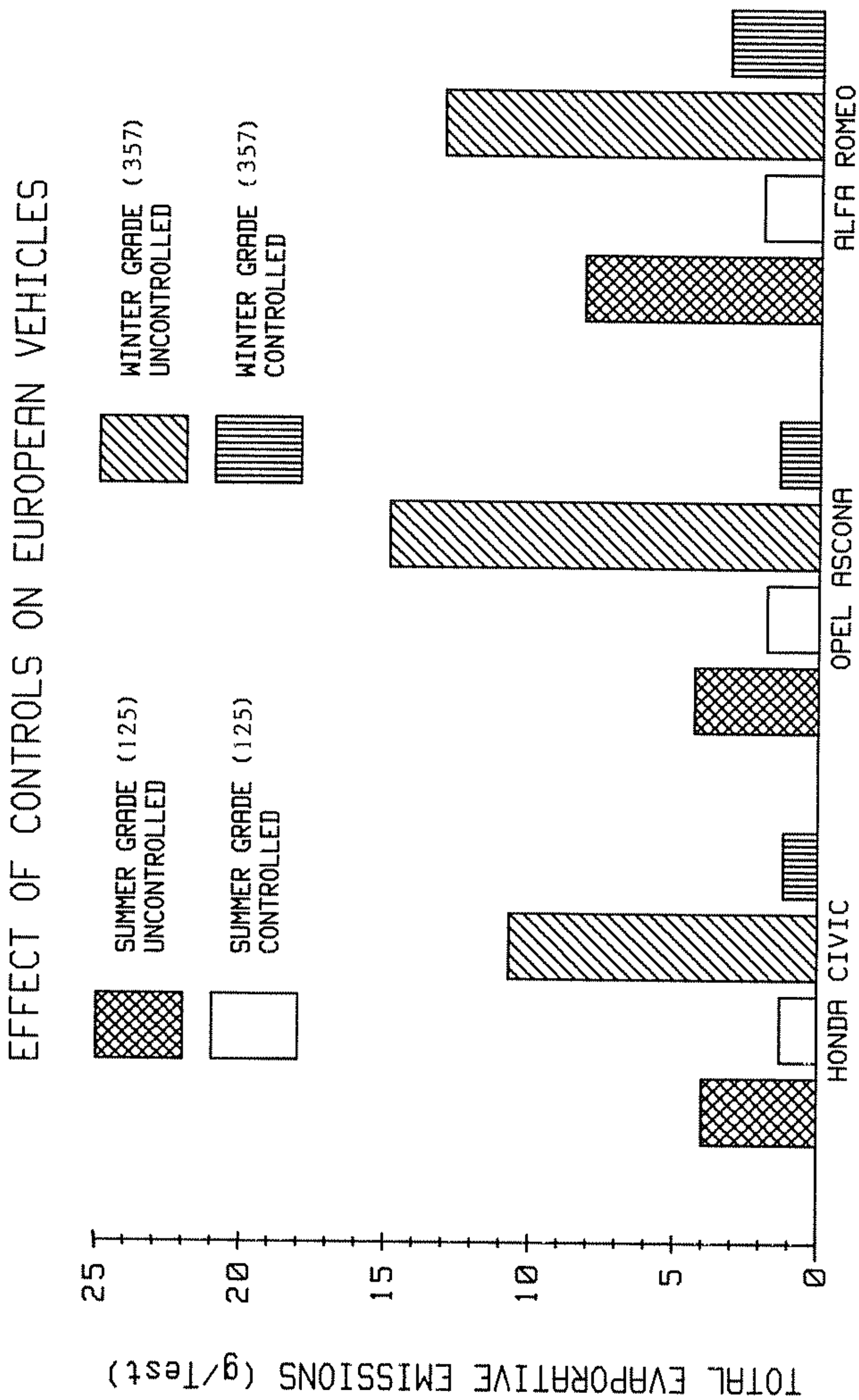

EFFECT OF CONTROLS ON EUROPEAN VEHICLES
SUMMER GRADE (125) UNCONTROLLED
SUMMER GRADE (125) CONTROLLED
WINTER GRADE (357) UNCONTROLLED
WINTER GRADE (357) CONTROLLED
HONDA CIVIC
OPEL ASCONA
ALFA ROMEO
0
5
10
15
20
25
TOTAL EVAPORATIVE EMISSIONS (g/Test)

Fig. 5

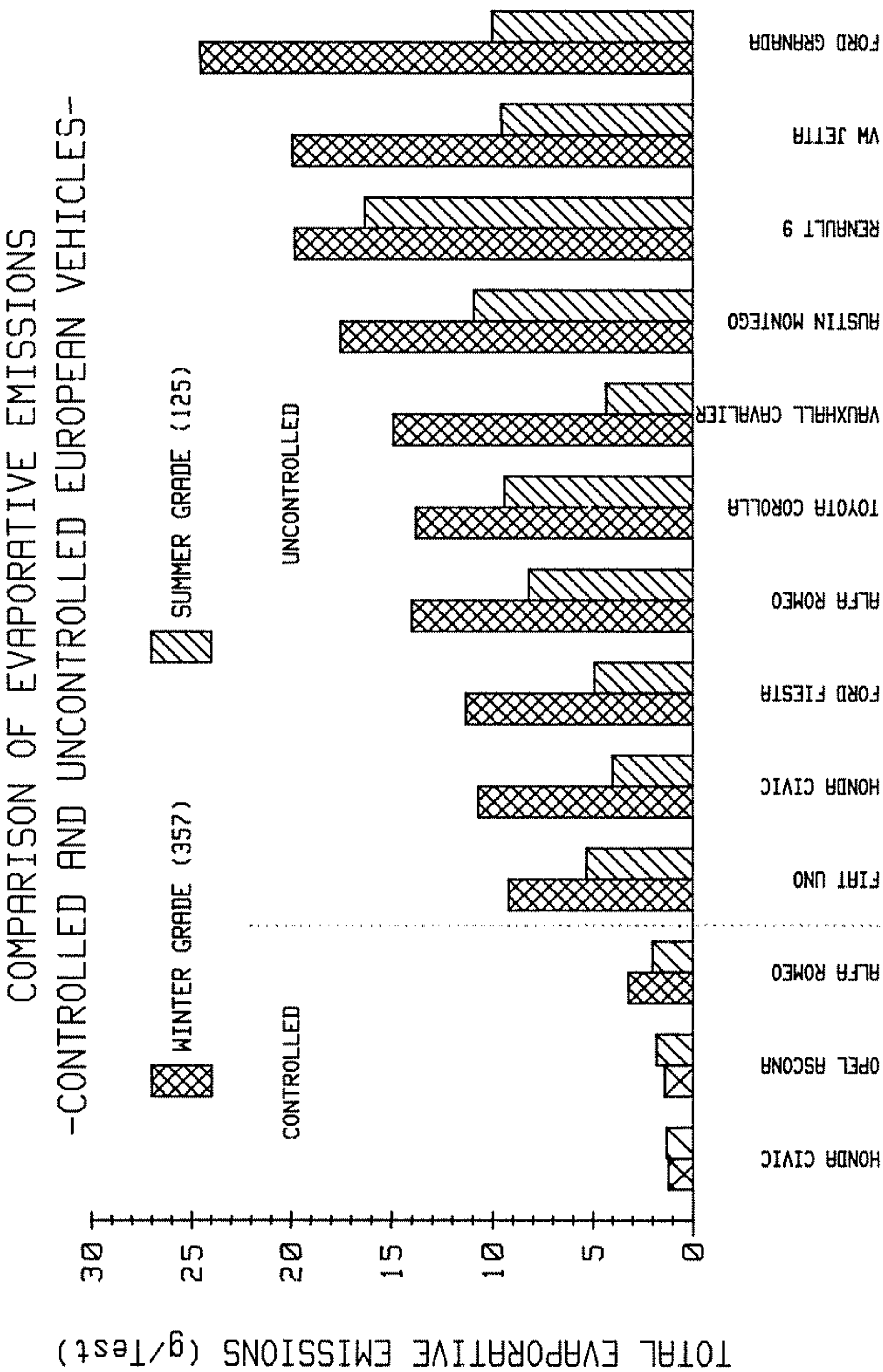

COMPARISON OF EVAPORATIVE EMISSIONS
-CONTROLLED AND UNCONTROLLED EUROPEAN VEHICLES-
WINTER GRADE (357)
SUMMER GRADE (125)
CONTROLLED
UNCONTROLLED
HONDA CIVIC
OPEL ASCONA
ALFA ROMEO
FIAT UNO
HONDA CIVIC
FORD FIESTA
ALFA ROMEO
TOYOTA COROLLA
VAUXHALL CAVALIER
AUSTIN MONTEGO
RENAULT 9
VW JETTA
FORD GRANADA
0
5
10
15
20
25
30
TOTAL EVAPORATIVE EMISSIONS (g/Test)

Fig. 6

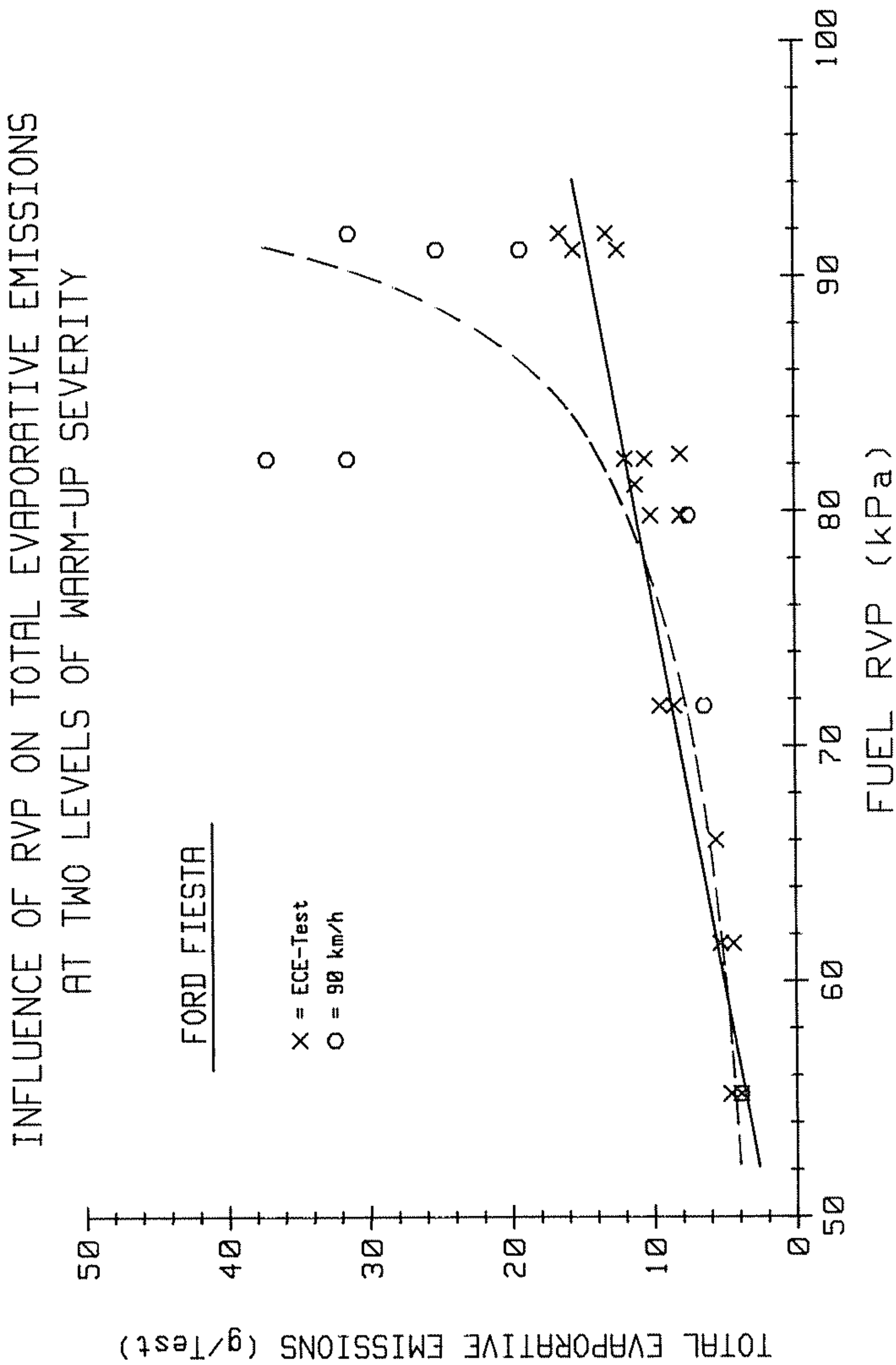

INFLUENCE OF RVP ON TOTAL EVAPORATIVE EMISSIONS
AT TWO LEVELS OF WARM-UP SEVERITY
FORD FIESTA
X = ECE-Test
O = 90 km/h
TOTAL EVAPORATIVE EMISSIONS (g/Test)
0
10
20
30
40
50
FUEL RVP (kPa)
50
60
70
80
90
100

Fig. 7

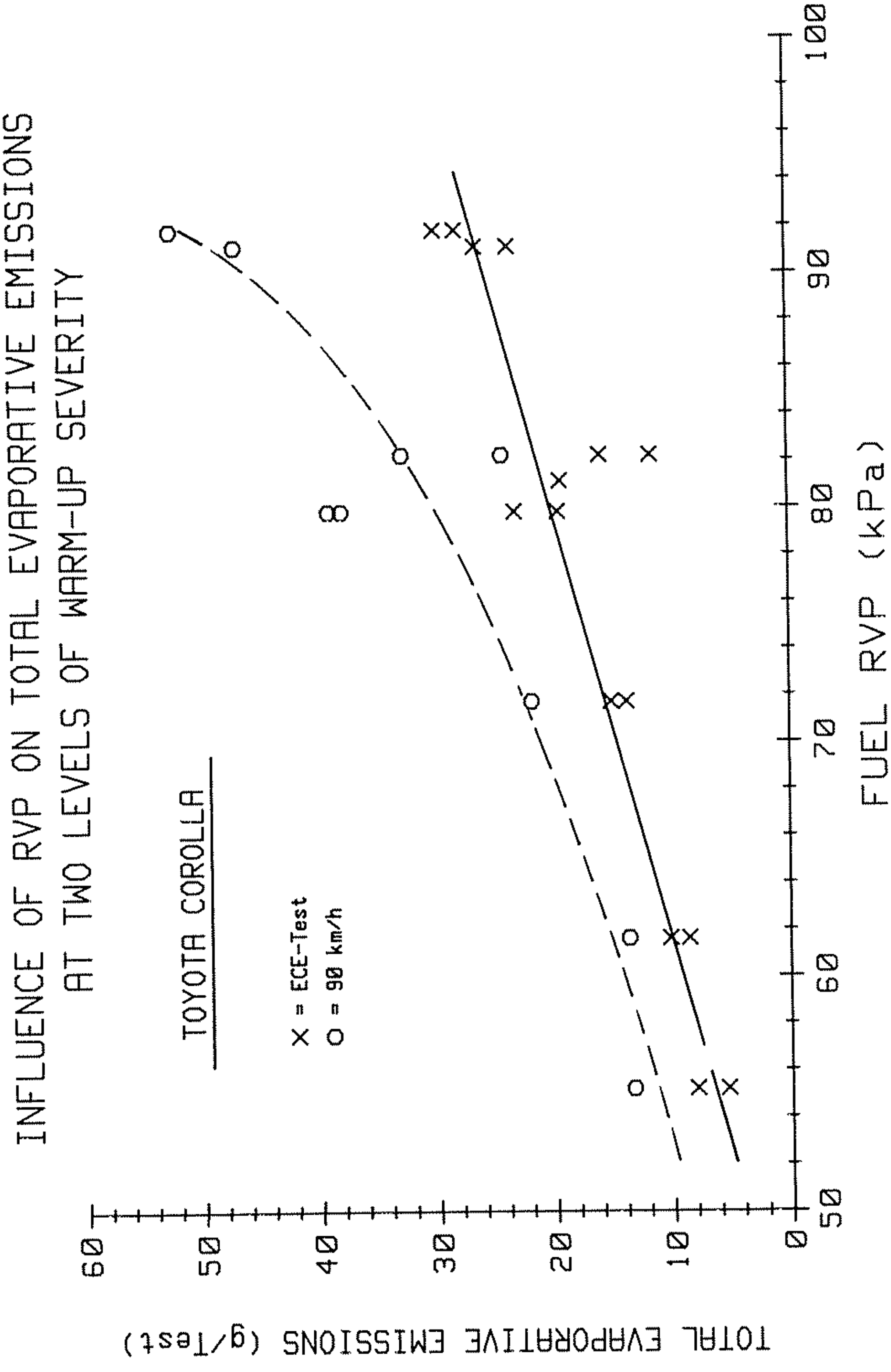

INFLUENCE OF RVP ON TOTAL EVAPORATIVE EMISSIONS
AT TWO LEVELS OF WARM-UP SEVERITY
TOYOTA COROLLA
X = ECE-Test
O = 90 km/h
TOTAL EVAPORATIVE EMISSIONS (g/Test)
0
10
20
30
40
50
60
FUEL RVP (kPa)
50
60
70
80
90
100

Fig. 8

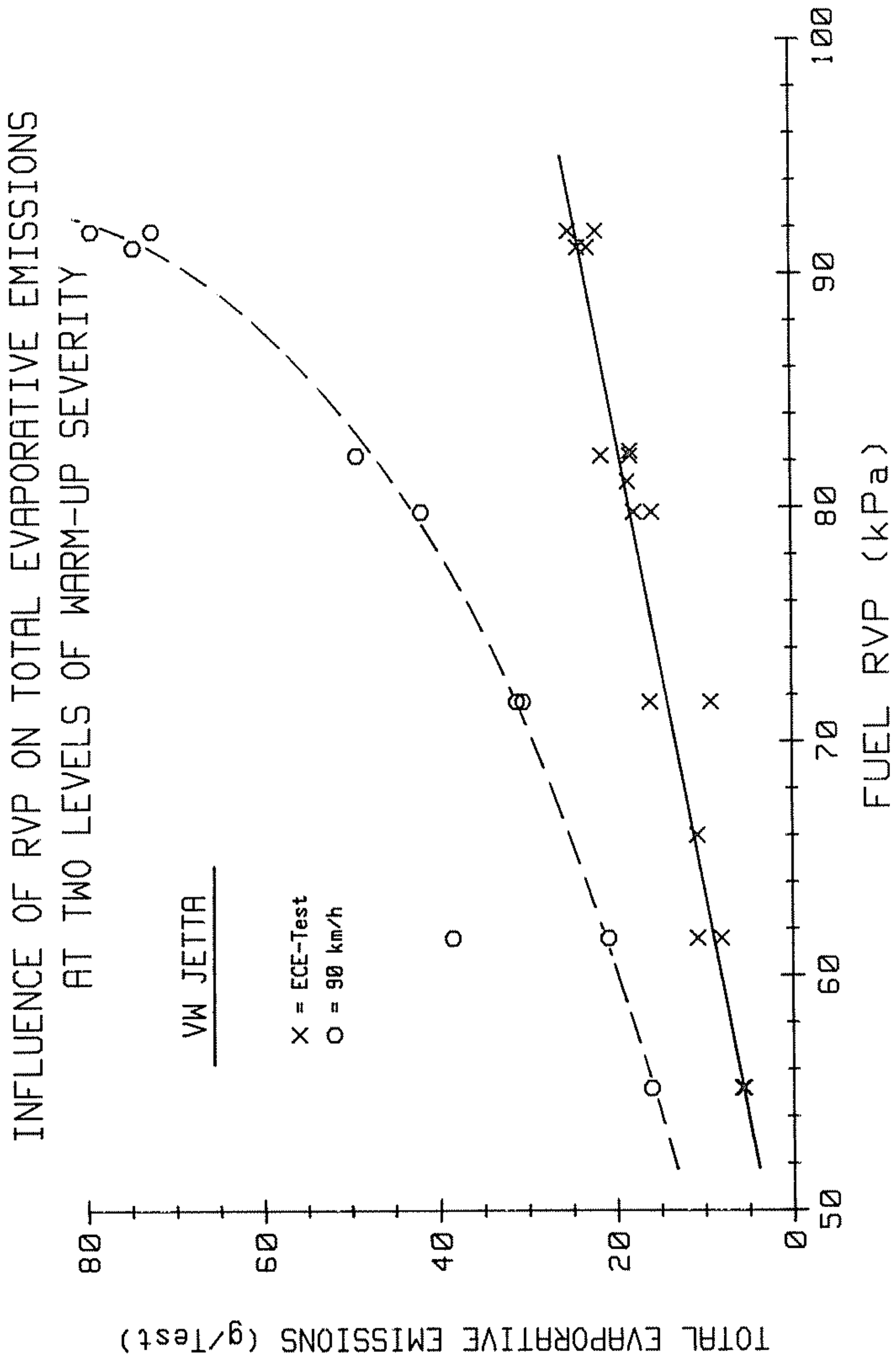

INFLUENCE OF RVP ON TOTAL EVAPORATIVE EMISSIONS
AT TWO LEVELS OF WARM-UP SEVERITY
VW JETTA
X = ECE-Test
O = 90 km/h
FUEL RVP (kPa)
TOTAL EVAPORATIVE EMISSIONS (g/Test)
50
60
70
80
90
100
0
20
40
60
80

Fig. 9

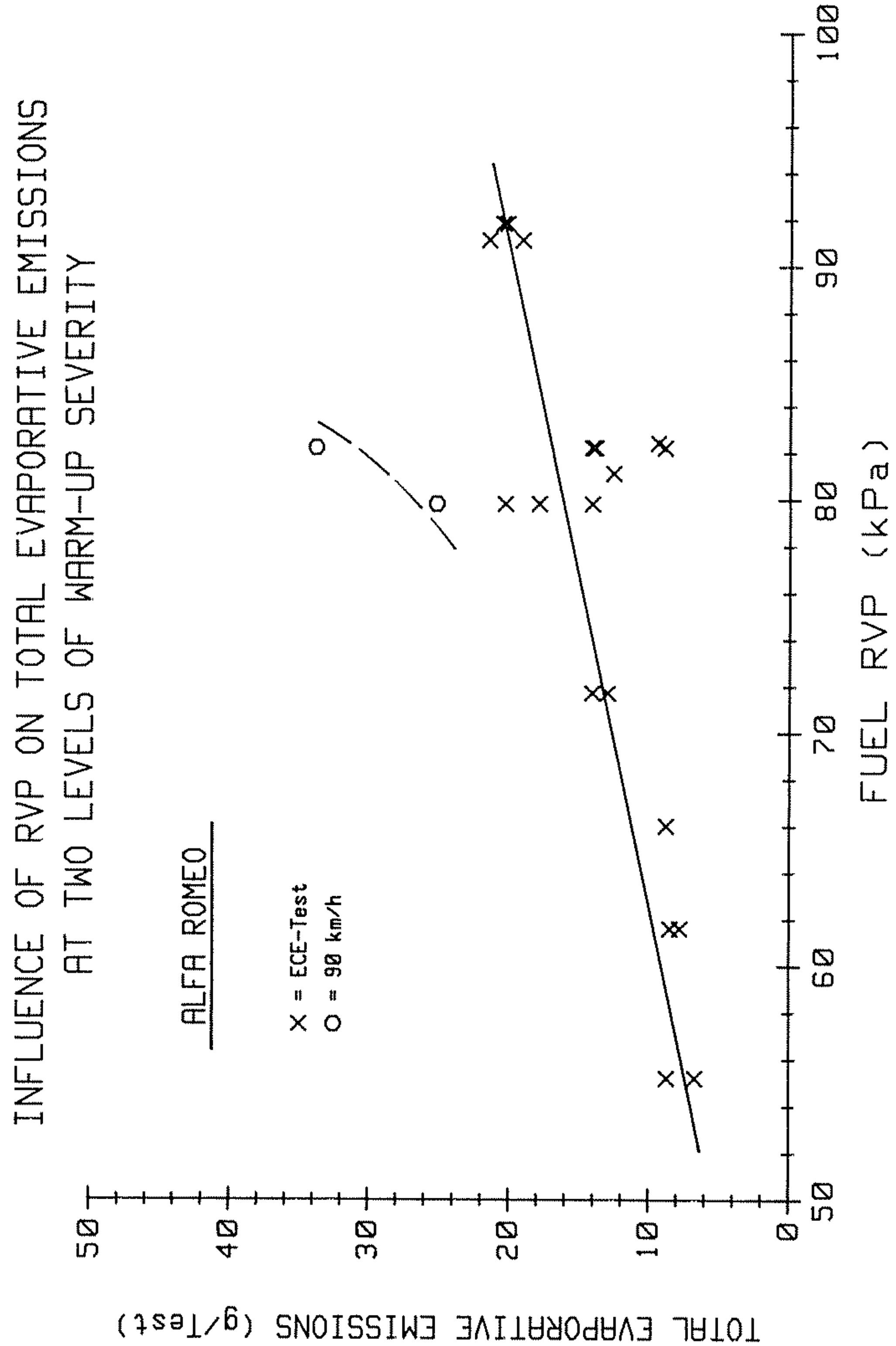

INFLUENCE OF RVP ON TOTAL EVAPORATIVE EMISSIONS
AT TWO LEVELS OF WARM-UP SEVERITY
ALFA ROMEO
X = ECE-Test
O = 90 km/h
TOTAL EVAPORATIVE EMISSIONS (g/Test)
FUEL RVP (kPa)
0
10
20
30
40
50
50
60
70
80
90
100

Fig. 10

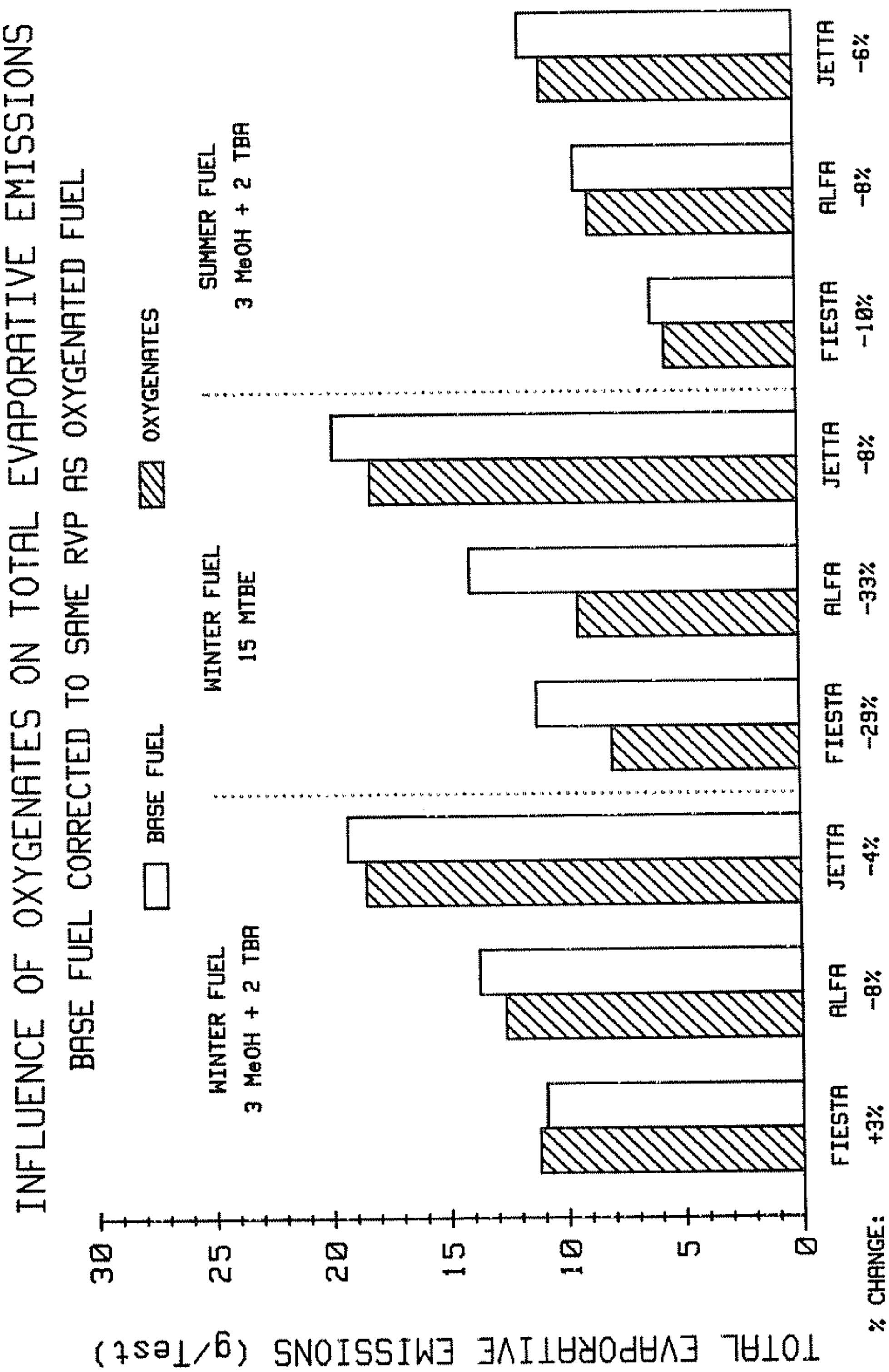

INFLUENCE OF OXYGENATES ON TOTAL EVAPORATIVE EMISSIONS
BASE FUEL CORRECTED TO SAME RVP AS OXYGENATED FUEL
BASE FUEL
OXYGENATES
WINTER FUEL
3 MeOH + 2 TBA
WINTER FUEL
15 MTBE
SUMMER FUEL
3 MeOH + 2 TBA
TOTAL EVAPORATIVE EMISSIONS (g/Test)
30
25
20
15
10
5
0
% CHANGE:
FIESTA
+3%
ALFA
-8%
JETTA
-4%
FIESTA
-29%
ALFA
-33%
JETTA
-8%
FIESTA
-10%
ALFA
-8%
JETTA
-6%

Fig. 11

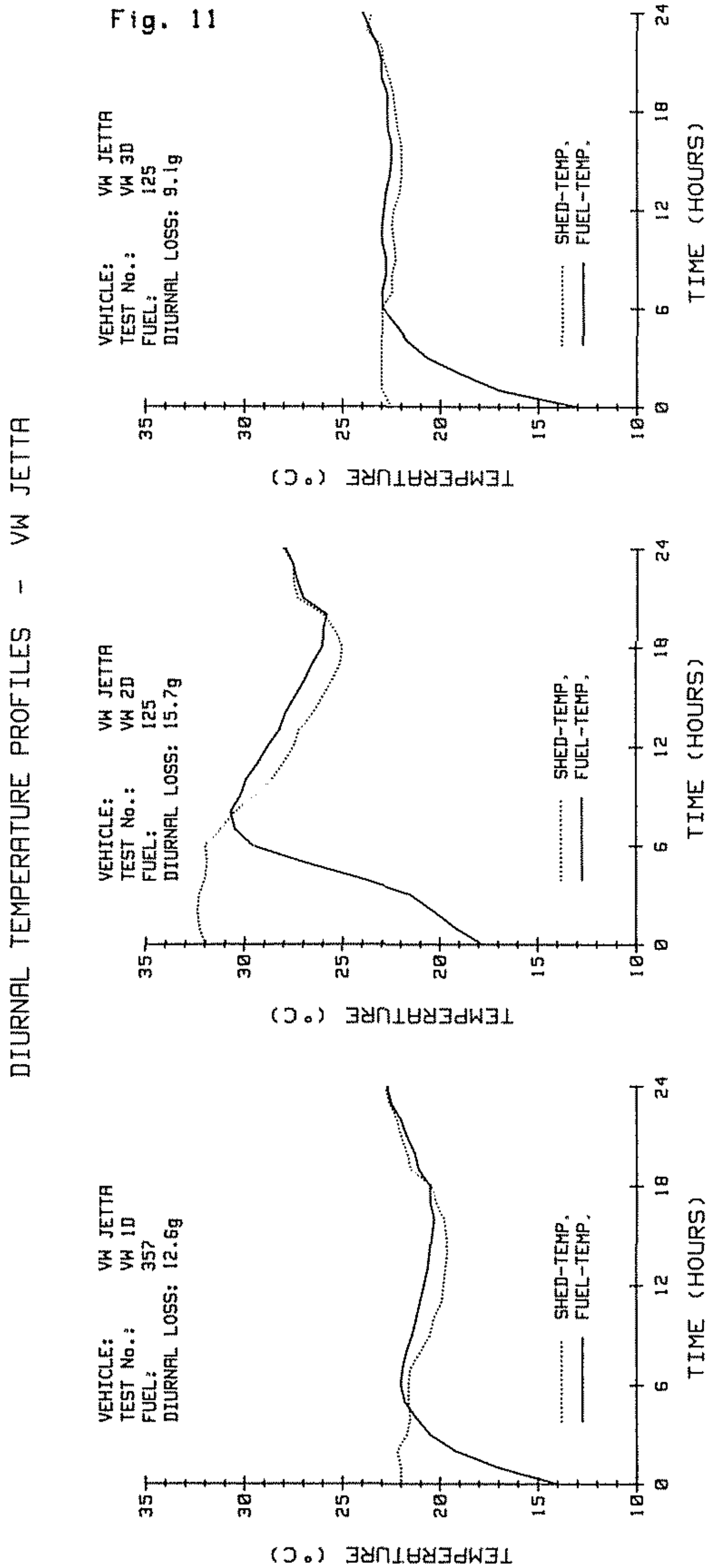

DIURNAL TEMPERATURE PROFILES - VW JETTA
VEHICLE: VW JETTA
TEST No.: VW 1D
FUEL: 357
DIURNAL LOSS: 12.6g
SHED-TEMP.
FUEL-TEMP.
TEMPERATURE (°C)
TIME (HOURS)
VEHICLE: VW JETTA
TEST No.: VW 2D
FUEL: 125
DIURNAL LOSS: 15.7g
SHED-TEMP.
FUEL-TEMP.
TEMPERATURE (°C)
TIME (HOURS)
VEHICLE: VW JETTA
TEST No.: VW 3D
FUEL: 125
DIURNAL LOSS: 9.1g
SHED-TEMP.
FUEL-TEMP.
TEMPERATURE (°C)
TIME (HOURS)

Fig. 12

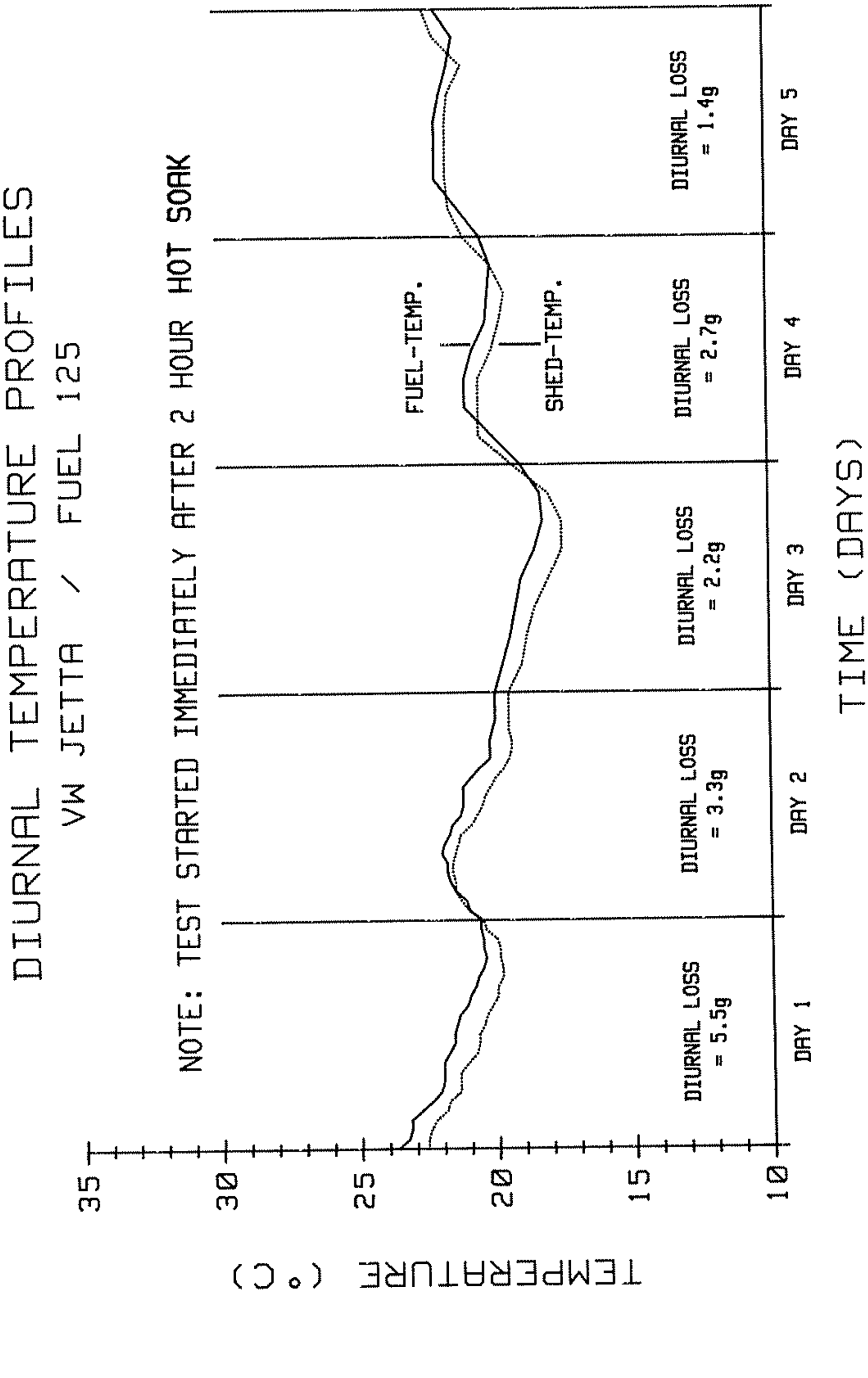

DIURNAL TEMPERATURE PROFILES
VW JETTA / FUEL 125
NOTE: TEST STARTED IMMEDIATELY AFTER 2 HOUR HOT SOAK
FUEL-TEMP.
SHED-TEMP.
DIURNAL LOSS = 5.5g
DIURNAL LOSS = 3.3g
DIURNAL LOSS = 2.2g
DIURNAL LOSS = 2.7g
DIURNAL LOSS = 1.4g
DAY 1
DAY 2
DAY 3
DAY 4
DAY 5
TIME (DAYS)
TEMPERATURE (°C)
35
30
25
20
15
10

Fig. 13

DIURNAL TEMPERATURE PROFILES - UNCONTROLLED VEHICLES

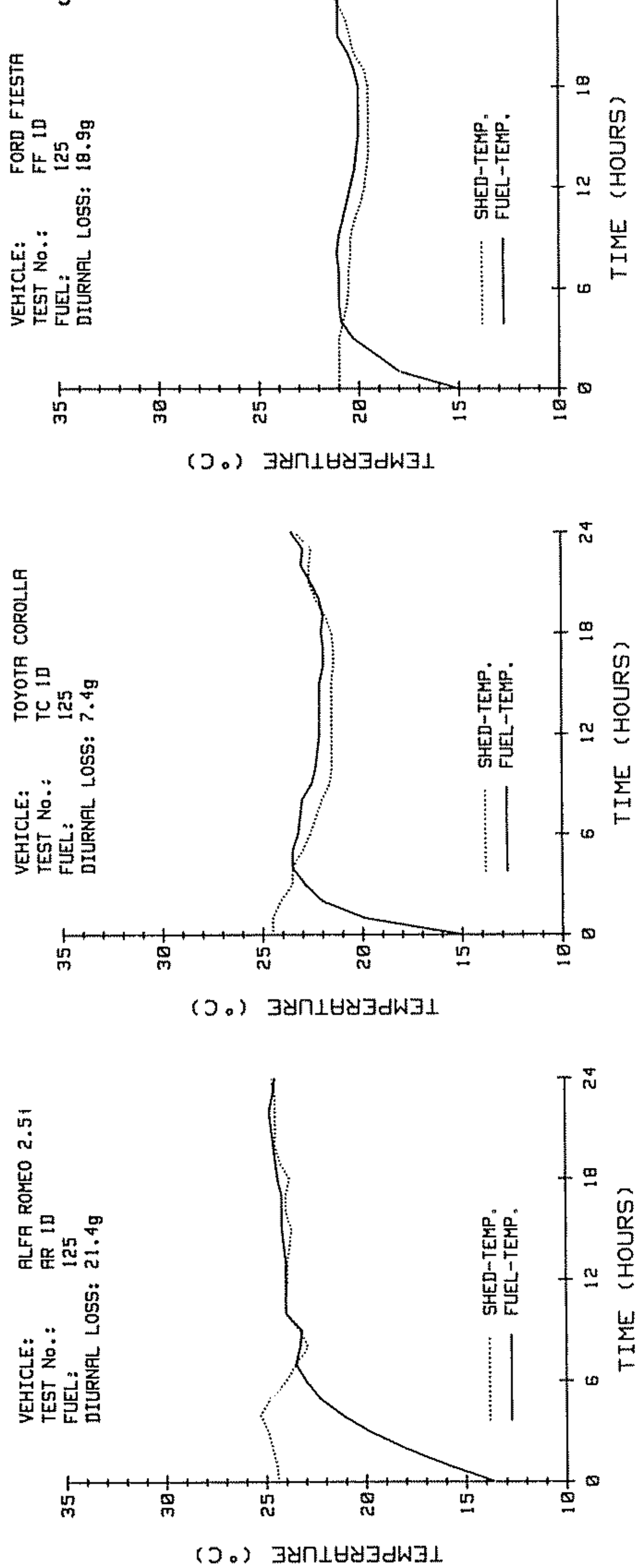


Fig. 14

DIURNAL TEMPERATURE PROFILES
VEHICLES FITTED WITH CONTROL CANISTERS

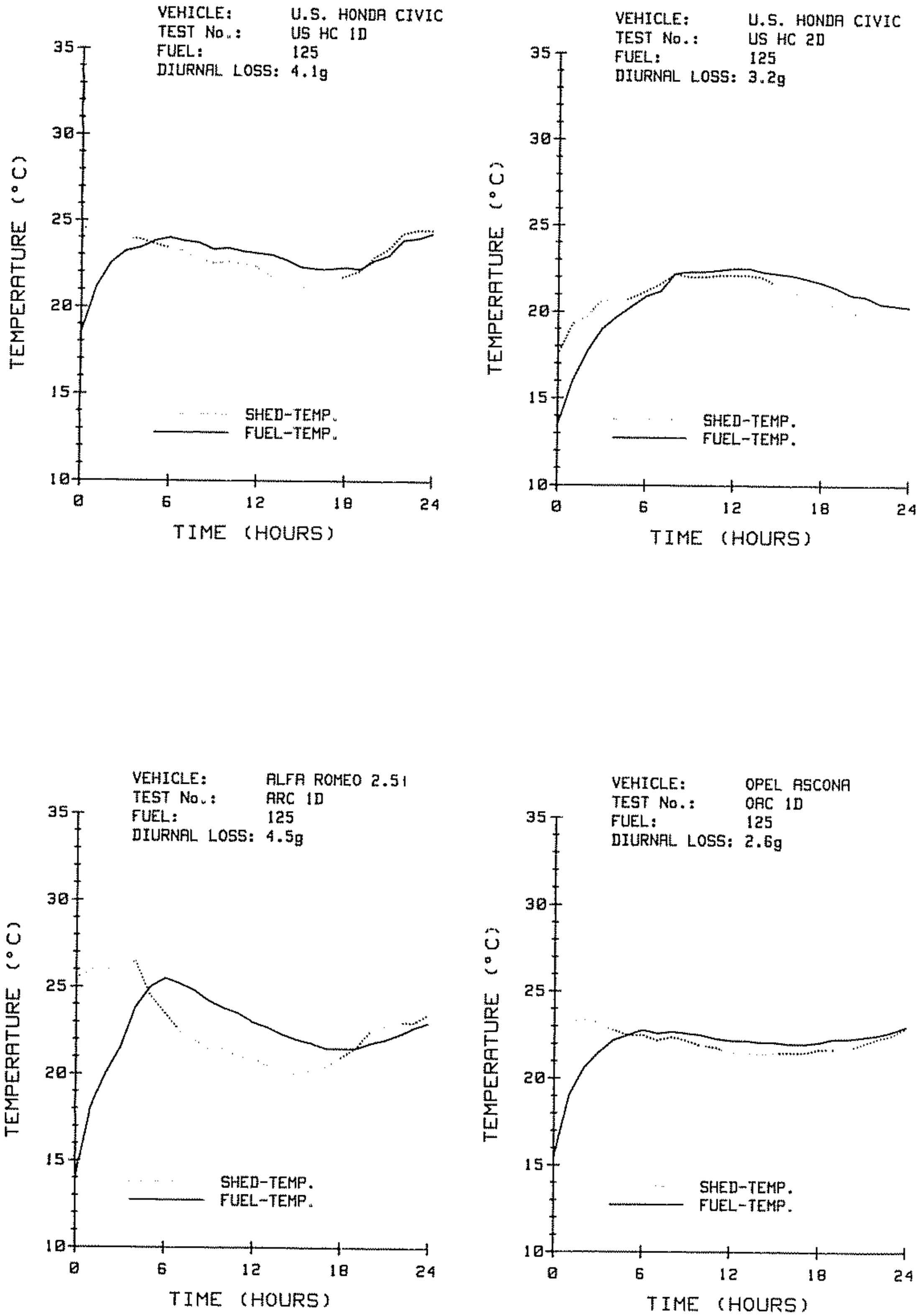


Fig. 15

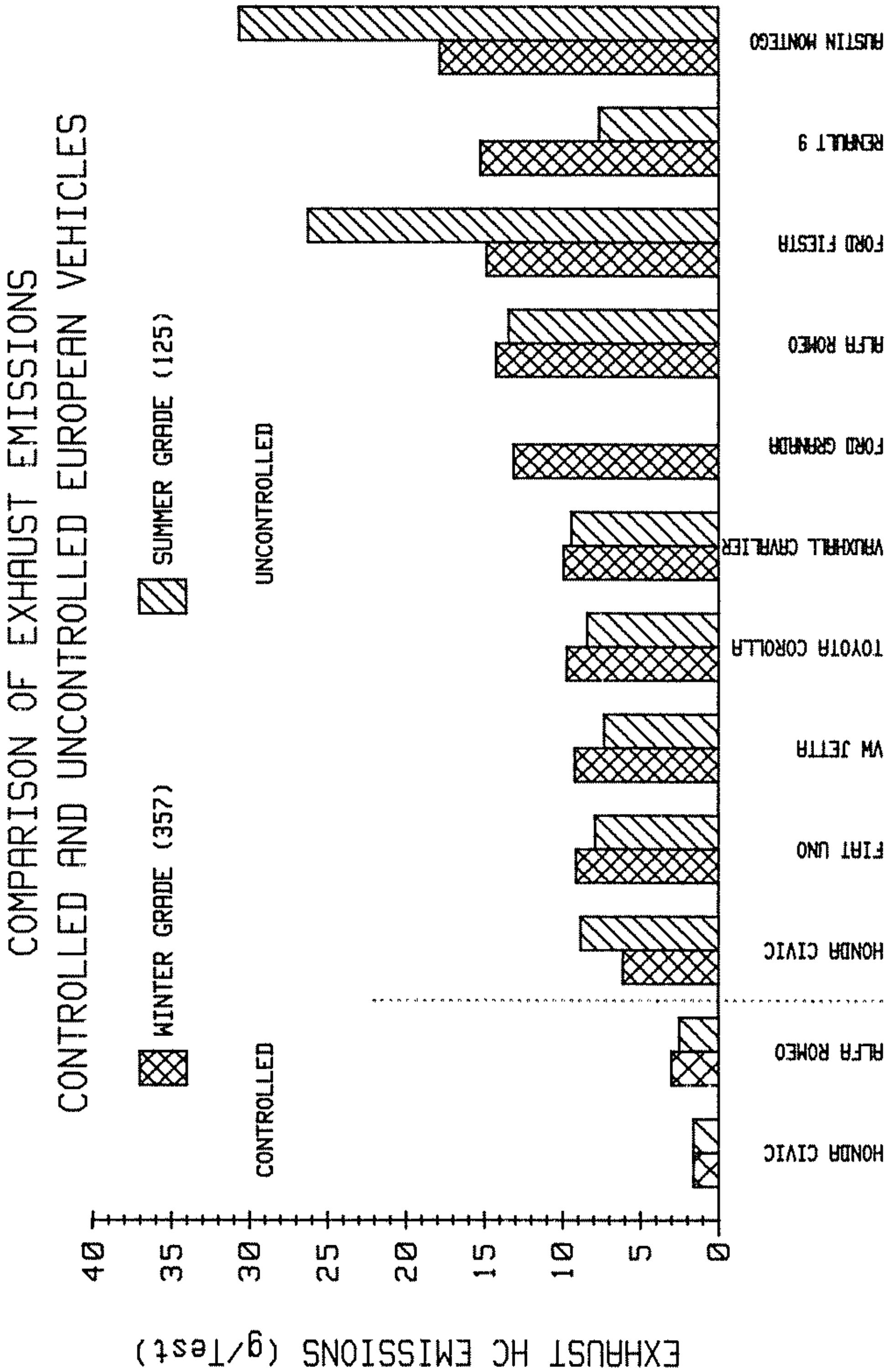

COMPARISON OF EXHAUST EMISSIONS
CONTROLLED AND UNCONTROLLED EUROPEAN VEHICLES
WINTER GRADE (357)
SUMMER GRADE (125)
CONTROLLED
UNCONTROLLED
HONDA CIVIC
ALFA ROMEO
HONDA CIVIC
FIAT UNO
VW JETTA
TOYOTA COROLLA
VAUXHALL CAVALIER
FORD GRANADA
ALFA ROMEO
FORD FIESTA
RENAULT 9
AUSTIN MONTEGO
0
5
10
15
20
25
30
35
40
EXHAUST HC EMISSIONS (g/Test)

Fig. 16

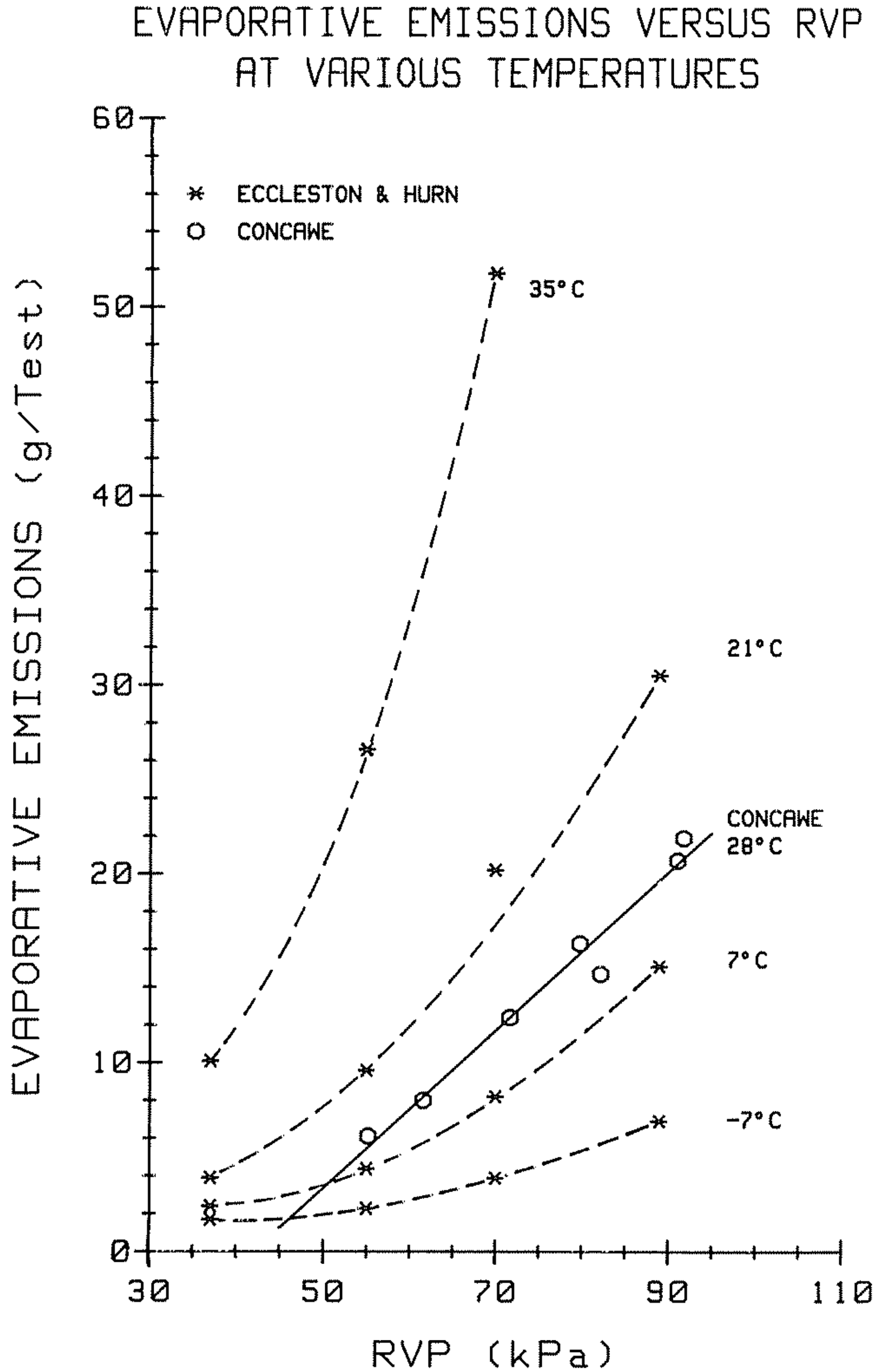
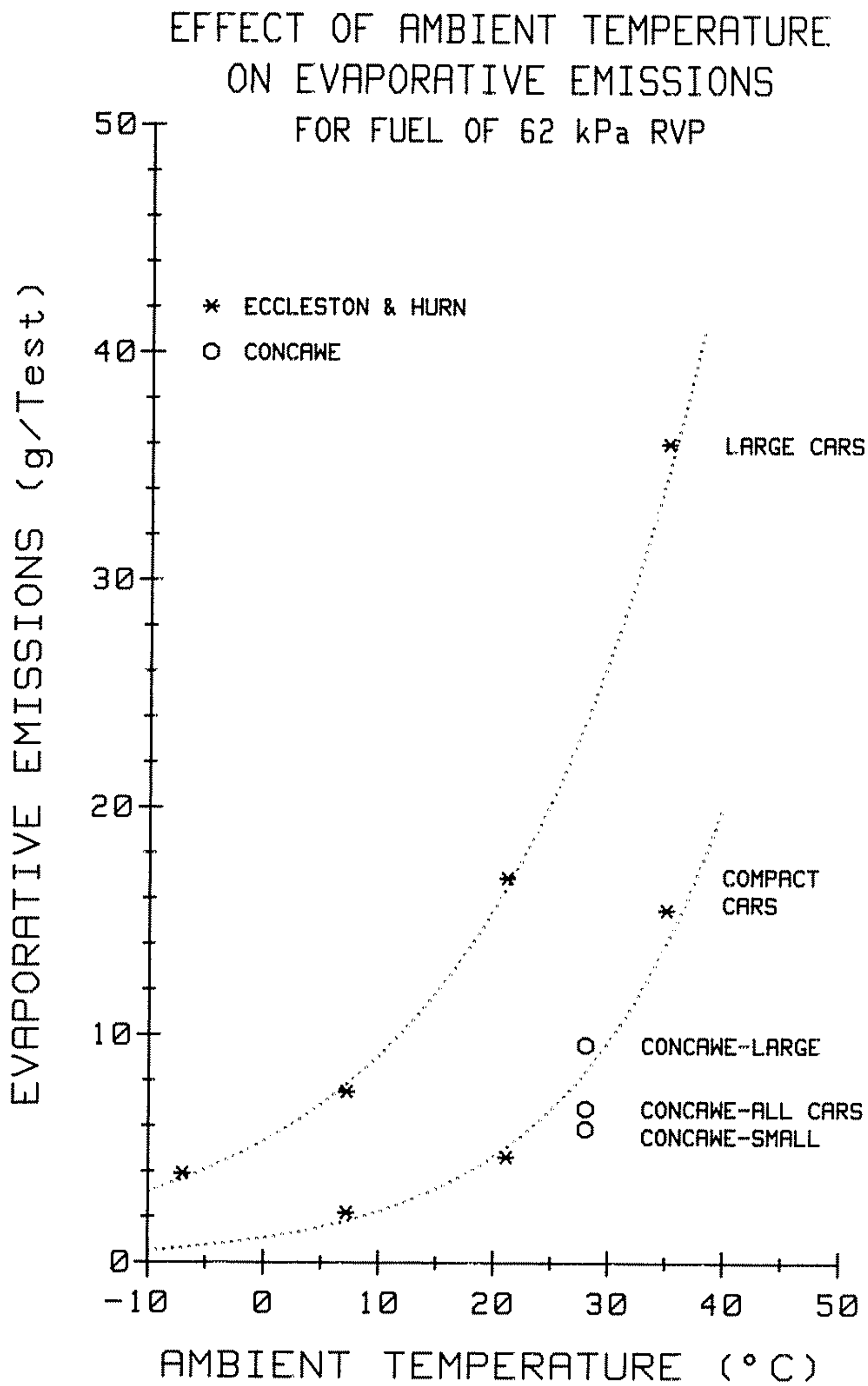

EVAPORATIVE EMISSIONS VERSUS RVP
AT VARIOUS TEMPERATURES
ECCLESTON & HURN
CONCAWE
35°C
21°C
CONCAWE
28°C
7°C
-7°C
EVAPORATIVE EMISSIONS (g/Test)
RVP (kPa)
0
10
20
30
40
50
60
30
50
70
90
110

Fig. 17


EFFECT OF AMBIENT TEMPERATURE
ON EVAPORATIVE EMISSIONS
FOR FUEL OF 62 kPa RVP
EVAPORATIVE EMISSIONS (g/Test)
50
40
30
20
10
0
* ECCLESTON & HURN
O CONCAWE
LARGE CARS
COMPACT
CARS
CONCAWE-LARGE
CONCAWE-ALL CARS
CONCAWE-SMALL
-10
0
10
20
30
40
50
AMBIENT TEMPERATURE (°C)

GLOSSARY OF TERMS

RVP	: Reid Vapour Pressure. This is a standardised vapour pressure measurement, made at 38°C with a vapour/liquid ratio to 4:1
E70	: percentage evaporated at 70°C
E100	: percentage evaporated at 100°C
E150	: percentage evaporated at 150°C
NO_x	: Nitrogen Oxides
CO	: Carbon Monoxide
HC	: Hydrocarbon
psi	: pressure in pounds per square inch
kPa	: kilopascal (1 psi = 6.89 kPa)
EPA	: Environmental Protection Agency
EEC	: European Economic Community
CEC	: Co-ordinating European Council
ECE	: Economic Commission for Europe
SHED	: Sealed Housing for Evaporative Determination
FTP	: Federal Test Procedure
ECE 15 cycle	: European urban driving cycle for fuel economy and emissions
CEC CF-11 test procedure	: European SHED test
TBA	: Tertiary Butyl Alcohol
MTBE	: Methyl Tertiary Butyl Ether
t statistic	: used for testing equality of regression coefficients against one another (a significance test)
R^2	: squared multiple correlation coefficient
(un)controlled	: (no) means provided for reducing hydrocarbon emissions by catalytic converters and carbon canisters
hot soak	: period where the fully warmed-up engine is switched off
TEV	: total evaporative emissions
HS	: hot soak losses
RL	: running losses

DL	: diurnal losses
GC	: gas chromatography
FID	: flame ionisation detector
DT	: total of increases in fuel temperature over the 24 hour period
TM	: maximum fuel temperature in degrees certigrade
Intercompany	: oil company co-operative group (volatility test data)

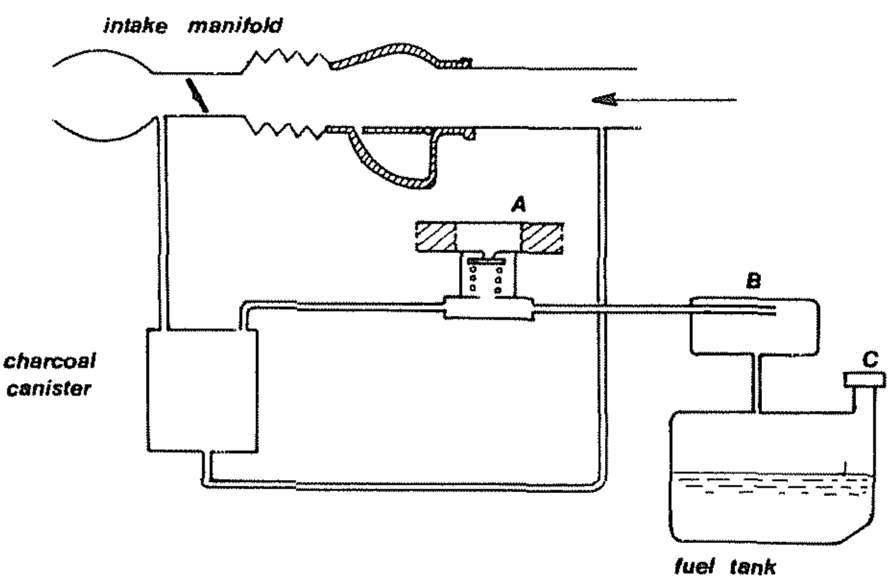
APPENDIX I - DETAILS OF EVAPORATIVE EMISSION CONTROLS ON ALFA ROMEO GTV-6, HONDA CIVIC 1.3 AND OPEL ASCONA 1.8i

Evaporative emission control systems

Simplified drawings of the evaporative emission control systems fitted to the three controlled cars are given below (18), and their operation is described.

Alfa Romeo GTV-6

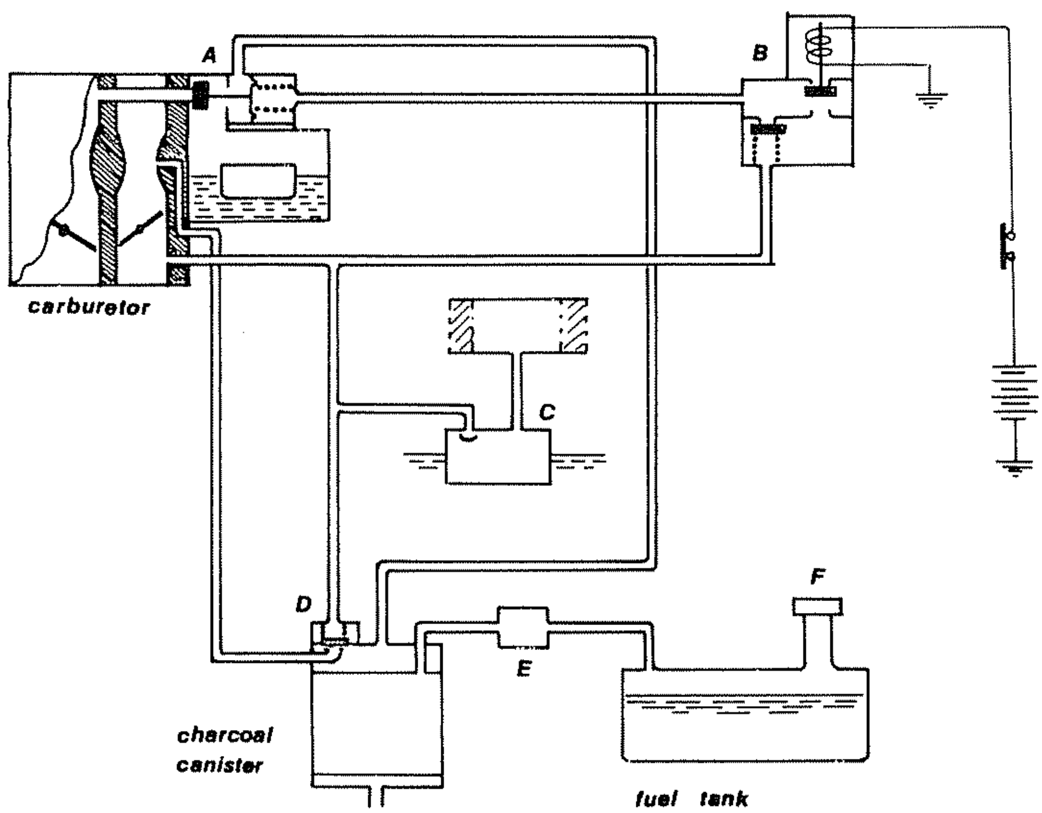
To prevent vapours from escaping to the atmosphere, a sealed filler tank cap is provided.
When the engine is soaking, gasoline vapours coming from the tank are collected into the vapour/liquid separator and then routed to the charcoal canister, where they are adsorbed and stored.
When engine is running, fresh air is drawn into the canister, and mixed with gasoline vapours which have been adsorbed on the activated charcoal.
Then the mixture enters a plenum chamber through the purge line and is burned.
The air inlet valve allows outside air to enter, in order to prevent excessive vacuum in the evaporative emission control system.



A - Air inlet valve
B - Vapour/liquid separator
C - Sealed tank cap

Honda Civic

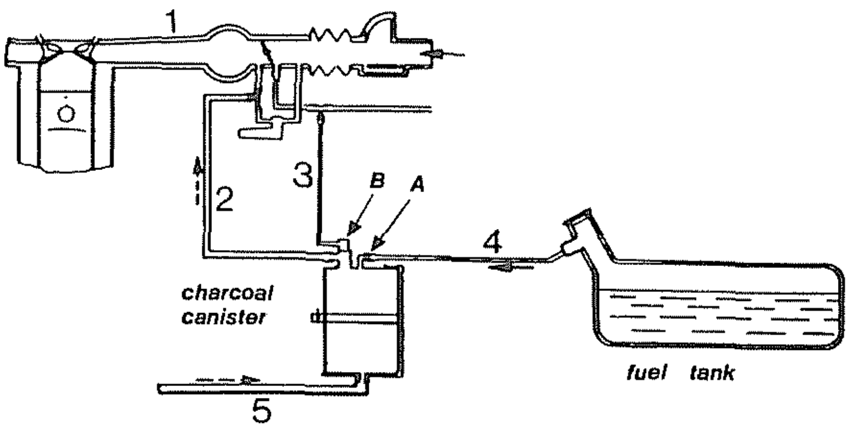
The fuel tank is fitted with a sealed cap (F) (which also functions as a safety valve), and when tank pressure exceeds a preset value, a two-way valve (E) opens allowing excess vapour to vent into the canister. The two way valve also acts as a vacuum relief valve if pressure in the tank falls below atmospheric.
When the engine coolant temperature exceeds a set value, the Thermovalve (C) closes allowing manifold vacuum to open the purge control valve (D). Purge air then flows through the canister and into the carburettor venturi.
When the engine is hot-soaking, the air vent cut-off valve (A) closes the float bowl vent to the carburettor and opens a vent line to the canister. When the engine is running however, manifold vacuum opens the air vent cut-off valve allowing vapour to vent into the carburettor. The vacuum holding solenoid valve (B) stabilises the vacuum supply to the cut-off valve. Finally a fuel cut-off solenoid valve is fitted (not shown) which shuts off the main and slow-running metering jets to the carburettor.



A - Air vent cut-off valve
B - Vacuum holding solen. valve
C - Thermovalve
D - Purge control valve
E - Two-way valve
F - Press./vacuum relief filler cap

Opel Ascona 1.8i

The charcoal canister is fitted under the left front wing to which vapour passes from the fuel tank via hose 4. Purge air enters the canister via vent line 5 and the vapour/air mixture flows to the engine via line 2. Purge flow is controlled by a valve B which is operated by manifold vacuum and opens when the engine is under load.



1 - Intake manifold
2 - Purge hose from charcoal canister to intake system
3 - Vacuum line from intake system to valve B
4 - Vent line from vehicle tank to charcoal canister
5 - Fresh air venting charcoal canister

A - Connection of tank vapour pipe to carbon canister
B - Purge control valve

APPENDIX II - TEST PROCEDURES FOR EVAPORATIVE EMISSIONS

1. CEC CF-11 Procedure

This test procedure covers the determination of hydrocarbon losses by evaporation from the fuel system of gasoline engine vehicles, and is a summary of the full procedure, reference RDF-73-83.

Car preparation

The inlet and exhaust systems of the vehicle should be checked to ensure that there are no leaks. All dirt and grease should be removed, preferably by steam cleaning. The vehicle itself should have completed some 5,000 miles on the road in order to ensure that hydrocarbon evaporation from upholstery, tyres, underseal etc. has been stabilised. If possible it is desirable to run the car at 35°C - 40°C for a period of one-two hours in order to minimise background hydrocarbon losses.

The fuel tank must be equipped with a thermocouple to allow temperature measurement of the test fuel at the approximate mid point of the fuel volume. Fittings and adaptors are necessary in order to ensure that the tank can be drained from the lowest point, and that canisters can be fitted to the carburettor and tank vents.

Preconditioning

1. Ensure that the fuel tank is completely empty and then fill with approximately ten litres of the appropriate test fuel.

2. Within one hour drive two ECE-15 cycles on the dynamometer followed by ten minutes at 80 km/h and then another two ECE-15 cycles.

3. Within five minutes drive the vehicle from the chassis dynamometer and park in the soak area.

4. Allow the vehicle to soak for at least six hours and not more than thirty hours at an ambient temperature of between 20° and 30°C without starting the engine.

Running loss and exhaust emissions test

1. Empty the tank of the test vehicle and refill with a quantity of fuel corresponding to 40% of the fuel tank capacity.

2. Connect the tank thermocouple to the recorder and when the temperature of the fuel has reached 15°C connect carbon canisters to the appropriate positions on the tank and carburettor (if applicable). These canisters should have been pre-weighed.

3. Push the vehicle onto the chassis dynamometer.

4. Operate the vehicle for four cycles according to the type 1 test required by ECE Regulation No. 15. Take bag samples and measure exhaust emissions.

5. Within one minute of completion of the ECE cycles disconnect the carbon canisters and seal the trap inlets and outlets.

6. Weigh the canisters when they have stabilised to the temperature of the room. Redetermine the weight every five minutes until it does not vary by more than 0.1 g.

Hot soak test

1. Switch on the SHED purge blowers.

2. Zero and span the FID hydrocarbon analyser. Switch on the SHED mixing fan.

3. Close the bonnet and drive the vehicle at minimum throttle from the dynamometer to the entrance of the SHED. Stop the engine before any part of the vehicle enters the chamber.

4. Check that the ambient temperature in the SHED is between 26 and 30°C.

5. Push the vehicle into the SHED and open the windows and luggage compartment. Connect the thermocouple for temperature measurement of test fuel.

6. Start the temperature recording system.

7. Switch off the SHED purge blowers and close and seal the SHED doors within two minutes of stopping the engine and within seven minutes from the time of driving the four ECE-15 cycles.

8. Immediately the SHED doors are sealed, measure the initial hydrocarbon concentration in the chamber using the FID analyser and recorder. Record the chamber temperature, the barometric pressure, and the time and date.

9. Allow the test vehicle to soak, undisturbed for a period of 120 minutes from the time recorded above. During the hot soak the ambient temperature in the chamber should remain with the range 26 - 30°C.

10. The FID hydrocarbon analyser should be zeroed and spanned immediately prior to the end of the hot soak period.

11. At the end of the hot soak measure the final hydrocarbon concentration in the SHED using the FID analyser and record. Record also the chamber temperature, barometric pressure and the time.

12. If required take a bag sample of the vapour in the SHED for hydrocarbon type analysis.

13. Push the vehicle out of the chamber ready to start a new test. Use a hydrocarbon face mask.

Calculation of evaporative emissions

1. Running losses is calculated by adding the differences between the final and initial weights for each carbon canister.

2. Hot soak losses are calculated from the following formula:

$$M_{HC} = k.V \times 10^{-4} \left(\frac{C_{HCF}\, P_{BF}}{T_F} - \frac{C_{HCI}\, P_{BI}}{T_I} \right)$$

where M_{HC} = mass of hydrocarbon hot soak losses in grams

k = 1.2 (12 + H/C)

V = net SHED volume in m^3

C_{HC} = hydrocarbon concentration as ppm carbon

P_B = barometric pressure in kPa

T = SHED ambient temperature, K

when I is initial SHED reading

F is final SHED reading

H/C is hydrogen/carbon ratio = 2.2 for hot soak emissions

3. Total evaporative losses are obtained by summing the running losses and the hot soak losses.

2. US Federal Evaporative Emissions test

The following is a summary of the US procedure highlighting differences between this and the CEC procedure. Details of the Diurnal test are not included as this was not used in the CONCAWE test programme.

Warm-up and exhaust emissions test

1. One hour maximum is permitted between the diurnal test if carried out and the Federal Test Procedure (FTP).

2. Carry out a normal FTP cycle and determine tailpipe emissions,

   - during the ten minute soak between Bags 2 and 3, disconnect, weigh and reconnect the ECS and RCS canisters;

   - run with bonnet open when driving and bonnet closed during soak.

3. During Bag 3 of the FTP, prepare for the hot soak test by,

   - purging the SHED;
   - zeroing and spanning the FID;
   - turning on the mixing fan.

Hot soak test

1. At the end of the FTP test,

   a. disconnect and weigh canisters;

   b. close bonnet;

   c. drive the test vehicle off the dyno to the entrance of the SHED;

   d. turn the engine off;

   e. push the vehicle into SHED;

   f. connect the thermocouples;

   g. open boot and windows;

   h. record the time;

   i. turn the purge blower off;

j. close the doors within two minutes of engine off and also within seven minutes of end of the FTP.

2. The 60 minute hot soak starts with the door closure.

3. Record the HC concentration at time zero.

4. Record barometric pressure and SHED temperature.

5. At 50 minutes, zero and span the FID and measure HC in the SHED.

6. At 60 minutes, measure the HC in the SHED.

7. Record barometric pressure and SHED temperature.

8. After the test,

   a. open doors;
   b. open purge opening (WEAR HC MASK);
   c. turn on purge blower and purge SHED;
   d. after SHED is purged,

      1) disconnect, weigh and reconnect the canisters;

      2) disconnect and remove heater;

      3) disconnect thermocouples.

SUMMARY OF TEST DATA ON ALL TEST VEHICLES

Table 1A Summary of tests on fuels 357 and 125 - all cars (ECE test cycles)

VEHICLE	Evap. controls fitted	WINTER FUEL (CODE 357)							SUMMER FUEL (CODE 125)						
		Test No.	EXHAUST EMISSIONS (g/test)			EVAP. EMISSIONS (g/test)			Test No.	EXHAUST EMISSIONS (g/test)			EVAP. EMISSIONS (g/test)		
			Bag 1 HC	Bag 2 HC	Total HC	RL	HS	Total		Bag 1 HC	Bag 2 HC	Total HC	RL	HS	Total
FORD FIESTA	no	F1 F3 means	7.8 7.5 7.7	6.8 7.5 7.1	14.6 15.0 14.8	2.4 1.9 2.2	8.1 10.0 9.1	10.5 11.9 11.3	F2 F4 means	12.8 19.8 16.3	9.0 10.8 9.9	21.8 30.6 26.2	0 0.2 0.1	4.4 5.1 4.8	4.4 5.7 4.9
TOYOTA COROLLA	no	TC1 TC4 means	5.5 -	4.2 -	9.7 -	4.2 3.9 4.1	7.4 12.0 9.7	11.6 15.9 13.8	TC2 TC3 means	- 4.0	- 4.4	- 8.4	2.9 3.7 3.2	5.7 6.5 6.1	8.6 10.2 9.4
RENAULT 9	no	 means	12.2 8.1 10.2	5.3 4.0 5.0	17.5 12.7 15.2	0.6 1.5 1.1	20.6 15.9 18.7	21.2 17.4 19.8		5.3 -	2.3 -	7.6 -	2.5 2.6 2.6	13.4 14.0 13.7	15.9 16.6 16.3
HONDA CIVIC	no		2.0	4.1	6.1	2.7	8.0	10.7	 means	5.3 4.6 5.0	3.8 3.8 3.8	9.1 8.4 8.8	0 0 0	4.5 3.5 4.0	4.5 3.5 4.0
FORD GRANADA	no		7.5	5.6	13.1	4.6	19.9	24.5		-	-	-	1.7	8.3	10.0
AUSTIN MONTEGO	no		8.7	9.1	17.8	3.7	13.8	17.5		9.7	20.9	30.6	2.9	8.0	10.9
VW JETTA	no	VW1 VW3 means	4.7 -	4.5 -	9.2 -	3.1 2.4 2.8	18.4 15.8 17.1	21.5 18.2 19.9	VW2 VW4 means	2.8 4.8 3.8	2.7 4.3 3.5	5.5 9.1 7.3	0.4 1.3 0.9	7.7 9.5 8.6	8.1 10.8 9.5
FIAT UNO TURBO	no		4.4	4.7	9.1	0	9.2	9.2		3.7	4.2	7.9	0.4	4.9	5.3
ALFA ROMEO	no	AR1 AR6 means	8.1 8.2 8.2	6.4 5.7 6.0	14.5 13.9 14.2	1.6 2.0 1.8	12.5 11.9 12.2	14.1 13.9 14.0	AR2 AR4 means	7.5 7.2 7.4	6.0 5.9 6.0	13.5 13.1 13.4	1.7 0 0.9	6.8 7.8 7.3	8.5 7.8 8.2
VAUXHALL CAVALIER	no		5.3	4.6	9.9	3.8	11.1	14.9		5.0	4.4	9.4	1.3	3.0	4.3
OPEL ASCONA	yes		-	-	-	0	1.4	1.4		-	-	-	0	1.8	1.8
ALFA ROMEO	yes		2.7	0.3	3.0	0	3.2	3.2		2.2	0.3	2.5	0	2.0	2.0
HONDA CIVIC	yes	HC1C	1.2	0.4	1.6	0	1.2	1.2	HC2C	1.3	0.3	1.6	0	1.3	1.3

Table 2A VW Jetta test data

Test No.	Fuel	Test Type	EXHAUST EMISSIONS (g/test) Bag 1 HC	Bag 2 HC	Bag 3 HC	Total HC	EVAPORATIVE EMISSIONS RL	HS	Federal Soak	Total	SHED TEMP. Start °C	End °C	Comments
VW 1	357	ECE	4.7	4.5	-	9.2	3.1	18.4	-	21.5	27.5	28.0	
2	125	ECE	2.8	2.7	-	5.5	0.4	7.7	-	8.1	27.5	28.0	
3	357	ECE	-	-	-	-	2.4	15.8	-	18.2	-	-	Exhaust analyser failure
4	125	ECE	4.8	4.3	-	9.1	1.3	9.5	-*	10.8	26.5	28.0	
5	357	Fed.	11.0	11.5	13.0	35.5	15.6	17.5	5.6*	33.1	27.5	29.0	
6	357	90 km/h	-	-	-	-	23.9	25.3	-	49.2	26.5	28.0	
7	357	90% V max	-	-	-	-	17.3	36.4	-	53.7	27.0	28.0	
8	71	ECE	6.1	4.9	-	11.0	2.4	13.4	-*	15.8	26.0	28.0	
9	71	Fed.	-	-	-	-	8.7	12.0	6.3*	70.7	29.5	30.0	
10	42	ECE	5.3	4.7	-	10.0	2.9	13.2	-	16.1	31.0	31.5	
11	16	ECE	5.8	5.3	-	11.1	0.8	4.8	-	5.6	26.4	28.0	
12	16	ECE	5.7	5.3	-	11.0	1.0	4.8	-	5.8	27.0	28.4	
13	71	ECE	5.6	4.9	-	10.5	3.9	13.9	-	17.8	27.0	28.4	
14	15A	ECE	3.3	3.5	-	6.8	0.3	10.5	-	10.8	26.0	28.0	
15	4	ECE	5.1	4.6	-	9.7	5.0	20.1	-	25.1	26.0	27.0	
16	4	ECE	5.1	4.5	-	9.6	5.0	17.0	-	22.0	25.0	26.2	
17	35A	ECE	-	-	-	-	2.0	16.5	-	18.5	26.0	26.4	
18	35E	ECE	-	-	-	-	2.7	15.5	-	18.2	26.0	27.0	Exhaust analyser failure
19	3	ECE	5.4	5.1	-	10.5	5.0	18.0	-	23.0	26.2	27.0	" " "
20	42	ECE	5.1	4.9	-	10.0	1.4	7.8	-	9.2	25.0	27.0	
21	3	ECE	4.7	4.9	-	9.6	4.9	19.2	-	24.1	24.4	27.0	
22	3	90 km/h	-	-	-	-	41.7	32.8	-	74.5	30.0	29.5	
23	16	90 km/h	-	-	-	-	7.6	8.5	-	16.1	27.0	29.0	
24	4	90 km/h	-	-	-	-	44.2	35.1	-	79.3	27.0	27.5	
25	42	90 km/h	-	-	-	-	17.1	14.1	-	31.2	27.0	27.5	
26	71	90 km/h	-	-	-	-	24.2	17.7	-	41.9	26.0	27.5	
27	125	90 km/h	-	-	-	-	6.8	31.5	-	38.3	27.0	28.0	
28	4	90 km/h	-	-	-	-	42.8	29.6	-	72.4	28.0	28.0	
29	42	90 km/h	-	-	-	-	15.4	15.1	-	30.5	26.0	27.0	
30	35E	ECE	5.6	4.4	-	10.0	3.0	-	-	-	-	-	
31	125	90 km/h	-	-	-	-	7.9	13.0	-	20.9	26.0	25.0	

* Not included in total

Table 3A Ford Fiesta test data

Test No.	Fuel	Test Type	EXHAUST EMISSIONS (g/test) Bag 1 HC	Bag 2 HC	Bag 3 HC	Total HC	EVAPORATIVE LOSSES (g/test) RL	HS	Federal Soak	Total	SHED TEMP. Start °C	End °C	Comments
FF 1	357	ECE	7.8	6.8	-	14.6	2.4	8.1	-	10.5	26.5	26.5	
2	125	ECE	12.8	9.0	-	21.8	0	4.4	-	4.4	25.5	26.5	
3	357	ECE	7.5	7.5	-	15.0	1.9	10.0	-	11.9	27.5	27.5	
4	125	ECE	19.8	10.8	-	30.6	0.2	5.1	-	5.3	27.5	28.0	
5	357	Fed.	16.9	21.0	16.1	54.0	3.6		1.7**		25.5	28.0	
6	357	90 km/h	-	-	-	-	19.2	18.0	-	37.2	28.5	31.0	
7	357	90% V max	-	-	-	-	14.8	16.0	-	30.8	28.0	28.8	
8	71	ECE	17.4	8.9	-	26.3	0	10.1	-	10.1	27.0	27.5	
9	71	Fed.	24.3	24.5	16.2	65.0	1.5	8.9	0.1**	10.4	26.0	28.2	
10	357	Fed.	14.1	21.1	16.7	51.9	3.5	9.4	0.8**	12.9	29.0	28.5	
11	357	90 km/h	-	-	-	-	15.5	16.0	-	31.5	31.0	31.0	
12	42	ECE	6.9	6.7	-	13.6	1.0	7.5	-	8.5	27.0	29.2	
13	42	ECE	7.7	7.2	-	14.9	1.2	8.3	-	9.5	30.0	30.2	
14	16	ECE	13.7	9.4	-	23.1	0.3	4.3	-	4.6	29.0	30.0	
15	71	ECE	21.6*	11.0	-	31.6	0.1	7.9	-	8.0	27.0	28.0	Bag 1 result suspect
16	16	ECE	11.9	10.1	-	22.0	0.2	3.7	-	3.9	25.0	27.0	
17	16	90 km/h	-	-	-	-	0.2	3.7	-	3.9	26.0	26.5	
18	4	ECE	9.2	7.1	-	16.3	1.4	11.8	-	13.2	26.0	27.0	
19	4	ECE	7.2	6.4	-	13.6	2.4	14.1	-	16.5	26.8	27.5	
20	3	ECE	11.8	8.1	-	19.9	2.6	12.9	-	15.5	24.5	27.0	
21	3	ECE	17.1	10.2	-	27.3	0.2	12.2	-	12.4	28.0	28.0	
22	3	90 km/h	-	-	-	-	14.2	11.0	-	25.2	29.5	30.0	
23	35A	ECE	15.0	8.9	-	23.9	0.7	10.5	-	11.2	26.0	27.0	
24	42	90 km/h	-	-	-	-	0.3	6.1	-	6.4	27.0	27.5	
25	35E	ECE	18.1	8.6	-	26.7	0.3	7.7	-	8.0	26.0	26.0	
26	15A	ECE	1.9	1.2	-	3.1	0	5.6	-	5.6	26.0	26.5	
27	71	90 km/h	-	-	-	-	0	7.5	-	7.5	28.0	27.0	
28	4	90 km/h	-	-	-	-	9.7	21.7	-	31.4	26.0	26.0	
29	125	90 km/h	-	-	-	-	0.8	7.0	-	7.8	26.0	26.0	
30	3	90 km/h	-	-	-	-	6.2	13.1	-	19.3	26.0	27.0	

* *Suspect result*
** Not included in total

Table 4A Toyota Corolla test data

Test No.	Fuel	Test Type	EXHAUST EMISSIONS (g/test) Bag 1 HC	Bag 2 HC	Total HC	EVAPORATIVE LOSSES RL g/test	HS g/test	Federal Soak	Total g/test	SHED TEMP. Start °C	End °C	Comments
TC 1	357	ECE	5.5	4.2	9.7	4.2	7.4	-	11.6	27.5	26.5	
2	125	ECE	-	-	-	2.9	5.7	-	8.6	26.5	26.5	Exhaust analyser failure
3	125	ECE	4.0	4.4	8.4	3.7	6.5	-	10.2	27.5	28.0	
4	357	ECE	5.0	4.9	9.9	7.1*	28.6*	-	35.7*	32.5	32.5	Spillage suspected
5	357	Fed.	-	-	-	18.3	12.2	8.1	30.5	26.5	28.0	Exhaust analyser failure
6	357	ECE	-	-	-	3.9	12.0		15.9	26.0	27.0	
7	357	90 km/h	-	-	-	9.4	14.9	-	24.3	27.0	27.5	
8	357	90% V max	-	-	-	39.8	20.3	-	60.1	28.4	29.0	
9	71	Fed.	-	-	-	19.8	12.0	6.7		29.5	29.4	Exhaust analyser failure
10	71	ECE	5.9	5.1	11.0	4.5	15.0	-	19.5	27.0	28.0	
11	42	ECE	5.4	4.8	10.2	2.9	10.9	-	13.8	29.5	30.0	
12	42	ECE	4.7	4.5	9.2	3.0	12.1	-	15.1	29.5	31.0	
13	71	ECE	6.0	5.1	11.1	6.2	17.0	-	23.2	28.0	30.0	
14	16	ECE	7.5	5.1	12.6	0	5.4	-	5.4	29.5	30.0	
15	16	ECE	6.2	4.9	11.1	2.5	5.5	-	8.0	27.2	28.2	
16	4	ECE	5.3	4.7	10.0	7.2	22.7	-	29.9	27.0	28.0	
17	4	ECE	4.8	4.1	8.9	9.5	18.6	-	28.1	26.0	27.2	
18	4	90 km/h	-	-	-	36.2	16.2	-	52.4	25.4	26.4	
19	3	ECE	5.3	4.6	9.9	5.9	20.5	-	26.4	26.0	27.0	
20	3	ECE	5.3	4.4	9.7	5.3	18.3	-	23.6	26.0	27.5	
21	3	90 km/h	-	-	-	27.6	19.3	-	46.9	27.0	28.0	
22	35A	ECE	6.3	5.4	11.7	4.9	14.4	-	19.3	30.5	30.0	
23	16	90 km/h	-	-	-	7.9	5.5	-	13.4	27.0	28.0	
24	42	90 km/h	-	-	-	14.1	7.8	-	21.9	25.0	27.0	
25	4	90 km/h	-	-	-	41.7	21.1	-	62.8	26.0	27.5	
26	71	90 km/h	-	-	-	22.3	15.7	-	38.0	27.0	27.5	
27	357	90 km/h	-	-	-	20.3	12.5	-	32.8	26.0	26.0	
28	125	90 km/h	-	-	-	6.1	7.6	-	13.7	26.0	27.0	
29	71	90 km/h	-	-	-	25.4	13.7	-	39.1	26.0	27.5	
30	15A	ECE	6.0	5.2	11.2	0.5	-	-	-	-	-	No SHED test
31	35E	ECE	6.6	4.9	11.5	3.4	-	-	-	-	-	" " "

* Suspect results

Table 5A Alfa Romeo test data (uncontrolled version)

Test No.	Fuel	Test Type	EXHAUST EMISSIONS (g/test) Bag 1 HC	Bag 2 HC	Bag 3 HC	Total HC	EVAPORATIVE LOSSES (g/test) RL	HS	Federal Soak	Total	SHED TEMP. Start °C	End °C	Comments
AR 1	357	ECE	8.1	6.4	-	14.5	1.6	12.5	-	14.1	27.5	28.0	
2	125	ECE	7.5	6.0	-	13.5	1.7	6.8	-	8.5	26.5	28.0	
3	357	ECE	2.2	0.3*	-	2.5	3.2	20.2*	-	23.4*	29.5	31.5	Suspect test
4	125	ECE	7.2	5.9	-	13.1	0	7.8	-	7.8	26.0	28.0	
5	357	Fed.	12.7	13.1	8.4		13.5	15.3	n.m.**		26.0	28.0	
6	357	90 km/h	-	-	-	-	10.4	23.4	-	33.8	26.5	29.0	
7	357	90% V max	-	-	-	-	11.4	38.0	-	49.4	26.0	28.5	
8	71	ECE	9.1	6.4	-	15.5	2.1	12.0	-	14.1	26.0	27.0	
9	71	Fed.	14.0	14.3	9.4		7.4	21.6	0.2		26.0	29.2	
10	71	90 km/h	-	-	-	-	5.3	19.9	-	25.2	27.5	29.0	
11	42	ECE	7.5	5.5	-	13.0	3.2	9.8	-	13.0	27.0	30.0	
12	42	ECE	6.5	5.2	-	11.7	1.1	13.0	-	14.1	32.0	32.0	
13	71	ECE	7.8	5.7	-	13.5	3.4	16.9	-	20.3	31.0	32.0	
14	16	ECE	7.9	5.8	-	13.7	1.9	6.8	-	8.7	28.0	29.5	
15	16	ECE	8.8	6.4	-	15.2	0.1	6.6	-	6.7	26.0	28.0	
16	357	ECE	8.2	5.7	-	13.9	2.0	11.9	-	13.9	26.0	27.4	Repeat of AR3
17	4	ECE	7.0	5.0	-	12.0	4.4	15.8	-	20.2	26.0	27.5	
18	4	ECE	6.0	4.6	-	10.6	4.0	16.5	-	20.5	27.0	28.5	
19	3	ECE	7.9	6.0	-	13.9	5.4	16.1	-	21.5	26.5	28.0	
20	3	ECE	8.2	6.4	-	14.6	4.3	14.8	-	19.1	27.0	29.0	
21	35A	ECE	6.9	5.3	-	12.2	1.9	10.7	-	12.6	28.0	29.0	
22	15A	ECE	6.6	5.0	-	11.6	1.0	7.8	-	8.8	25.0	27.0	
23	35E	ECE	7.4	5.3	-	12.7	1.8	7.6	-	9.4	25.0	26.0	
24	71	ECE	-	-	-	-	1.0	16.9	-	17.9	26.0	26.0	
25	357	ECE	-	-	-	-	0.8	8.1	-	8.9	25.0	26.0	
26	35E	ECE	7.3	5.1		12.4	1.0	-	-	-	-	-	

* Suspect results

** n.m. = not measured

Table 6A Honda Civic (evap. controlled model) test data

Test No.	Fuel	Test Type	EXHAUST EMISSIONS (g/test) Bag 1 HC	Bag 2 HC	Total HC	EVAPORATIVE LOSSES (g/test) RL	HS	Federal Soak	Total	SHED TEMP. Start °C	End °C	Comments
HC 1C	357	ECE	1.2	0.4	1.6	0	1.2	-	1.2	27.0	27.5	
2C	125	ECE	1.3	0.3	1.6	0	1.3	-	1.3	28.0	28.5	
3C	35A	ECE	1.0	0.2	1.2	0	1.4	-	1.4	27.5	28.0	
4C	15A	ECE	1.1	0.3	1.4	0	1.8	-	1.8	28.0	29.0	
5C	125	90 km/h	-	-	-	0	1.6	-	1.6	30.0	30.0	
6C	35A	90 km/h	-	-	-	0	1.9	-	1.9	28.0	30.5	

Table 7A Diurnal tests using VW Jetta

Test No.	VW 1D		VW 2D		VW 3D		VW 4D		VW 5D		VW 6D		VW 7D		VW 8D	
Fuel	357		125		125		125		125		125		125		125	
Starting conditions	Engine cold		Engine cold		Engine cold		Engine hot (after HS)		Continued from 4D		Continued from 5D		Continued from 6D		Continued from 7D	
Temp. measured	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL
Temp. at start (°C)	22.0	14.0	32.0	17.8	22.5	13.0	22.6	23.7	20.5	20.6	19.5	20.0	19.3	19.0	21.0	20.4
" " 1 hour	22.0	17.0	32.3	19.2	23.0	17.0	22.6	23.3	21.0	21.0						
" " 2	22.2	19.2	32.4	20.3	23.0	19.0	22.5	23.2	21.3	21.1						
" " 3	21.7	20.5	32.3	21.5	23.0	20.7	22.3	23.2	21.5	21.5	19.0	19.7	20.5	20.0	21.5	21.2
" " 4	21.5	21.2	32.0	24.1	23.0	21.7	21.9	22.8	21.5	21.7						
" " 5	21.6	21.8	31.9	27.0	23.0	22.3	21.8	22.4	21.6	21.8						
" " 6	21.6	22.0	32.0	29.6	23.0	23.0	21.4	22.1	21.6	21.8	18.8	19.4	20.5	21.0	21.6	22.0
" " 7	21.5	21.9	31.2	30.5	22.5	23.0	21.4	22.0	21.5	22.0						
" " 8	21.0	21.7	30.5	30.7	22.5	22.8	21.4	22.0	21.4	21.9						
" " 9	20.5	21.4	29.5	30.2	22.3	22.8	21.1	22.0	21.3	21.7	18.5	19.2	20.5	21.0	21.6	22.0
" " 10	20.3	21.2	28.6	29.9	22.4	23.0	20.8	21.8	20.9	21.6						
" " 11	19.9	21.0	28.0	29.3	22.5	23.0	20.7	21.6	20.7	21.3						
" " 12	19.8	20.8	27.5	28.8	22.4	22.9	20.7	21.6	20.5	21.2	18.0	19.0	20.0	20.7	21.6	22.0
" " 13	19.7	20.6	27.2	28.2	22.1	22.8	20.5	21.5	20.4	21.2						
" " 14	19.6	20.5	26.5	27.9	22.0	22.6	20.4	21.4	20.2	21.2						
" " 15	19.7	20.4	26.0	27.4	22.0	22.5	20.2	21.1	20.0	20.9	17.5	18.5	19.7	20.2	21.5	21.8
" " 16	19.8	20.3	25.5	26.9	22.0	22.5	20.0	21.0	19.7	20.6						
" " 17	20.2	20.5	25.1	26.5	22.2	22.7	20.0	20.8	19.5	20.2						
" " 18	20.4	20.5	25.0	26.0	22.3	22.7	19.8	20.7	19.4	20.2	17.5	18.2	19.5	20.1	21.0	21.5
" " 19	21.5	21.1	25.4	26.0	22.4	22.7	19.8	20.5	19.4	20.2						
" " 20	21.7	21.3	26.0	25.8	22.6	23.0	19.9	20.4	19.5	20.1						
" " 21	22.0	21.7	27.3	27.0	22.9	23.0	19.9	20.5	19.5	20.0	18.0	18.3	20.0	20.0	22.0	21.3
" " 22	22.2	22.0	27.5	27.3	23.0	23.2	20.0	20.5	19.5	20.0						
" " 23	22.6	22.5	27.5	27.5	23.8	23.6	20.4	20.6	19.5	20.0						
" " 24	22.8	22.7	28.0	27.9	23.5	24.0	20.5	20.6	19.5	20.0	19.3	19.0	21.0	20.4	22.4	22.0
Max. temp.	22.8	22.7	32.0	30.7	23.8	24.0	22.6	23.7	21.6	22.0	19.5	20.0	21.0	21.0	22.4	22.0
Min. temp.	19.6	14.0	25.0	17.8	22.0	13.0	19.8	20.4	19.5	20.0	17.5	18.2	19.3	19.0	21.0	20.4
Sum of temp. increases	3.2	10.3	3.5	15.0	2.5	11.7	3.6	3.5	1.2	1.4	1.8	0.8	2.7	2.4	2.0	2.3
g HC at end	12.6		15.7		9.1		5.5		3.3		2.2		2.7		1.4	

Table 8A Diurnal test data - other vehicles

Test no.	US HC 1D		US HC 2D		ARC 1D		ARD D		TC 1D		FF 1D		OAC 1	
Vehicle	US Honda Civic		US Honda Civic		Alfa Romeo Contr.		Alfa Romeo		Toyota Corolla		Ford Fiesta		Opel Ascona Contr.	
Fuel	125		125		125		125		125		125		125	
Starting condition	Engine cold		Engine cold		Engine cold		Engine cold		Engine cold		Engine cold		Engine cold	
Temp. measured	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL	SHED	FUEL
Starting temp. °C	24.5	18.5	17.5	13.5	25.5	14.0	24.4	13.5	24.5	15.0	21.0	15.0	23.0	15.5
Temp. after 1 hour	24.6	21.1	19.3	16.0	26.0	18.0	24.5	15.9	24.5	19.9	21.0	18.0	23.2	19.0
" " 2	24.5	22.5	19.7	17.7	26.0	20.0	24.7	18.0	24.1	22.0	21.0	19.7	23.4	20.6
" " 3	24.0	23.2	20.7	19.0	26.0	21.5	24.9	19.8	23.5	22.9	21.0	20.3	23.2	21.5
" " 4	23.9	23.4	20.6	19.7	26.5	23.8	25.3	21.2	23.5	23.5	20.8	20.9	22.8	22.2
" " 5	23.6	23.8	20.8	20.3	24.5	25.0	24.8	22.3	23.0	23.5	20.6	21.0	22.5	22.5
" " 6	23.4	24.0	21.2	20.9	23.5	25.5	24.0	23.0	22.6	23.2	20.5	21.0	22.5	22.8
" " 7	23.2	23.8	21.6	21.2	22.5	25.2	23.5	23.5	22.3	23.1	20.5	21.0	22.4	22.7
" " 8	22.8	23.7	22.2	22.2	22.0	24.8	22.9	23.3	22.0	23.0	20.4	21.1	22.4	22.7
" " 9	22.5	23.3	22.0	22.3	21.5	24.2	23.3	23.2	21.6	22.5	20.4	21.0	22.2	22.6
" " 10	22.6	23.4	22.0	22.3	21.5	23.8	24.0	24.0	21.5	22.3	20.2	20.8	21.9	22.5
" " 11	22.5	23.2	22.1	22.4	21.0	23.5	24.0	24.0	21.5	22.2	19.9	20.6	21.8	22.3
" " 12	22.3	23.1	22.1	22.5	21.0	23.0	23.9	24.0	21.5	22.1	19.7	20.4	21.5	22.2
" " 13	21.8	23.0	22.1	22.5	20.5	22.7	23.9	24.0	21.5	22.1	19.6	20.2	21.5	22.2
" " 14	21.5	22.7	22.0	22.3	20.5	22.3	23.8	24.1	21.5	22.1	19.5	20.1	21.4	22.1
" " 15	21.1	22.3	21.5	22.2	20.0	22.0	23.7	24.2	21.5	22.1	19.5	20.0	21.5	22.1
" " 16	21.3	22.2	21.2	22.1	20.3	21.8	24.0	24.2	21.4	22.1	19.5	20.0	21.5	22.0
" " 17	21.5	22.2	20.9	21.9	20.5	21.5	24.0	24.2	21.4	21.9	19.5	20.0	21.5	22.0
" " 18	21.8	22.3	20.6	21.7	21.0	21.5	23.8	24.4	21.5	22.0	19.5	20.0	21.7	22.1
" " 19	22.1	22.2	20.3	21.4	21.5	21.5	24.3	24.5	21.8	21.9	19.7	20.2	21.7	22.3
" " 20	22.9	22.7	20.0	21.0	22.5	21.8	24.5	24.6	22.3	22.1	20.2	20.5	21.7	22.3
" " 21	23.4	23.0	19.8	20.9	22.8	22.0	24.5	24.7	22.6	22.5	20.4	21.0	22.0	22.4
" " 22	24.3	23.9	19.5	20.5	23.0	22.3	24.5	24.8	22.6	23.0	20.6	21.0	22.3	22.5
" " 23	24.5	24.0	19.5	20.4	23.0	22.7	24.5	24.6	22.5	22.9	21.0	21.0	22.5	22.7
" " 24	24.5	24.3	19.6	20.3	23.5	23.0	24.7	24.5	23.3	23.5	21.5	21.0	22.9	23.0
Max. temp.	24.6	24.3	22.2	22.5	26.5	25.5	25.3	24.8	23.3	23.5	21.5	21.1	23.4	23.0
Min. temp.	21.1	18.5	17.5	13.5	20.0	14.0	22.9	13.5	21.4	15.0	19.5	15.0	21.4	15.5
Sum of temp. increases	3.2	7.6	4.8	9.0	4.5	13.0	2.7	11.6	1.9	10.2	2.0	7.1	1.9	8.3
HC at end	4.1		3.2		4.5		21.4		7.4		18.9		2.6	

Table 9A Analyses of vapour in SHED versus fuel

VW Jetta

Carbon no. of molecule	Saturate (S) Olefin (O) Aromatics (A)	FUEL 3			FUEL 4			FUEL 16			FUEL 42		
		GC Analyses			GC Analyses			GC Analyses			GC Analyses		
		Vapour(V) wt %	Fuel(F) wt %	Ratio V/F	Vapour(V) wt %	Fuel(F) wt%	Ratio V/F	Vapour(V) wt %	Fuel(F) wt %	Ratio V/F	Vapour(V) wt %	Fuel(F) wt %	Ratio V/F
2	S + O	0	0	-	0	0.02	-	0	0.01	-	0	0	-
3	S + O	0	0.2	-	7.0	0.8	8.8	0	0.07	-	0	0.3	-
4	S	13.3	6.9	1.9	47.3	10.8	4.4	18.5	2.40	7.7	12.4	6.9	1.8
	O	4.1	0.7	5.9	1.2	0.3	3.0	3.1	0.47	8.8	2.4	0.3	8.0
5	S	19.8	13.1	1.5	12.9	4.8	2.7	36.7	9.94	3.7	8.4	7.7	1.1
	O	17.3	6.5	2.7	5.1	0.8	6.4	11.6	1.51	7.8	5.6	3.1	1.8
6	S	15.3	10.5	1.5	24.3	55.4	0.4	10.6	8.17	1.3	10.0	35.2	0.3
	O	13.9	5.6	2.5	0	0.5	-	0	1.58	-	11.7	1.6	7.3
	A	3.1	1.3	2.4	0.7	0.2	3.5	2.8	2.91	1.0	18.6	2.7	6.9
7	S	7.8	3.4	2.3	1.5	1.3	1.2	3.8	4.58	0.8	9.1	5.7	1.6
	O	0	2.5	-	0	0.3	-	0	1.93	-	0	0.9	-
	A	5.4	1.5	3.6	0	0.5	-	4.8	7.95	0.6	21.7	6.7	3.2
7+	S + O + A	0	47.4	-	0	24.3	-	7.1	57.48	0.1	0	28.9	-
MeOH	Oxy.	0	0	-	0	0	-	0	0	-	0	0	-
TBA	Oxy.	0	0	-	0	0	-	0	0	-	0	0	-
MTBE	Oxy.	0	0	-	0	0	-	0	0	-	0	0	-
Totals (ppm)	by: bag GC	828			423			146			822		
	by: SHED FID	702			620			180			415		
	Ratio GC/FID	1.18			0.68			0.81			1.66		

Carbon no. of molecule	Saturate (S) Olefin (O) Aromatics (A)	FUEL 71			FUEL 15A			FUEL 35A			FUEL 35E		
		GC Analyses			GC Analyses			GC Analyses			GC Analyses		
		Vapour(V) wt %	Fuel(F) wt %	Ratio V/F	Vapour(V) wt %	Fuel(F) wt %	Ratio V/F	Vapour(V) wt %	Fuel(F) wt %	Ratio V/F	Vapour(V) wt %	Fuel(F) wt %	Ratio V/F
2	S + O	0	0.01	-	0	0	-	0	0	-	0	0	-
3	S + O	0	0.14	-	0	0	-	0	0	-	0	0.1	-
4	S	28.1	8.8	3.2	4.1	0.4	10.2	8.5	2.1	4.0	26.2	6.1	4.3
	O	8.9	1.9	5.0	4.7	0.7	6.7	2.1	0.3	7.0	0	0.1	-
5	S	40.7	13.4	3.0	40.0	12.7	3.1	38.1	18.0	2.1	37.5	16.6	2.3
	O	7.8	2.0	3.9	12.6	5.9	2.1	10.7	4.3	2.5	1.9	0.3	6.3
6	S	6.3	3.7	1.7	25.8	14.3	1.8	16.4	10.8	1.5	16.6	9.3	1.8
	O	0	1.6	-	0	1.5	-	4.8	2.7	1.8	1.3	1.7	0.8
	A	1.7	2.8	0.6	3.0	1.5	2.0	1.2	1.5	0.8	5.3	1.3	4.1
7	S	1.1	4.9	0.2	5.8	5.9	1.0	17.2	7.6	2.3	0	8.2	-
	O	0	2.1	-	0	1.5	-	0	1.9	-	2.4	1.1	2.2
	A	2.4	11.3	0.2	0	25.2	-	0	8.3	-	1.5	4.5	0.3
7+	S + O + A	3.0	47.4	0.06	0	24.8	-	0	32.5	-	0	41.9	-
MeOH	Oxy.	0	0	-	0.8	3.3	0.24	0.2	3.0	0.07	0	0	-
TBA	Oxy.	0	0	-	3.0	2.3	1.3	0.8	2.0	0.4	0	0	-
MTBE	Oxy.	0	0	-	0	0	-	0	0	-	7.4	8.8	0.8
Totals (ppm)	by: bag GC	437			135			501			379		
	by: SHED FID	479			384			602			568		
	Ratio GC/FID	0.91			0.35			0.83			0.67		

APPENDIX IV - EFFECT OF AMBIENT TEMPERATURE ON EVAPORATIVE EMISSIONS

Effect of ambient temperature caps on evaporative emissions

Ambient temperature will clearly have a major effect on evaporative emissions, as it will affect the temperatures of a vehicles fuel system, and especially the cool-down rate. However, the only way to study this effect using the SHED test procedure would be to use a controlled climate chassis dynamometer and SHED. Such a facility was not available for this test programme, and all tests reported were carried out within the official recommended temperature range of 26-30°C, corresponding to a summer climate.

The most comprehensive published work in which ambient temperature was varied was a programme carried out for the API by the US Bureau of Mines in the late 60s/early 70s (15, 16). In two programmes they examined emissions from a wide range of uncontrolled US vehicles at four ambient temperatures (20, 45, 70, 95°C or -7, 7, 21, 35°C) using a carbon canister measurement technique. Fig. 1A summarises their results and shows a dramatic increase in evaporative emissions with increasing temperature.

A more recent programme (17) carried out by the EPA looked at diurnal and hot-soak emissions over a limited temperature range for current US vehicles (with canisters). Their results, summarised in Fig. 2A also show a dramatic effect of temperature on diurnal emissions, but only a relatively minor effect on hot-soak emissions. This may be due to the much greater quantities of vapour causing canister breakthrough in the diurnal tests, or to the fact that the bulk fuel temperature does not reach ambient levels in the hot-soak test, whereas this is the temperature quoted in the diurnal measurements.

Fig. 1A

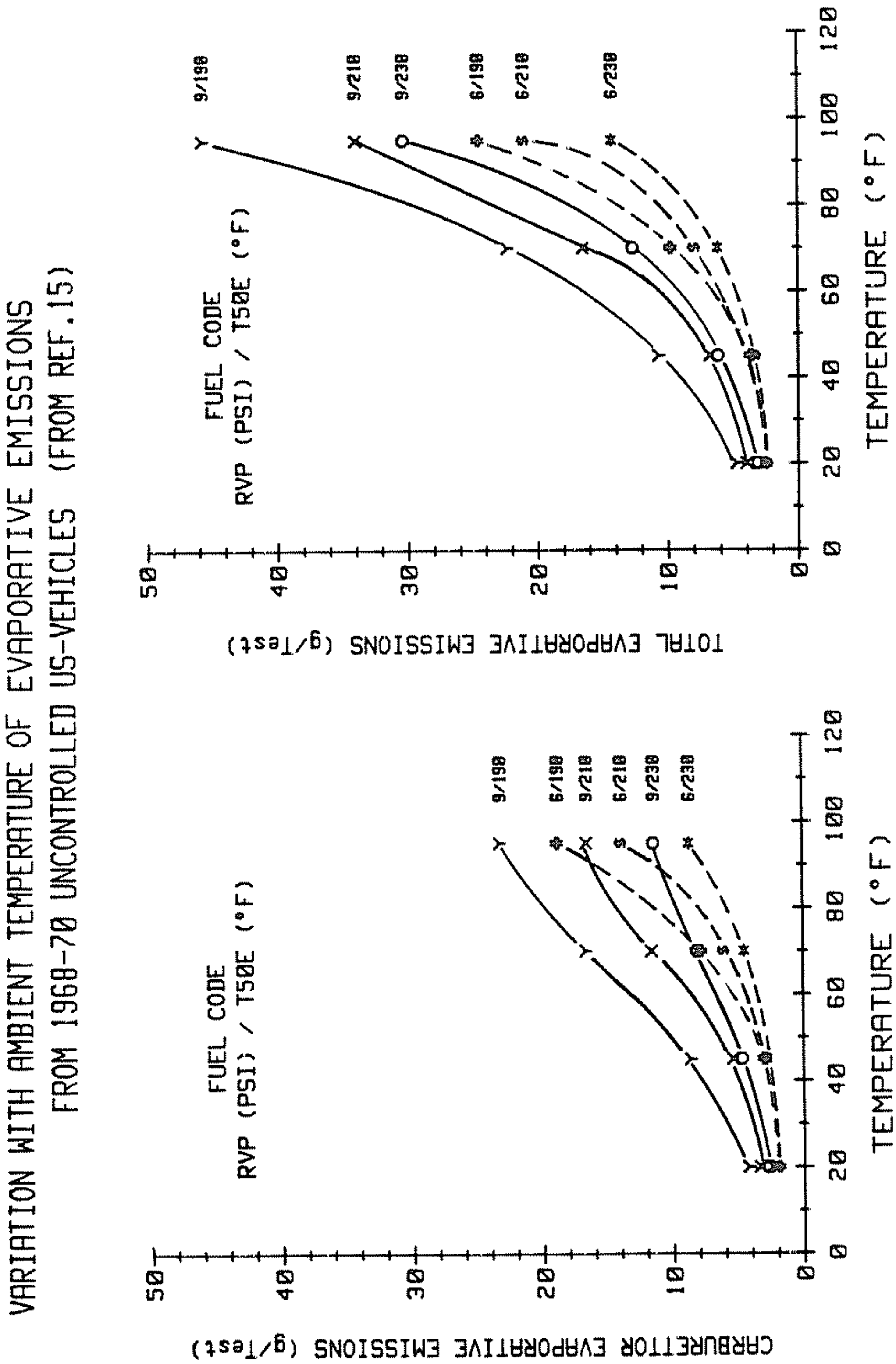
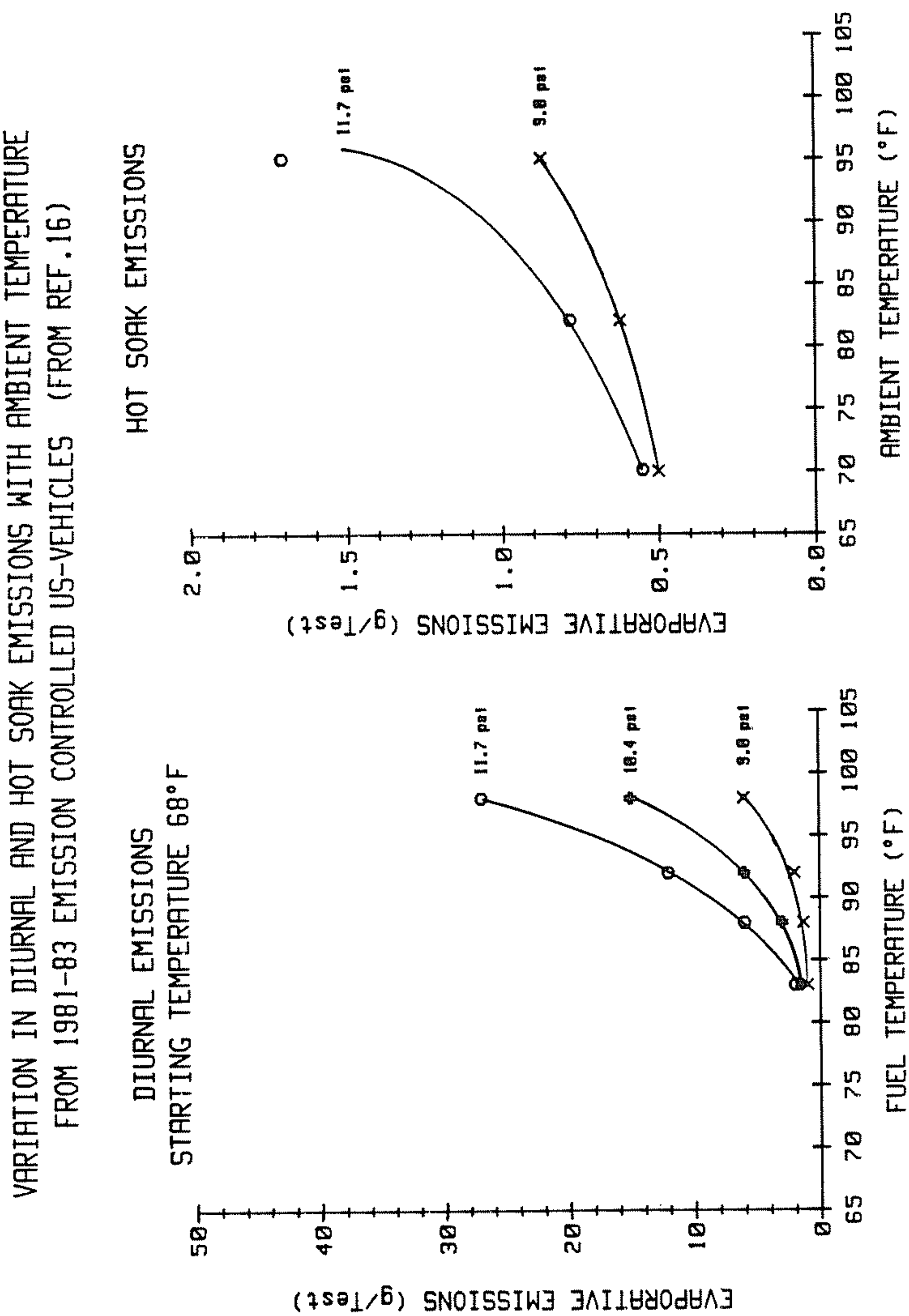

VARIATION WITH AMBIENT TEMPERATURE OF EVAPORATIVE EMISSIONS
FROM 1968-70 UNCONTROLLED US-VEHICLES (FROM REF.15)
FUEL CODE
RVP (PSI) / T50E (°F)
9/190
6/190
9/210
6/210
9/230
6/230
CARBURETTOR EVAPORATIVE EMISSIONS (g/Test)
TEMPERATURE (°F)
FUEL CODE
RVP (PSI) / T50E (°F)
9/190
9/210
9/230
6/190
6/210
6/230
TOTAL EVAPORATIVE EMISSIONS (g/Test)
TEMPERATURE (°F)

Fig. 2A


VARIATION IN DIURNAL AND HOT SOAK EMISSIONS WITH AMBIENT TEMPERATURE
FROM 1981-83 EMISSION CONTROLLED US-VEHICLES (FROM REF.16)
HOT SOAK EMISSIONS
11.7 psi
9.8 psi
EVAPORATIVE EMISSIONS (g/Test)
2.0
1.5
1.0
0.5
0.0
65
70
75
80
85
90
95
100
105
AMBIENT TEMPERATURE (°F)
DIURNAL EMISSIONS
STARTING TEMPERATURE 68°F
11.7 psi
10.4 psi
9.8 psi
EVAPORATIVE EMISSIONS (g/Test)
50
40
30
20
10
0
65
70
75
80
85
90
95
100
105
FUEL TEMPERATURE (°F)