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the control of vehicle evaporative and refuelling emissions - the "on-board" system

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ABSTRACT

In this research programme to further investigate "on-board" control of evaporative Volatile Organic Compound (VOC) emissions from gasoline fuelled vehicles, an Opel Ascona and a Honda Civic were tested with specially installed enlarged carbon canisters to control refuelling emissions. Both installations achieved refuelling emissions below 0.05 g/litre of fuel dispensed representing control efficiencies of about 97% or more. The total evaporative emissions as normally measured, being the sum of diurnal, hot soak and refuelling losses, were below 2 g/test with all the fuels used which ranged between 61 kPa and 103 kPa RVP. No significant changes in exhaust emissions or in hot or cold weather driveability were seen between the standard and converted cars, and the tests demonstrated that regeneration of the canisters was achieved much more quickly than required to cope with the vapour from subsequent refuellings.

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SUMMARY

The subject of evaporative Volatile Organic Compound (VOC) emissions from gasoline fuelled vehicles has recently become of major interest in Europe. Emissions generated when refuelling vehicles are of lesser importance but are still coming under scrutiny. The various options to control evaporative VOC emissions from vehicles have been reviewed by CONCAWE (3) and to support this work, two European-model cars were equipped with enlarged carbon canisters which can control both evaporative and refuelling emissions. Such systems have been developed and demonstrated in the USA and are called "on-board" systems.

The two cars chosen were an Opel Ascona 1.8i and a Honda Civic 1.3. They had been used in a previous CONCAWE programme and were already fitted with catalysts and small carbon canisters to meet current US emission limits. The conversions were carried out in the USA, using existing expertise, but the converted vehicles were then fully tested and evaluated in Europe.

The standard 0.9 litre canister on the Ascona was replaced with a new 4.9 litre canister which fitted in the same space in the left front wheel well. For the Civic, the standard 0.5 litre canister was retained to control carburettor emissions and a second 3 litre canister fitted behind the front grille to control fuel tank evaporative and refuelling emissions. Mechanical seals at the dispenser nozzle/fuel filler interface were found to be unnecessary as the liquid fuel flowing into the tank draws air in with it and effectively prevents any VOC emissions. Large bore vapour vent lines were fitted from fuel tank to carbon canister, with vapour/liquid separators and rollover shut-off valves fitted at the fuel tank end of these lines.

Refuelling emission tests were carried out on both standard and converted cars using fuels with a wide range of volatilities, at high but realistic ambient temperatures. For the converted Honda Civic, emissions were below 0.05 g/litre of fuel dispensed giving a control efficiency of about 97%. The converted Ascona was even better, generating only 0.01 g/litre of fuel dispensed, a control-efficiency of over 99%. Evaporative emissions from the converted cars were below 2 g/test on all fuels. With the standard cars, vapour "breakthrough" was observed with the most volatile fuels giving much higher emissions. No significant change in exhaust emissions was seen for the converted vehicles, and both US-Federal and ECE 15 emission limits were met. The Honda Civic met the recently adopted EEC emission limits for vehicles below 1.4 litres without a catalyst. No significant change in hot or cold weather driveability was seen between the standard and converted cars.

To be effective, a canister must be purged of VOC vapour during vehicle operation more quickly than fuel is consumed so that it has sufficient capacity to adsorb vapour from the next refuelling when the vehicle tank is empty. With both converted vehicles, a saturated canister could be regenerated sufficiently to cope with a 90% tank capacity refuelling when less than 8% of tank fuel had been used.

1. INTRODUCTION

CONCAWE has studied the subject of hydrocarbon, or more correctly Volatile Organic Compound (VOC) emissions for several years, and has published a number of reports on the subject (1-3,6,7,9). Evaporative emissions have been shown to form a significant part (10%) of total European man-made VOC emissions, but emissions from vehicle refuelling make only a minor contribution (below 2%). The various options available to control evaporative VOC emissions from gasoline engined vehicles have been reviewed by CONCAWE (3) and the work described here was carried out to support this review.

Carbon canisters containing activated charcoal to adsorb evaporative emissions have been used for many years in the USA, Japan and Australia, and CONCAWE has shown (2) that these devices would be very effective in Europe also. More recent work in the USA (4,5) has shown that refuelling emissions can also be controlled if enlarged carbon canisters with sufficient capacity to adsorb both evaporative and refuelling emissions are used. These enlarged canisters are commonly referred to as "on-board" systems.

In view of the wide interest in this work, CONCAWE decided to equip two European vehicles with these "on-board" systems for evaluation. The two vehicles were selected from those used in a previous test programme (2) and both were fitted with emission control systems meeting US requirements:

Honda Civic	1.3 litre
Opel Ascona	1.8 litre

The conversions were carried out by Exxon (Civic) and Mobil (Ascona) in the USA, as these companies had considerable experience from their own work on US cars. After conversion both vehicles were fully tested at Esso Research Centre, Abingdon. This report describes in detail the conversion of both vehicles and gives all test results from their evaluation. In addition a video is available from CONCAWE which describes and explains the work carried out.

2. BACKGROUND INFORMATION

2.1 SOURCES OF EVAPORATIVE VOC EMISSIONS

Evaporative VOC emissions from vehicles can be divided into four categories, as below:

RUNNING LOSSES

These are defined as losses which occur while the vehicle is being driven. These have been investigated in a previous study (2) but have not been measured in this programme and will be the subject of further investigations.

DIURNAL LOSSES

These occur while a vehicle is stationary with the 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 dissipated into the fuel system causing evaporation of the fuel from the tank and, if fitted, the carburettor bowl.

REFUELLING LOSSES

These arise during vehicle refuelling due to displacement of vapour from the fuel tank by incoming liquid fuel, and are influenced by fuel volatility and the temperature of the dispensed and in-tank fuel.

The first three sources together are known as "vehicle evaporative emissions" as they arise during normal vehicle operation. "Refuelling emissions" however are specific to the refuelling process and are normally referred to separately.

Evaporative VOC emissions also arise during the production, storage and distribution of gasoline from refinery to service station. These are reviewed in other CONCAWE reports (6,7).

2.2 EVAPORATIVE EMISSION CONTROL IN THE USA

Vehicle evaporative VOC emissions were first controlled in California in 1970 and these controls were extended to the rest of the USA in 1971. Legislation has subsequently been introduced in Japan, Australia and more recently in Austria, Sweden, Norway and Switzerland.

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

- using pressurized fuel tanks with pressure/vacuum 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 in 1970-71, but were not sufficient as the limit was progressively tightened in later years. The technique universally adopted to meet these more severe limits employs canisters filled with activated carbon to which all external 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. This purge system also controls any running losses from the fuel tank and carburettor, by drawing them into the engine. A typical example of this type of system is shown in Fig. 1.

Regulations have also been introduced in the USA to control gasoline refining and distribution emissions in most major urban areas, as shown in Table 1, which include control of emissions from bulk road deliveries to service station tanks. This is referred to as "Stage 1" control and is achieved by vapour balance, i.e. vapours displaced from the underground tank are piped into the road tanker to replace the fuel dispensed. These vapours are then returned to the depot and recovered.

The only remaining area is that of refuelling emissions. These have in fact been controlled in some counties in California since 1974 by the use of Service Station Vapour Recovery Systems, referred to as "Stage 2" systems. These operate by using a separate pipe to send displaced vapour from the vehicle fuel tank back to the underground tank. To operate a "Stage 2" recovery system, the dispensing nozzle has to be equipped with a flexible tubular bellows positioned around the nozzle spout. This also requires all US vehicles to be equipped with a standardized fuel filler orifice, as has been the case for the last ten years. The "Stage 2" nozzle is linked with a vapour passage through the hand held dispenser, which is connected to the vapour return hose. The bellows and extra hose make these units heavier and more difficult to handle.

When these "Stage 2" systems were first implemented in California, there were many technical problems resulting in poor performance. Improved design and maintenance in recent years, coupled with effective monitoring has resulted in improved performance. "Stage 2" systems were originally designed in the USA to capture 95% of refuelling emissions, but the US EPA estimates (14) that actual efficiency of operating installations varies from 56% to 86% depending on the level of maintenance enforcement.

"Stage 2" systems are also being used in Washington DC and most recently in St. Louis, Missouri.

An alternative technique to control refuelling emissions has been developed and demonstrated (4,5). This uses an enlarged version of the carbon canister described above which is connected to the fuel tank with a large bore vent line. Vapour emissions during refuelling are thus adsorbed on-board the vehicle in the canister, hence this is known as the "on-board" system. The canisters are regenerated in the normal way by drawing air through them and into the engine. They have the further advantage that evaporative emissions are more effectively controlled due to the increased capacity of the canister.

For several years the US EPA has been concerned about both refuelling and evaporative emissions, and had announced its intention to tighten legislation in this area. The latter concern stems from "in service" measurements made by the EPA which showed that many vehicles do not meet the statutory evaporative emission limits. This was considered to be largely due to the unrealistically low volatility of the fuel on which vehicles are certified which is not representative of current marketed fuels. After several years of deliberation and a fierce debate between the US oil and motor industries over the relative merits of the various control systems, the EPA finally proposed new legislation in August 1987 (8). The main points of this proposal are that:

- refuelling emissions will be limited to 0.1 g/US gal of fuel dispensed;

- "on-board" refuelling control systems will be required for all new light duty cars and trucks, implementation to be at least 2 years after final rule is agreed;

- gasoline volatility will be restricted in two stages;

- "Stage 2" control systems will <u>not</u> be required.

2.3 PREVIOUS CONCAWE WORK

As a previous literature survey had shown that almost all the literature on evaporative and refuelling emissions related to US cars, in 1986 the CONCAWE task force AE/STF-1 carried out a test programme to determine typical evaporative emission levels from European cars. A range of ten uncontrolled European cars were tested using a modified SHED test procedure. Three extra vehicles were tested which were equipped with evaporative and exhaust emission control systems, but of the same make and model as three of the uncontrolled test cars. The vehicles were tested using several different warm-up cycles and on a range of fuels whose volatility parameters were independently varied, including oxygenate blends. Exhaust emissions were determined and a few measurements of true diurnal emissions carried out.

Vehicle fuel system design was shown to have the greatest effect on evaporative emissions which varied between 4 and 16 g/test on a typical European summer fuel. Gasoline volatility had a significant but smaller effect and RVP was shown to be the dominant fuel property. At the same volatility, oxygenate blends gave similar or lower emissions than hydrocarbon fuels. Hot-soak and running losses increased significantly with increasing warm-up cycle severity. True diurnal emissions were found to be significant and of similar magnitude to combined hot-soak and running losses. The standard carbon canister emission control systems tested were very effective and reduced emissions by up to 85%. This work is described in detail in Reference (2) and has also been presented as an SAE paper (9).

3. OBJECTIVES AND STRATEGY

The overall objective of the test programme was to equip two European model vehicles (Opel Ascona 1.8i and a Honda Civic 1.3) with a fully operational "on-board" refuelling emission control system meeting the following performance targets.

- Refuelling emissions should be controlled to at least 95% efficiency when dispensing gasoline of 83 kPa (12 psi) Reid Vapour Pressure (RVP).

- Vehicle evaporative emissions during hot soak and diurnal tests should not exceed 2 g/test with 83 kPa (12 psi) RVP gasoline.

- Exhaust emissions should not be significantly increased.

- Vehicle driveability and performance should not deteriorate.

- The "on-board" system should be totally compatible with existing European gasoline dispensing nozzles and vehicles should be capable of being fuelled at 38 litres/min (10 US gal/min), or, if lower, the maximum acceptable flow rate without "spit-back" in the unconverted condition.

The programme of work carried out to evaluate each performance target was as follows. Both vehicles were shipped to the USA for conversion, the Civic to Exxon Research and Engineering at Linden, New Jersey, the Ascona to Mobil Research and Development Corporation at Paulsboro, New Jersey. After routine servicing (the Ascona was fitted with a new catalyst and oxygen sensor), baseline tests were carried out in the USA as below:

Exhaust emissions	- US Federal Procedure ECE 15 Procedure
Hot soak and diurnal emissions	- US SHED Procedure CEC CF-11 Procedure
Refuelling emissions	- Draft US EPA Procedure
Driveability	- Hot weather - CEC CF-24 Procedure - Cold weather - CEC CF-24 Procedure

When the conversions had been completed, some tests were carried out in the US laboratories to assess refuelling emission control efficiency and to demonstrate compliance with exhaust and evaporative emission limits. The vehicles were then shipped to the Esso Research Centre, Abingdon, where a full evaluation was carried out.

4. "ON-BOARD" SYSTEM INSTALLATION

4.1 OPEL ASCONA

Test Vehicle

A 1985 Opel Ascona 1.8i with a 1.8 litre engine was selected for this project as shown in Plate 1. This vehicle model was built in West Germany and certified to meet US 1983 emission standards, and is described in Table 2. It was equipped with a three-way catalyst with closed loop control of air-fuel ratio, and an evaporative emission control system using a 0.9 litre carbon canister to capture fuel tank evaporative emissions.

The test vehicle had 37 000 km on the odometer when delivered to be converted. The exhaust catalyst and exhaust oxygen sensor were replaced before beginning this project.

Design Basis

The "on-board" refuelling control system for the Opel Ascona was based on a previously tested system, as described in (5) and is shown schematically in Fig. 2. The system consists of a carbon canister to capture refuelling emissions, a vapour/liquid separator to prevent carry-over of liquid to the canister, a large bore vent pipe from the fuel tank to the canister and a dispenser-nozzle actuated vapour vent valve which closes the refuelling vapour vent line at all times except during refuelling. Normal breathing of the tank is maintained through the standard, production breathing vent line and the check valve mounted on the fillpipe. The major system components will be described further below.

To facilitate design and construction of the "on-board" refuelling control system, a fuel tank and fillpipe identical to those on the Opel Ascona were set up on a bench test rig. The tank and fillpipe were mounted in the same geometrical relationship to each other as on the vehicle. Fig. 3 is a schematic drawing of the tank and fillpipe showing critical lengths and elevations.

In the production configuration, refuelling vapours are vented from the tank through 10 mm ID tubing running between the vapour space of the tank and the top of the fillpipe. During refuelling, vapours are expelled from the mouth of the fillpipe. The nozzle shut-off mechanism is actuated by liquid fuel backing up in the fillpipe or carried to the top of the fillpipe by vented vapours. This liquid blocks a venturi vent tube located near the end of the nozzle, and causes the nozzle to shut off.

Tank breathing, when the fillpipe is sealed with the filler cap, occurs through 5 mm ID tubing routed to the evaporative emission control canister. This vent line is routed through a check valve mounted on the side of the fillpipe near its top. This check valve assembly contains a flow control orifice (1.5 mm) which limits the rate of tank breathing. The check valve and orifice protect the canister from accidental carry-over of liquid fuel and limit spillage in the event that the vehicle is overturned in an accident.

Fillpipe Seal

A refuelling emission control system requires a sealing mechanism to prevent escape of vapours at the mouth of the fillpipe and to force the vapours into the carbon canister. In earlier on-board control development programmes (10,11), both mechanical and liquid seals were demonstrated. Mechanical seals consist of a ring-shaped device in the fillpipe into which the nozzle spout fits snugly to form a vapour-tight seal. Liquid seals are designed so that liquid fuel in the fillpipe blocks escape of vapour through the pipe during fuelling. This can be done by creating a depression in the fillpipe - a so-called "J-tube". It has also been shown that the flowing liquid in the fillpipe can create a very effective seal with no modification of the pipe (4,5).

For the Opel Ascona, both the "flowing-liquid" and "J-tube" type seals were tested on the bench rig. The unmodified fillpipe was used for the "flowing-liquid" seal. For the "J-tube" type seal, a U-shaped section of tubing was inserted in the fillpipe just before it enters the tank. This section had the same diameter as the fillpipe and was shaped so that static liquid in the U-shaped trap blocked any passage of vapour. In testing both seals, the refuelling vapour outlet from the tank was routed to an 8-litre carbon canister (used for initial testing only) through 16 mm ID (5/8 inch) flexible tubing. This tubing followed the path of the production 10 mm tubing to the top of the fillpipe to maintain tank back pressure and nozzle shut-off characteristics.

With both seals, the quantities of vapours displaced from the tank (called potential emissions in Table 3 and later tables) were larger than the uncontrolled emissions of the production system - approximately 2.4 g/litre versus 1.8 g/litre uncontrolled with 800 mbar fuel. This difference results from aspiration of air into the fillpipe by the flowing liquid. This aspirated air causes evaporation of additional fuel which is displaced to the canister. This phenomenon does not occur in the production configuration because tank vapours vented through the fillpipe minimize aspiration of air into the system.

The "flowing-liquid" seal was selected for the Opel Ascona because of its simplicity, since it required no modification of the fillpipe, and no changes to dispenser nozzles or to customer refuelling technique.

A mechanical seal would prevent aspiration of air into the system and thus produce less displaced vapour, allowing the use of a smaller canister. The "J-tube" type seal produced slightly less displaced vapour than the "flowing-liquid" seal, but the difference was not large enough to warrant its use. Seal type and canister size are parameters that can be traded off in designing an "on-board" control system as will be discussed later.

Carbon Canister

The carbon canister designed for the "on-board" system is illustrated in Fig. 4. The canister is a cylindrical, two pass design with all inlet and outlet fittings located on the top. It is divided by a baffle which extends into the carbon bed about 80% of its depth. The carbon bed on one side of the baffle is open to the atmosphere to vent air during refuelling and to admit air during purging. On the other side of the baffle are fittings to attach the vapour line from the fuel tank and the purge control valve. This control valve is the vacuum-actuated valve used on the production evaporative emission control canister of the Opel Ascona.

Canister size is determined by the quantity of vapours expected to be displaced from the fuel tank and by the adsorptive capacity of the carbon. This canister was filled with 1990 g, or 4.7 litres, of Calgon BPL F3, 6x16 mesh carbon.

The canister was fabricated using materials and techniques readily available in a laboratory machine shop. The housing and internal baffle were made of aluminium sheet with welded joints. Wire mesh (stainless steel) was used to create plenum spaces at the top of the carbon bed on each side of the baffle, and a reticulated polyurethane foam was used to prevent carbon from passing through the mesh. The purge control valve was attached with epoxy cement. The canister design could easily be adapted for production by the same methods as current evaporative emission control canisters.

The height-to-diameter ratio of the canister was selected to fit its intended location on the Opel Ascona inside the left front wing, or wheel well, the same position as the standard canister.

Vapour Vent Valve

Refuelling vapours are carried from the fuel tank to the canister through the vapour vent pipe which must be large enough to handle the vapour flow rate during refuelling without excessive back pressure. However this pipe could provide a leakage path in an accident. Therefore, a valve was designed to close this vapour vent line at all times except during refuelling. Tank venting during normal operation is maintained through the venting system of the production vehicle which uses small diameter tubing and a flow-restricting orifice.

The vapour vent valve is a dispenser-nozzle actuated valve mounted on the fillpipe as illustrated in Figs. 5 and 6. It was designed to meet US motor vehicle safety requirements to restrict leakage in the event that the vehicle is overturned in an accident; consequently, the valve is often called a rollover valve. Rollover leakage protection can also be provided by a check valve, as demonstrated by others (4).

The vapour vent valve is operated by a plunger which passes through a hole drilled in the production fillpipe (Fig. 5). The plunger is positioned so that insertion of a nozzle spout through the leaded fuel restrictor pushes the plunger into the valve body and opens the valve. When the nozzle is withdrawn, the compressed spring closes the valve. The valve assembly is sealed to the fillpipe with silicone sealant and O-rings are used to prevent leakage. On the prototype valve, there is provision to drain any liquid that might leak past the valve seat. This is drained back into the fuel tank through the breathing vent. This drain is the small curved tube visible on the valve body in Fig. 6.

The prototype valve was designed for ease of construction in a laboratory machine shop. The housing was constructed from brass bar stock, and the plunger and guide from stainless steel. Valves serving the same function could be designed for manufacture using common automotive industry methods such as plastics moulding or sheet metal stamping. The fillpipe of the test vehicle is made entirely of moulded plastic. The vapour vent valve could be designed to be moulded as an integral part of the fillpipe.

Vapour/Liquid Separator

A vapour/liquid separator is included in the system to prevent carry-over of liquid gasoline to the canister. The separator provides an expansion volume in the vapour vent line to allow settling of any liquid droplets carried along with the refuelling vapours.

The separator was constructed from a 0.5 litre (1 pint) solvent can with fittings soldered at top and bottom for connection to the vapour vent line. The separator has a check valve in the top exit fitting to prevent passage of liquid in the event of an accidental tank overfill. The check valve was constructed from a 19 mm (3/4 inch) plastic ball mounted in a wire cage so that rising liquid will cause the ball to float and seal the exit of the separator. No packing was needed in the separator, but conventional vapour/liquid separator packings could be included if necessary to improve separation of liquid droplets.

Plate 1 The 1985 Opel Ascona 1.8i

Plate 2 Ascona enlarged carbon canister fits into the left front wheel-well

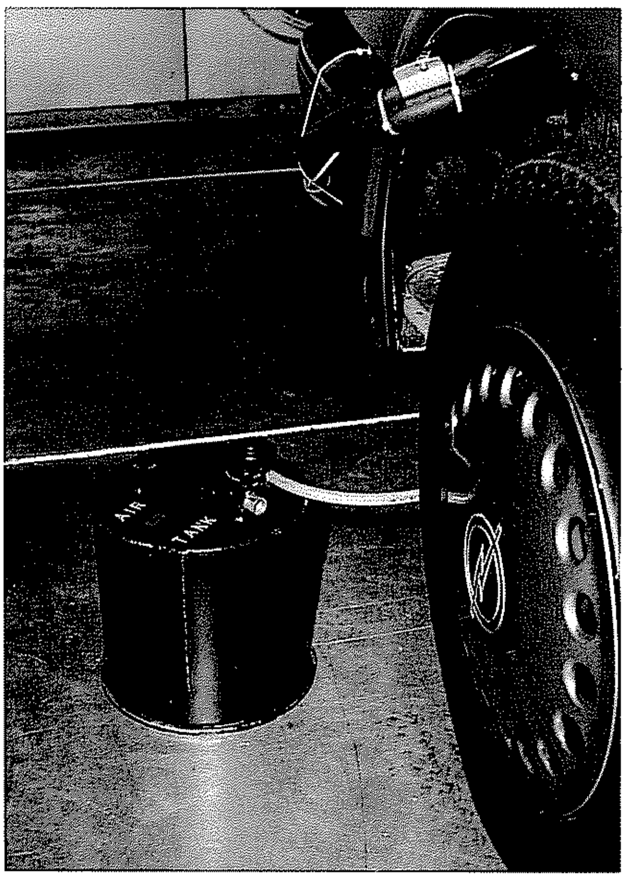
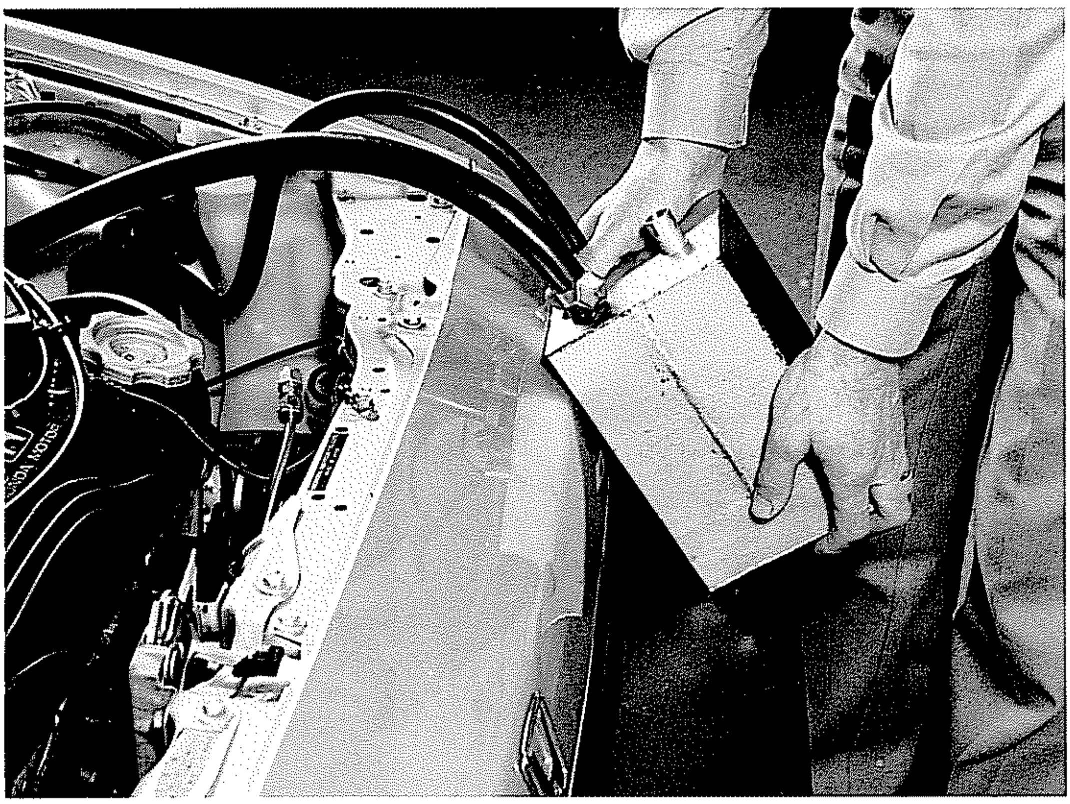


Plate 3 The 1986 Honda Civic 1.3 litre

Plate 4 Honda separate on-board refuelling canister fits behind the front grill



The separator was designed for mounting adjacent to the top of the fillpipe in the right rear wheel well of the vehicle. It must be mounted at this elevation, or higher, to prevent overflow of liquid gasoline through the vapour vent line as liquid rises in the fillpipe to actuate the nozzle shut-off mechanism.

Installation on Vehicle

The components described above were installed on the test vehicle for final testing. The fillpipe with the vapour vent valve attached was mounted in its production location in the right rear quarter panel. The fillpipe was connected to the tank in the normal manner. The vapour/liquid separator was mounted on the rear wall of the wheel well adjacent to the top of the fillpipe, allowing clearance for vertical movement of the wheel. The exit of the separator was connected to the inlet of the vapour vent valve with 16 mm ID (5/8 inch) plastic tubing.

The inlet of the separator was connected to the standard refuelling-vapour outlet fitting of the fuel tank with copper tubing routed through the luggage compartment of the vehicle. This routeing was necessary to maintain a slope so that any liquid fuel in the line could drain freely back to the tank. Routeing the line external to the luggage compartment caused a low spot where the line passed below the vehicle frame, and liquid collecting there interfered with operation of the system.

The carbon canister was located in the left front wheel well adjacent to the headlamp housing as shown in Plate 2. The canister was connected to the exit of the vapour vent valve by means of copper tubing running under the body of the vehicle. The production tank vent with its check valve mounted on the fillpipe was connected to the copper tubing through a "T" fitting at the vapour vent valve. All connections of the copper tubing to the other components were through flexible plastic tubing.

The copper tubing used on the vehicle was readily available 19 mm ID (3/4 inch) tubing. Smaller 16 mm ID (5/8 inch) tubing was shown to operate well on the bench rig, but metal tubing of this diameter was not available for use on the vehicle. With the system on the vehicle, back pressure on the fuel tank was typically 100 mm of water or less during refuelling and 150 mm or less at the moment of nozzle shut-off. The same back pressure values were obtained with the 16 mm tubing on the bench rig. Use of smaller diameter tubing may be feasible but was not investigated.

Canister Purging

Purging of the production Ascona canister is controlled by a valve actuated by inlet system vacuum sensed upstream of the throttle plate, hence operating the engine under load opens the valve. The production purge rate is controlled by a 1.3 mm orifice fitted in the purge line near its entry into the inlet manifold.

With the enlarged canister fitted, the purge rate had to be increased somewhat to cope with the refuelling emissions. Several different orifices from 2.0 to 3.6 mm diameter were evaluated to assess their effect on purge rate and exhaust emissions. A 2.0 mm orifice was finally chosen as this showed no significant effect on exhaust emissions, but was capable of purging 140 g of vapour from the canister in five US Federal test cycles.

4.2 HONDA CIVIC

A 1986 Honda Civic with a 1.3 litre engine was used, as described in Table 2 and shown in Plate 3. This vehicle was built in Japan, but was a US model, and had been imported specially for the previous CONCAWE programme (2). The vehicle was certified to meet current US emission limits and was equipped with an open loop control 3-way catalyst. A 0.5 litre capacity carbon canister was fitted to control evaporative emissions from both carburettor and fuel tank. Prior to conversion, the vehicle had covered 10 000 km.

In order to convert the production vehicle, the standard production canister was retained to handle evaporative losses from the carburettor, but the fuel tank vent was connected to the new enlarged carbon canister as follows:

- the production fuel tank vent was plugged at the top of the tank, where it was normally connected by flexible tubing to the top of the fillpipe. Both ends of this vent line were plugged;

- the standard pressure relief valve (10 kPa, 1.5 psi) in the vent pipe from fuel tank to the vapour canister was removed. The tank could then breath through the enlarged canister at all times;

- the vehicle fillpipe was modified as shown in Fig. 7. The production fillpipe enters the fuel tank at the bottom, and then extends upwards to within 12 mm of the top of the tank. In essence therefore, the production fillpipe is a "J-tube", as promoted by the US EPA as one possible type of liquid seal. However, as shown by previous Exxon work on "on-board" systems (4) and as found in the Ascona conversion, the "flowing liquid" seal is very effective and a "J-tube" is not needed. The existing internal pipe was therefore removed and replaced by a straight extension to take incoming fuel past the fuel level sender and fuel pickup unit. This new filler is submerged when the tank is around half full, and thus has the added advantage that vapour formation due to splashing from the existing filler will be reduced;

- the production Evaporative Control System (ECS) was split into two systems (again see Fig. 7). The pipework was modified so that the production ECS canister (0.5 litre) which was designed to handle both fuel tank and carburettor emissions now handles only carburettor losses. The tank losses are now adsorbed by a separate on-board refuelling canister. This new canister contains 3 litres of Calgon BPL F3 activated carbon, the same carbon as the Ascona, as shown in Fig. 8. It is fitted behind the front grill of the vehicle as shown in Plate 4.

- the production fuel tank evaporative loss pipe was disconnected and plugged. A new larger bore (16 mm, 5/8 inch ID) vent line was connected to the top of the tank, in the vapour dome. This pipe runs through the same production pipe trench up to the engine compartment where it is connected to the new on-board canister. The vapour/liquid separator, the rollover valve and the overfill valve are also in this line. These three components are built into one unit which sits directly on top of the fuel tank;

- the production purge system was retained. This system purges at around 8 litres/min and is controlled by a valve and flow restricting orifice in the production ECS canister. A second, identical purge valve was used to control purging of the new 3 litre canister in parallel with the existing one as shown in Fig. 7. To make this extra valve, a spare production canister was opened up, the charcoal removed, and the canister resealed. This valve was connected to the outlet of the new 3 litre canister, and to the inlet manifold, in parallel with the standard production canister valve. The vacuum control signal was also connected in parallel to both valves using the same control schedule as the production vehicle. The vent to atmosphere on the canister controlling the carburettor losses was restricted by an additional 1.5 mm orifice, while the refuelling canister utilizes the production orifice. The resulting purge rates are 6 litres/min for the refuelling canister and 2 litres/min for the carburettor loss canister. There is therefore no net effect of the "on-board" system on the carburation of the engine.

5. TEST PROGRAMME

5.1 TEST PROCEDURES

The vehicles were tested both before and after conversion using a number of test procedures. However, most of the work was carried out using a modified version of the CEC CF-11 Evaporative Emission test procedure. This is described below and set out in detail in Appendix A. The major differences from the CF-11 procedure were:

- o Running losses were not measured;
- o Diurnal losses were measured using a modified US EPA procedure;
- o Refuelling emissions were measured using a draft EPA procedure.

The CONCAWE test programme is compared below with current US EPA legislation, and probable future requirements.

Type of test	Current EPA legislation	CONCAWE measurements	Probable future US EPA rqt.
Refuelling	No	Yes	Yes
Running loss	No	No	Yes
Diurnal loss	Yes	Yes	Yes
Hot soak loss	Yes	Yes	Yes
Exhaust emission	Yes	Yes	Yes

Some tests were also carried out using official US EPA test procedures and cycles (Section 5.1.2). However, as tests were carried out on four fuels (Section 5.2) it proved impractical to carry out all evaporative and exhaust emission tests using both European and US procedures. The full schedule of tests carried out is shown in Table 6.

5.1.1 European Test Procedure

The evaporative emission test procedures used in this programme were based on the method (Ref. RDF-73-83) developed by the CEC PF-11 group (emissions from petrol and diesel engines), as used in the 1986 CONCAWE programme, with the addition of diurnal and refuelling loss measurements based on EPA test procedures. Generally, after preconditioning and an overnight soak, a fixed series of tests was carried out on one vehicle/fuel combination during a working day. The procedures are detailed in Appendix A and are summarized below in their sequence of operation.

Preconditioning

The test commences at the end of a working day with a preconditioning phase to ensure that the vehicle and carbon canister are in a repeatable, known condition. The canister is fully loaded by repeated refuellings to saturation (i.e. vapour breakthrough occurs), then partially purged by driving two ECE 15 cycles followed by 10 minutes at 80 km/h and a further two ECE cycles. The vehicle is then left to soak overnight (6-30 hours) at an ambient temperature between 20 and 30°C.

Diurnal Test

The following morning the fuel tank is drained and filled to 40% capacity with fresh fuel at a temperature below 15°C. Diurnal losses are then simulated by increasing the fuel tank temperature from 15°C to 23°C over a one hour period in a SHED. The 8°C increase is a typical diurnal temperature change in Europe (2). The equivalent typical diurnal variation in USA is 13°C, as used in the Federal test procedure.

Exhaust Emission Test

Four ECE 15 cycles are carried out to measure exhaust emissions and warm-up the vehicle for the hot soak evaporative emission test. For the Honda Civic 10 minutes at 80 km/h and a further two ECE 15 cycles were added to increase the warmed-up vehicle temperature, and thus test severity.

Hot Soak Evaporative Loss Test

Within 7 minutes of the end of the warm-up drive cycle the vehicle is pushed into the SHED and the hot soak evaporative emissions measured over a two hour period.

Canister Purge

Prior to the refuelling test the carbon canister is purged to a predetermined weight. This ensures that the initial conditions for each refuelling test are the same. The canister can be purged on the vehicle by driving. However, it is normally more convenient, and faster, to purge by drawing air through the canister off the vehicle. The predetermined canister weight is one which will allow one complete refuelling without breakthrough and which will exhibit breakthrough if a second refuelling is attempted.

Refuelling Test

The vehicle is refuelled in a SHED from 10% full to automatic shut-off of the fuel dispensing nozzle (typically 95% full) and the hydrocarbon losses measured.

The temperature of the fuel in the vehicle tank and the dispensed fuel temperature are closely controlled. The control temperatures vary with test fuel volatility and represent high temperatures for European regions where such fuels might be used.

	Control Temperatures	
Fuel RVP, kPa	Initial Tank Temp °C	Dispensed Fuel Temp °C
62	27	28
83	27	28
93	23	23
103	17	17

The EPA procedure on which this test is based uses a tank temperature of 80°F (27°C) and a dispensed fuel temperature of 83°F (28°C) for a 62 kPa test fuel. One goal of this work was to demonstrate refuelling emission control on a more volatile fuel (83 kPa) at the same temperatures, and the other temperature/RVP combinations were based on previous work by Exxon.

5.1.2 US Test Procedure

The equivalent US EPA test procedures were also used. The key differences between the European and USA procedures are shown below.

Test Phase	European Procedure	US Procedure
Preconditioning	2 ECE cycles, 10 min. 80 km/h 2 ECE cycles	1 FTP-75 cycle
Diurnal Losses	15°C to 23°C in 1 hour	15°C to 28°C in 1 hour
Exhaust Emissions	4 ECE cycles	FTP-75 cycle
Hot Soak	2 hours	1 hour

5.1.3 Drivedown Purge Verification

This procedure is used to measure the relationship between fuel consumption and capacity in the canister. Providing the canister purges faster than fuel is consumed then it will always have capacity to accept refuelling emissions, regardless of whether this is a complete refill or just a top-up.

The canister is brought to breakthrough on a 83 kPa fuel. The canister weight is then monitored during repeated driving cycles consisting of 2 ECE 15 cycles, 10 minutes at 80 km/h, a further 2 ECE 15 cycles, and 10 minutes engine-off hot soak. These cycles are repeated until the canister is purged sufficiently to accept at least one refuelling.

5.1.4 Driveability Tests

Driveability performance is measured to ensure that the modifications to the vehicle have not introduced any driveability problems. The standard European CF 24 hot and cold test procedures are used with reference fuels RF-43 and RF-45. The carbon canister is brought to a breakthrough condition prior to the test to represent the extreme loaded condition. The test is repeated without the canister for comparison.

5.1.5 Running Losses

Running losses can be important for cars which are not equipped with carbon canisters. However, the CONCAWE work on evaporative emissions in 1986 showed that running losses were reduced to negligible amounts by carbon canisters and so no attempt was made to measure these for vehicles equipped with enlarged canisters.

5.1.6 Filler Cap Opening Losses

One source of evaporative emissions which was not measured is the release of vapour from a pressurized fuel tank when the filler cap is removed. Pressurized fuel tanks are frequently used on cars without a carbon canister and also on cars with small canisters, to minimize vapour losses. In the USA, the current evaporative emissions test does not measure the losses when the filler cap is removed and the use of a pressurized tank enables cars to pass the test with a smaller canister. The enlarged carbon canisters fitted to the Honda Civic and Opel Ascona have ample capacity and do not require a pressurized tank to meet hot soak and diurnal loss limits. Hence filler cap opening losses are negligible on cars with the "on-board" system, compared with cars with pressurized fuel tanks.

Prior to its conversion to the "on-board" system the Honda Civic had a pressurized tank. When the filler cap was removed with the vehicle in a SHED, around 6 g of hydrocarbon was released, indicating that this can be an important source of emissions for which a test procedure needs to be developed.

5.2 TEST FUELS

The previous work (2) had shown that evaporative emissions correlate with gasoline RVP and that other volatility parameters (as defined by ASTM distillation points) were not significant. Four fuels were therefore chosen with RVP levels covering the range observed in Europe. Target RVP levels were:

62 kPa (9.0 psi)
83 kPa (12.0 psi)
93 kPa (13.5 psi)
103 kPa (15.0 psi)

Other volatility parameters were kept within normal ranges. Separate fuel series were made up by the US and UK laboratories, so there was some small variation in fuel properties, as shown in Table 4.

These fuels were used for all refuelling, evaporative and exhaust emissions testing. For the driveability tests standards CEC reference fuels RF-45 and RF-43 were used, as described in Table 5.

6. RESULTS

6.1 REFUELLING EMISSIONS

Hydrocarbon losses during refuelling were measured in the SHED using the four test fuels. As shown in Tables 7 and 8 and Figs. 9 and 10 the on-board carbon canister was very effective in reducing the refuelling emissions. On the Honda Civic the refuelling losses were cut by about 97% while the Opel Ascona "on-board" system consistently reduced emissions by over 99%. There is close agreement between repeat measurements of refuelling losses. The results also show clearly that when the on-board canister was fitted, refuelling emissions did not increase significantly with gasoline RVP.

Baseline refuelling losses on the Honda Civic were measured prior to conversion on all four test fuels. For the Opel Ascona baseline refuelling tests were only made with one test fuel. For this car baseline losses were established on the converted car with the enlarged canister disconnected. There was close agreement between the measurements made before and after conversion; 1.84 and 1.80 g/l on the 83 kPa fuel.

6.2 EVAPORATIVE EMISSIONS

6.2.1 Opel Ascona

Full evaporative emission test results for the Opel Ascona are given in Table 10.

(i) US Federal tests

Total evaporative emissions for the Opel Ascona in its baseline configuration were 0.66 and 6.94 g/test with the 61 kPa and 85 kPa fuels respectively. The high result with the more volatile fuel represents vapour "breakthrough" with the small canister. After conversion to the "on-board" system, evaporative emissions were again measured in the USA. For the low volatility (61 kPa) test fuel, a small increase was observed, but this may have been due to the non-optimized (2.4 mm) purge orifice. However with the 85 kPa fuel, breakthrough was eliminated and emissions reduced from 6.94 g/test to below 1.6 g/test. Even on the 93 kPa fuel, emissions were only 1.76 g/test, well within the US limit. These results highlight the ability of a correctly sized and optimized canister to control evaporative emissions and prevent vapour breakthrough on more volatile fuels at high ambient temperatures.

(ii) European tests

Baseline evaporative emissions for the Ascona measured using the European procedure were 0.48 and 1.32 g/test respectively using the 61 kPa and 85 kPa fuels. Measurements after conversion to the "on-board" system were carried out in the UK and a small increase was observed. The differences however are probably within the reproducibility of the method, and all test results are well within the US limit of 2.0 g/test. This limit was comfortably met on even the most volatile fuel.

6.2.2 Honda Civic

Tests were carried out using both US and European CEC test procedures, and full results are shown in Table 9. Total evaporative emissions (diurnal plus hot soak) for the converted car were below the 2 g/test target on all fuels tested. As the baseline and converted vehicle tests were carried out in different laboratories, it is not easy to compare results. Repeatability of the CEC SHED test is only around ± 25% (2) and interlab reproducibility has not been determined. It is likely that the small differences observed are due to variation in test severity between the two laboratories.

6.3 EXHAUST EMISSIONS

Baseline exhaust emissions were measured for both cars in the USA using both US Federal and ECE 15 test procedures. Full results are shown in Tables 9 and 10.

For the Honda, results were obtained on all four test fuels using both procedures. Additional emission tests were carried out using the ECE 15 cycle with the catalyst removed, to see if the vehicle could meet the latest EEC limits (for vehicles below 1.4 litres) without a catalyst. As shown in Table 9, it was well inside these limits, so the decision was made to concentrate on measurements without the catalyst for the converted car. All emission tests on the converted car, were made at ERCA.

For the Ascona, baseline tests were made using only the two lower volatility fuels, and no measurements were made without the catalyst. After conversion, exhaust emission tests were carried out before the vehicle was shipped to Europe, and as shown in Table 10, very high CO emissions were recorded. It was felt that the catalyst might have overheated due to a misfire problem which occurred during conversion. Consequently a new catalyst was fitted at ERCA before a further full set of emission tests was carried out. A number of emission tests were carried out during development of both "on-board" systems, but these are not reported here. The only exceptions are a few US Federal results for the Ascona with a 2.4 mm purge orifice, which are included as there was no time to repeat them with the final 2.0 mm orifice.

In baseline form both vehicles easily met the latest US and EEC emission limits, except that the Honda had high CO emissions on the most volatile fuel in the US test. After conversion the Honda met the limits on all fuels tested and furthermore the EEC limits were met without catalyst on all fuels. The results show a consistent reduction in CO for the converted car, together with a small increase in HC and NO_x emissions. This bias is most probably due to the fact that the baseline and converted tests were carried out by two different laboratories. For example a small difference in test inertia weight setting could be responsible. It is important to note however that there is no change in emissions with fuel volatility for the converted car. If anything they tend to decrease with increasing volatility.

The converted Ascona when initially tested did not meet US or EEC limits due to high CO emissions as discussed above, although neither HC nor NO_x were affected. After the new catalyst had been fitted however, very low CO emissions were recorded, well below the baseline figures. All ECE 15 results are well within the latest limits for cars between 1.4-2.0 litres, and apart from a small increase in CO, do not change with increasing volatility.

6.4 CANISTER PURGING

The canister purge drivedown procedure is used to ensure that the canister will purge, from a fully loaded breakthrough condition, faster than fuel is consumed.

The test procedure described previously (2 ECE cycles, 10 minutes at 80 km/h, 2 ECE cycles and 10 minutes hot soak) was used with the Honda Civic for two initial conditions of canister loading. Firstly the canister was fully loaded to breakthrough on 83 kPa RVP fuel to give an initial weight of 3385 g. A capacity for approximately 80 g of hydrocarbon is needed to adsorb the vapour displaced during the standard refuelling test. As shown in Fig. 11 the canister purges to provide this capacity when only 8% of the fuel in the tank has been used.

A second drivedown test was made starting from a lower canister weight, 3340 g, representative of the normal maximum loading expected in practice. In this case the capacity required to accept a refuelling was reached before 3% of the fuel in the vehicle tank had been consumed.

Finally, a third drivedown purge was made using a more severe driving condition of 90 km/h to check the effect of a faster rate of fuel consumption. As shown in Fig. 11 the result was very close to the slower standard cycle. These results indicate that the purge rate used on the Honda Civic rapidly regenerates the carbon canister after a refuelling operation. The "on-board" system provides capacity to control losses from another refuelling well before there is room in the tank.

The larger fuel tank on the Opel Ascona requires a canister adsorption capacity for approximately 100 g of hydrocarbon to control a 90% tank refill. As shown in Fig. 12 this capacity is purged from a breakthrough condition with only one of the standard cycles being required for a fuel consumption of about 2% of the tank's capacity.

These results show that for both vehicles the purge rates used are more than adequate to purge the large carbon canisters after a refuelling so that they have sufficient capacity to accept subsequent refuelling.

6.5 DRIVEABILITY

The driveability of the modified cars was tested according to established CEC driveability procedures. Test procedure CEC M-08-T-83 was used for Cold Weather Driveability (CWD) at -5°C and -15°C. The procedure CEC M-09-T-84 was used to assess the Hot Fuel Handling (HFH) performance at +40°C.

Test fuels used were the unleaded North American fuels for volatility tests at -15°C to 5°C (CEC RF-45-A-83) and at about 35°C (CEC RF-43-A-83). Fuel specifications are given in Table 5.

Tests were carried out both with the enlarged carbon canisters loaded to breakthrough, and with the enlarged carbon canister disconnected. These conditions represent the most extreme canister operating conditions that a vehicle equipped with an "on-board" system can experience.

The CWD test results are presented in Table 11 for the Opel Ascona and for the Honda Civic. Lowering the fuel volatility (i.e. from that of RF-43 to RF-45) produces a deterioration in the CWD performance, but the effect of temperature was insignificant for both vehicles. Apart from the Ascona on fuel RF-45, there was essentially no difference between tests at -5 and -15°C.

The results clearly show that the CWD performance with an on-board carbon canister loaded to breakthrough is slightly better than with a purged canister.

The hot weather test results are shown in Table 12. Clearly the Honda Civic has no HFH-performance problems under the most extreme conditions, i.e. test temperature 40°C, highly volatile fuel and the carbon canister loaded to breakthrough.

The Opel Ascona was, under the same test conditions, slightly more critical, but the results still represent totally acceptable HFH-performance. In two tests, demerits due to stalls at start had to be given, however, under this condition the purge control-valve is not open. That indicates that these driveability problems do not originate from the excessive HC-vapours from the enlarged carbon canister.

Generally it can be seen that the "on-board" system does not have any significant effects on driveability under hot and cold weather conditions.

6.6 DIURNAL EMISSIONS

Two types of diurnal test were carried out, the official US test and a modified procedure to simulate European conditions, as described in Section 4.2. In both methods the diurnal losses were estimated by applying heat to the tank of the vehicle by means of an electric blanket over a period of one hour, and measuring emissions in the SHED. For the US procedure fuel temperature was raised from 15 to 28°C, while for the modified European test it was raised from 15 to 23°C.

Test results are shown in Tables 9 and 10 for both cars. When baseline tested using the US procedure, both cars showed very high diurnal emissions on one or more of the more volatile fuels, indicating that vapour breakthrough was taking place. The Ascona was tested on the same fuels after conversion, when diurnal emissions were reduced from 6.41 g/test to 0.65 g/test, i.e. breakthrough was eliminated. Using the European procedure, diurnal emissions were very low for both cars on all fuels, both with and without the "on-board" system, generally below 0.5 g/test. Clearly the higher temperature reached in the US test has a significant effect on vapour generation.

7. DISCUSSION

Converting the two cars for the "on-board" system was relatively straightforward. The canisters used were generously sized, but there were no problems fitting them in place in either vehicle. For the Ascona the 4.7 litre enlarged canister replaced the standard unit but was fitted in the same position inside the left front wing. In the case of the Civic, a separate 3.0 litre canister was used to control refuelling and fuel tank evaporative emissions, which was fitted behind the front grill. The original small canister was retained to control carburettor emissions. Thus two different approaches to conversion have been demonstrated and shown to be effective.

The effectiveness of the "flowing liquid" seal was clearly demonstrated with both vehicles. The liquid stream flowing into the tank draws air in with it so that no vapour is emitted. This means that no positive fuel filler seal is required, as is the case for "Stage 2" refuelling nozzle systems, and the customer cannot perceive any difference from a conventional refuelling system. In the Ascona conversion, a mechanically operated flap valve was used to prevent liquid loss down the vent line in the event of a rollover accident. For the Civic, a ball valve was used which would seal the line in the event of a rollover. Either approach could be used to prevent the escape of liquid fuel after an accident.

Control efficiency was always about 97% for the Civic, and over 99% for the Ascona. It should also be noted that as the converted vehicles did not have pressurized fuel tanks, no vapour was released when the filler cap was removed. For the baseline Civic at least, emissions of around 6 g of vapour were measured when the filler cap was released after a hot soak.

The fuel vapour pressures used were chosen to be representative of extreme RVP levels observed throughout Europe, and the refuelling tests were carried out with fuel temperatures much higher than would be expected for fuels of these volatilities, for example the 103 kPa fuel was tested at 17°C, much warmer than would be expected in a Scandinavian winter.

Evaporative emissions from the converted cars were below 2 g/test on all fuels, even up to 103 kPa RVP, using both US Federal and European CEC test procedures at the standard test temperature of 28°C. Over the US Federal test procedure, breakthrough was observed for both baseline cars. For example, before conversion to the "on-board" system, the Civic gave 12.3 g/test on 93 kPa fuel and the baseline Ascona 6.9 g/test on 85 kPa fuel. After conversion the Ascona emissions were reduced to 1.6 g/test on the 85 kPa fuel, and 1.8 g/test on the higher 92 kPa fuel. Clearly breakthrough has been eliminated. Over the much milder CEC test, breakthrough was not observed on any fuel for either baseline or converted cars. Some minor increases in emissions were seen for the converted cars, but these are most likely due to variation between laboratories, as some tests were carried out in the USA, and some in the UK.

Exhaust emissions from the converted cars also remained within the relevant US or EEC limits on all fuels tested. For the Civic, the new EEC limits for vehicles less than 1.4 litres were easily met without a catalyst. Over the ECE 15 cycle, CO emissions from the baseline Civic increased substantially with increasing fuel volatility. However, after conversion to the "on-board" system they were significantly lower and fell with increasing volatility. For the converted Ascona, CO emissions increased slightly with volatility, but were much lower than from the standard car.

The success in optimizing canister purge rates is demonstrated by the results of the purgedown tests. Using a relatively mild driving cycle, a saturated canister was purged sufficiently to cope with a standard 90% tank capacity refuelling when only 8% of the fuel had been used. When a more severe driving procedure was used (90 km/h constant speed), this was even reduced to only 3% of fuel volume used. Clearly the purge rates used are high enough to rapidly purge a loaded canister, but will not affect exhaust emissions.

Driveability was determined using standard European test procedures at high and low temperatures. Cold-weather driveability of both the converted cars was slightly better than the baseline cars. Hot-weather performance of the Civic was improved after conversion, while that of the Ascona was slightly worse. In all cases the differences were small, and the overall conclusion is that driveability was not affected by the "on-board" system.

8. CONCLUSIONS

- Two cars from the European market have been converted to the "on-board" system using enlarged carbon canisters with no major problems. In both vehicles adequate space was found to mount the canister.

- Refuelling emissions were controlled to very low levels, around 0.05 g/litre for the Honda Civic and 0.01 g/litre for the Opel Ascona. These levels are equivalent to control efficiencies of about 97% and over 99% respectively.

- No mechanical seal was required at the fill-pipe/dispenser nozzle interface. The liquid fuel flowing into the tank entrains air and effectively prevents any hydrocarbon emission.

- After conversion to the "on-board" system, evaporative emissions from both cars were below 2 g/test on all fuels tested. Both the Civic and Ascona in standard form showed vapour breakthrough on the more volatile fuels using the US test procedure. This was eliminated with the enlarged canisters.

- The Honda Civic met the latest EEC exhaust emission limits for vehicles below 1.4 litres without a catalyst. A small decrease in CO and increase in HC + NO_x was observed with the converted car, but emissions did not increase with increasing fuel volatility.

- No significant change in exhaust emissions was seen for the Opel Ascona, and all relevant emission limits were met.

- Canister purgedown tests showed that a saturated canister could be regenerated sufficiently to cope with a 90% tank refuelling when less than 8% of the tank fuel had been used.

- No significant change in hot or cold weather driveability was seen between the standard and converted cars.

9. GLOSSARY OF TERMS

RVP	: Reid Vapour Pressure. This is a standardized vapour pressure measurement, made at 38°C with a vapour/liquid ratio of 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	: Coordinating European Council
ECE	: Economic Commission for Europe
SHED	: Sealed Housing for Evaporative Determination
FTP	: Federal Test Procedure (US driving cycle for exhaust emissions)
ECE 15 cycle	: European urban driving cycle for fuel economy and emissions
CEC CF-11 test procedure	: European SHED test
(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 ionization detector
Intercompany	: oil company cooperative group (which measures hot and cold vehicle driveability performance)

10. REFERENCES

1. CONCAWE (1986) Volatile organic compound emissions: an inventory for Western Europe. Report No. 2/86. The Hague: CONCAWE

2. CONCAWE (1987) An investigation into evaporative hydrocarbon emissions from European vehicles. Report No. 87/60. The Hague: CONCAWE

3. CONCAWE (1987) Volatile organic compound emissions in Western Europe: control options and their cost-effectiveness for gasoline vehicles, distribution and refining. Report No. 6/87. The Hague: CONCAWE

4. Musser, G.S., Shannon, H.F. (1986) Onboard control of refuelling emissions. SAE paper 861560. Warrendale, PA: Society of Automotive Engineers

5. Koehl, W.J., Lloyd, D.W., McCabe, L.J. (1986) Vehicle on-board control of refuelling emissions - system demonstration on a 1985 vehicle. SAE paper 861551. Warrendale, PA: Society of Automotive Engineers

6. CONCAWE (1985) Hydrocarbon emissions from gasoline storage and distribution systems. Report No. 85/54. The Hague: CONCAWE

7. CONCAWE (1987) Cost-effectiveness of hydrocarbon emission controls in refineries from crude oil receipt to product despatch. Report No. 87/52. The Hague: CONCAWE

8. Control of air pollution from new motor vehicles and new motor vehicle engines: refuelling emission regulations for gasoline - fuelled light-duty vehicles and trucks and heavy-duty vehicles. Notice of proposal rule making US Federal Register Volume 52, No. 160, 19th August 1987, pp 31162-31271

9. Evaporative emissions from modern European vehicles and their control. SAE paper No. 880315. Detroit: International congress and exposition, March 1988

10. API (1978) On-board control of vehicle refuelling emissions, demonstration of feasibility. Publication No. 4306. Washington, D.C.: American Petroleum Institute

11. (API) Vehicle on-board refuelling control. Publication No. 4424. Washington, D.C.: American Petroleum Institute

12. Code of federal regulations. Part 86, Vol. 24, No. 124. Federal Register, 28th June 1977

13. ECE 15-04 Regulation, Directive No. 83-351-EEC.

14. API (1986) American Petroleum Institute comments on gasoline volatility and vehicle hydrocarbon emissions. Submitted to the US-EPA, March 27, 1986 Washington DC: American Petroleum Institute

Table 1 Petroleum industry hydrocarbon sources subject to control in USA

Source	Controls*
Production & Storage	
Fixed Roof Tanks	Vent Controls or Internal Floating Cover
Floating Roof Tanks	Secondary Seals
Fugitive Emissions	Periodic Monitoring & Housekeeping
Refinery Processes	
Vacuum Producing Systems	Hot Well Covers & Vapour Incineration
Wastewater Separators	Cover
Process Unit Turnarounds	Vapour Holding & Recovery
Fugitive Emissions	Periodic Monitoring & Housekeeping
Bulk Gasoline Terminals	Vapour Recovery or Incineration
Gasoline Tank Trucks	Vapour Recycling to Terminal & Closed Loading and Vent Controls
Service Station	
o Bulk Delivery	Vapour Recycling to Tank Truck (Stage 1)
o Vehicle Refuelling**	Vapour Capture on Vehicle or at Station

* Controls required as of 1982 in all US ozone non-attainment areas, but applied earlier in some states.

** Pending in US EPA, but service station controls used in California since 1974.

Table 2 Test vehicle specifications

Make	Opel	Honda
Model	Ascona 1.8i Cat.	Civic Cat.
Model year	1985	1986
Country of origin	Germany	Japan
Displacement, cc	1796	1342
Number/arrangement of cylinders	IL-4 front	IL-4 front
Compression ratio	8.9:1	8.7:1
Rated power, kW/RPM	73.5/5800	45/5500
Carburettor/ fuel injection system	Bosch LU-Jetronic	Downdraft 2 stage carb.
Transmission/number of gears	M 5	M 5
Driven axle	front	front
Max. speed, km/h	180	157
Tank capacity, litres	61	46
Cooling fan	electric	electric
Fuel recirculation	yes	yes
Exhaust gas treating system	3-way-cat.	oxidation cat.
Carbon canister (standard)	0.9 litre	0.5 litre

Table 3 Fillpipe seal selection "on-board" system bench rig[a]

800 mbar RVP Fuel[b]

Seal Type	Tank Filling Rate, litre/min	Control[c] Efficiency, %	Potential[d] Emissions, g/litre	Actual Emissions, g/litre
"Flowing-Liquid"	7.5	99.3	2.54	0.013
	11	99.7	2.49	0.006
	38	99.7	2.39	0.006
	38	99.7	2.41	0.005
"J-Tube"	38	99.7	2.31	0.006
	38	99.7	2.27	0.005

(a) 8-litre canister, vapour/liquid separator, 16 mm (5/8 inch) ID vapour line.

(b) Initial fuel level, 6 litres; final fuel level, ~60 litres.
Fuel temperature: dispensed, 28°C (83°F); tank, 27°C (80°F).

(c) Based on uncontrolled emissions of 1.84 g/litre with 800 mbar RVP fuel.

(d) Total mass of hydrocarbon vapour displaced from tank.

Table 4 Test fuel properties

Nominal RVP kPa	Laboratory	Actual RVP kPa	E70 % vol	E100 % vol	E150 % vol
62	Mobil	61	19.5	46	87
62	Exxon	62	22	47	86
62	Esso	62	24	49	83
83	Mobil	85	22	41	85
83	Exxon	83	25	49	87
83	Esso	83	34	56	85
93	Mobil	92	26	47	94
93	Exxon	93	29	52	89
93	Esso	93	37	58	85
103	Mobil	100	29	49	88
103	Exxon	103	30	50	88
103	Esso	103	43	62	86

Table 5 Driveability test fuels
CEC reference fuels - specifications

Fuel Ref. Application		RF-45-A-83 Volatility tests Moderate cold weather -15°C to +5°C	RF-43-A-83 Volatility tests Hot weather about 35°C
RON	min	93.0	93.0
RVP (kPa)	min	50	80
	max	60	90
E70 (% vol)	min	15	40
	max	20	45
E100 (% vol)	min	40	65
	max	45	70
E150 (% vol)	min	75	83
	max	85	93
E180 (% vol)	min	85	85
Oxidation stability (min)	min	480	480
Existent gum (mg/100 ml)	max	4	4
Lead (g/l)	max	0.005	.005
Anti-icing DPG (ppm) treatment		1000	-

Table 6 Civic and Ascona testing schedule

Car	Status	Fuel RVP	Exhaust emissions US Fed.	Exhaust emissions ECE	Evap. emissions US Fed.	Evap. emissions CEC	Refuelling emissions
Civic	Baseline	62	E	E	E	E	E + A
"	"	83	E	E	E	E	E + A
"	"	93	E	E	E	E	E + A
"	"	103	E	E	E	E	E + A
Civic	On-board	62		A*		A	A
"	system	83	A*	A*	A*	A	A
"	without	93		A		A	A
"	catalyst	103		A		A	A
Ascona	Baseline	62	M	M	M	M	A
"	"	83	M	M	M	M	M + A
"	"	93					A
"	"	103					A
Ascona	On-board	62	M	A	M	A	M + A
"	system	83	M	M + A	M	M + A	M + A
"	"	93	M	A	M	A	M + A
"	"	103		A		A	M + A

* Also tested with catalyst

E = Exxon Research, Linden New Jersey USA
M = Mobil Research, Paulsboro New Jersey USA
A = Esso Research, Abingdon UK

Table 7 Refuelling tests on Honda Civic

Fuel RVP kPa	Temp. °C	Refuelling Loss g/l Uncontrolled	Refuelling Loss g/l Controlled	Control %
62	28	1.39	0.040	97.1
83	28	1.80	0.050	97.2
83	28		0.046	97.4
83	28		0.055	96.9
83	28		0.058	96.8
83	28		0.052	97.1
83	28		0.052	97.1
83	28		0.055	96.9
93	23	1.77	0.049	97.2
93	23		0.044	97.5
103	17	1.74	0.065	96.3
103	17		0.054	96.9

Table 8 Refuelling tests on Opel Ascona

Fuel RVP kPa	Temp. °C	Refuelling Loss g/l Uncontrolled	Refuelling Loss g/l Controlled	Control %
62	28	1.35	0.006	99.6
62	28		0.005	99.6
83	28	1.80	0.014	99.2
83	28		0.007	99.6
83	28		0.008	99.6
83	28		0.006	99.7
83	28		0.011	99.4
93	23	1.76	0.012	99.3
93	23		0.008	99.5
103	17	1.75	0.011	99.4
103	17		0.013	99.3
103	17		0.005	99.7

Table 9 Exhaust and evaporative emissions - Honda Civic

	US Federal Test Procedure - g/mile					US SHED Procedure		
Fuel RVP kPa	Test Status	CO g/mi	HC g/mi	NO_x g/mi	No. of Tests	Diurnal	Hot Soak	Total
62	Baseline	1.44	0.20	0.90	2	0.13	0.40	0.53
83	Baseline	2.96	0.29	0.81	2	0.27	0.52	0.79
83	Converted	2.81	0.40	0.95	1	0.84	1.00	1.84
83	" (no cat)	4.81	2.70	1.47	1	0.54	0.82	1.36
93	Baseline	3.01	0.29	0.87	2	11.65	0.66	12.30
103	"	4.16	0.29	0.82	1	9.92	0.66	10.6
	US Federal limits	3.4	0.41	1.0		-	-	2.0

	European ECE 15 Test Procedure - g/test						CEC CF-11 Procedure g/test		
Fuel RVP kPa	Status	CO g/test	HC g/test	NO_x g/test	HC + NO_x g/test	No. of Tests	Diurnal	Hot Soak	Total
	With Catalyst								
62	Baseline	8.0	1.5	1.9	3.4	5	0.28	0.86	1.14
83	"	13.9	2.0	1.7	3.7	2	0.12	1.01	1.13
83	Converted	17.5	2.8	2.3	5.1	*	-	-	-
93	Baseline	18.2	1.7	2.1	3.8	2	0.22	1.08	1.30
93	Converted	15.5	2.1	1.7	3.8	*	-	-	-
103	Baseline	35.1	2.8	4.0	6.8	1	0.27	0.94	1.21
	Without Catalyst								
62	Baseline	22.2	7.7	2.5	10.1	3	-	-	-
62	Converted	20.7	9.8	3.0	12.8	1	0.36	1.40	1.76
83	Baseline	28.3	8.2	2.4	10.5	2	-	-	-
83	Converted	18.8	9.0	3.3	12.3	2	0.42	1.47	1.89
93	Baseline	28.0	7.6	2.8	10.4		-	-	-
93	Converted	19.1	8.7	3.2	11.9		0.44	1.21	1.63
103	Baseline	38.4	7.9	2.5	10.4		-	-	-
103.5	Converted	15.2	8.5	3.2	11.7		0.54	1.42	1.96
	Latest EEC Limits	45	-	6	15		-	-	

Table 10 Exhaust and evaporative emissions - Opel Ascona

	US Federal Test Procedure						US SHED Procedure		
Fuel RVP kPa	Test Status	CO g/mile	HC g/mile	NO_x g/mile	No. of Tests	Comments	Diurnal	Hot Soak	Total
61	Baseline	2.45	0.37	0.09	2		0.30	0.36	0.66
61	Converted	3.14	0.33	0.15	1	2.4 mm purge	0.93	1.21	2.14
65	Baseline	3.43	0.42	0.11	3		6.41	0.33	6.94
85	Converted	3.78	0.35	0.12	2		0.65	0.94	1.59
85	Converted	5.10	0.38	0.12	1	2.4 mm purge	-	-	-
83	Converted (new cat)	1.53	0.37	0.19	1		0.62	0.53	1.15
92	Converted	6.01	0.42	0.13	1	2.4 mm purge	0.57	1.19	1.76
	US Federal limits	3.4	0.41	1.0			-	-	2.0

Table 10 Exhaust and evaporative emissions - Opel Ascona (cont.)

European ECE 15 Test Procedure							CEC CF-11 Procedure g/test		
Fuel RVP kPa	Test Status	CO g/test	HC g/test	NO_x g/test	HC + NO_x g/test	No. of Tests	Diurnal	Hot Soak	Total
61	Baseline	24.7	4.1	0.7	4.8	2	0.18	0.30	0.48
62	Converted (new cat)	10.0	3.2	0.8	4.0	2	0.27	0.85	1.12
85	Baseline	28.8	3.9	0.8	4.7	2	0.91	0.41	1.32
85	Converted	37.7	3.7	0.9	4.6	2	0.49	1.26	1.74
83	Converted (new cat)	11.8	3.1	0.8	3.9	3	0.39	0.93	1.32
93	" " "	20.0	3.8	0.7	4.5	2	0.27	0.87	1.14
103	" " "	16.5	3.1	0.7	3.8	3	0.36	0.87	1.23
	EEC Limits	30	-	-	8.0		-	-	

Table 11 Cold weather driveability results

Car	Fuel	Temp. (°C)	Demerits* under breakthrough cond.	Demerits* without on-board canister
Opel Ascona 1.8 i	RF-43	-5	161	236
		-15	161	250
	RF-45	-5	221	280
		-15	268	398
Honda Civic	RF-43	-5	79	121
		-15	102	128
	RF-45	-5	219	337
		-15	219	297

* Demerits were rated according the CEC-driveability procedure CEC-M07-83T

Table 12 Hot weather driveability results

Car	Fuel	Temp. (°C)	Soak cond.	Performance under breakthrough cond.		Performance without on-board canister	
				Demerits*	Category	Demerits*	Category
Opel Ascona 1.8 i	RF-43	40°	Engine-off	29	2[(a)]	2	1
	"	"	"	20	2[(a)]	-	-
	"	"	"	9	1	-	-
	"	"	Engine-idle	11	1	3	1
	RF-45	"	"	15	1	0	1
Honda Civic	RF-43[(b)]	40°	Engine-off	0	1	17	1
	"	"	Engine-off	0	1	17	1
	"	"	Engine-idle	1	1	9	1

(a) Category 2 due to stall at start
(b) For the standard car, 103 kPa test fuel was used

* Demerits were rated according to CEC test procedure CEC-M-09-T-84

Fig. 1 Typical evaporative loss control system

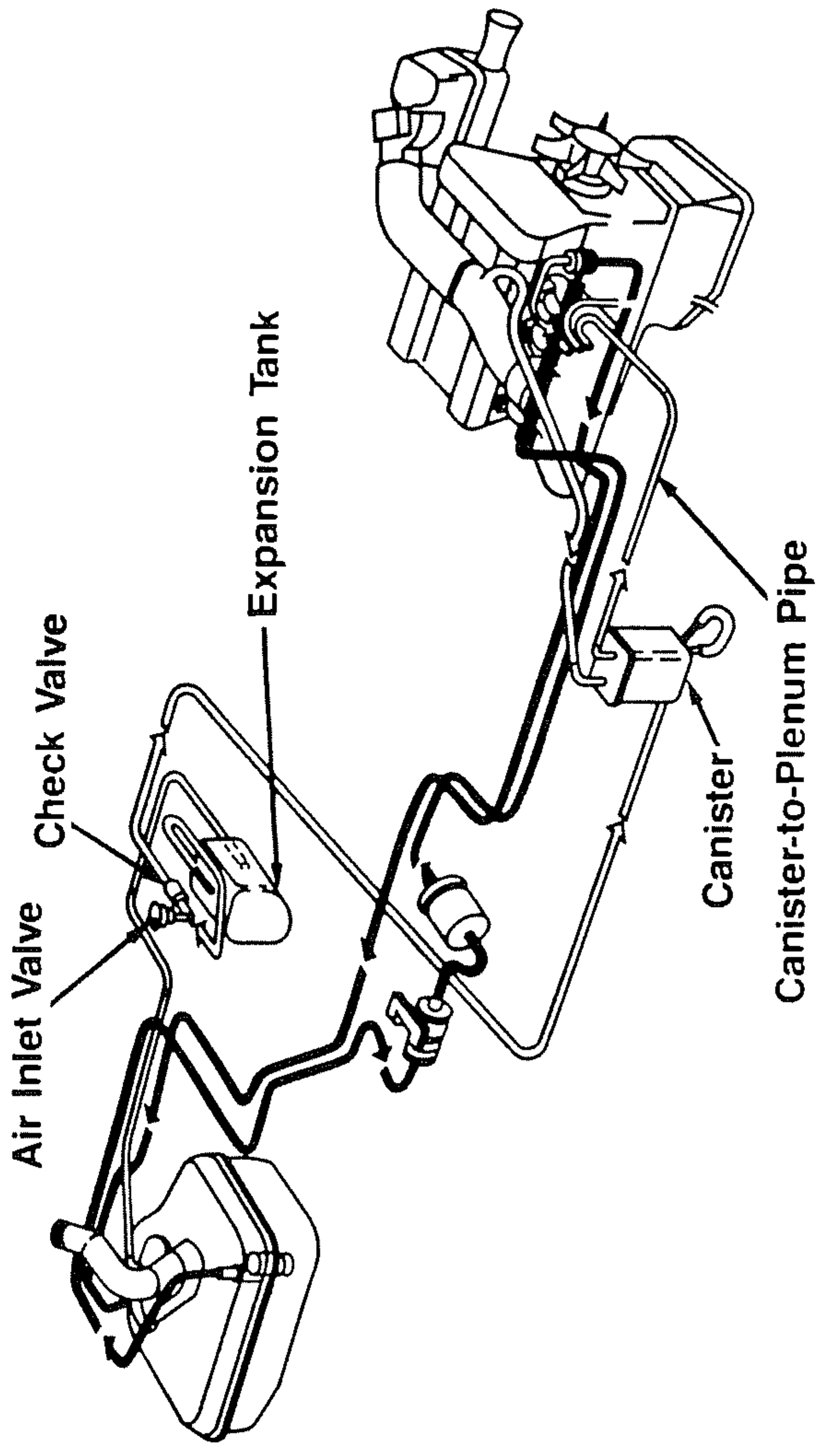


Fig. 2 Schematic of "on-board" refuelling emission control system for Opel Ascona

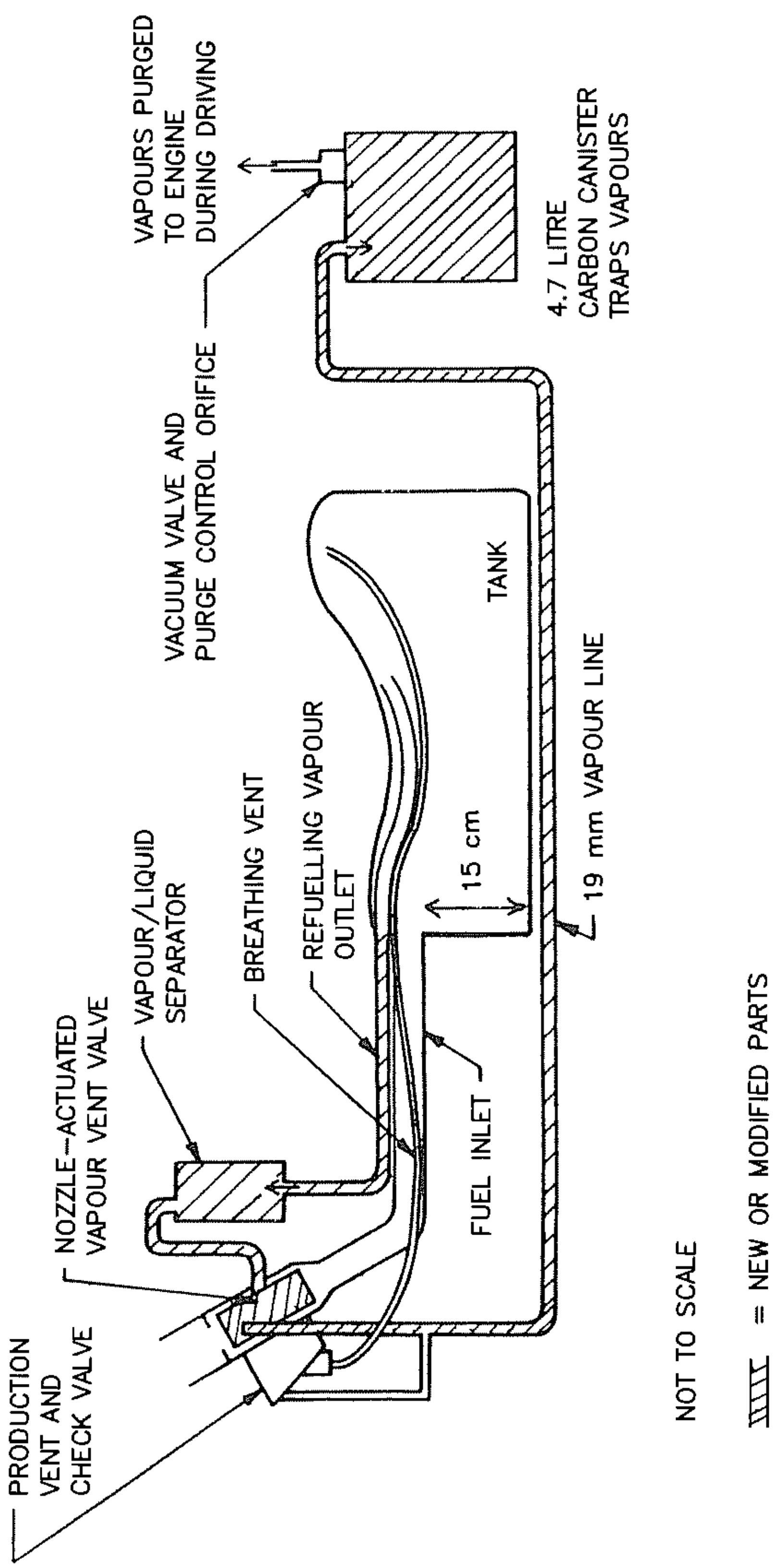


Fig. 3 Production fuel tank and fillpipe configuration of Opel Ascona

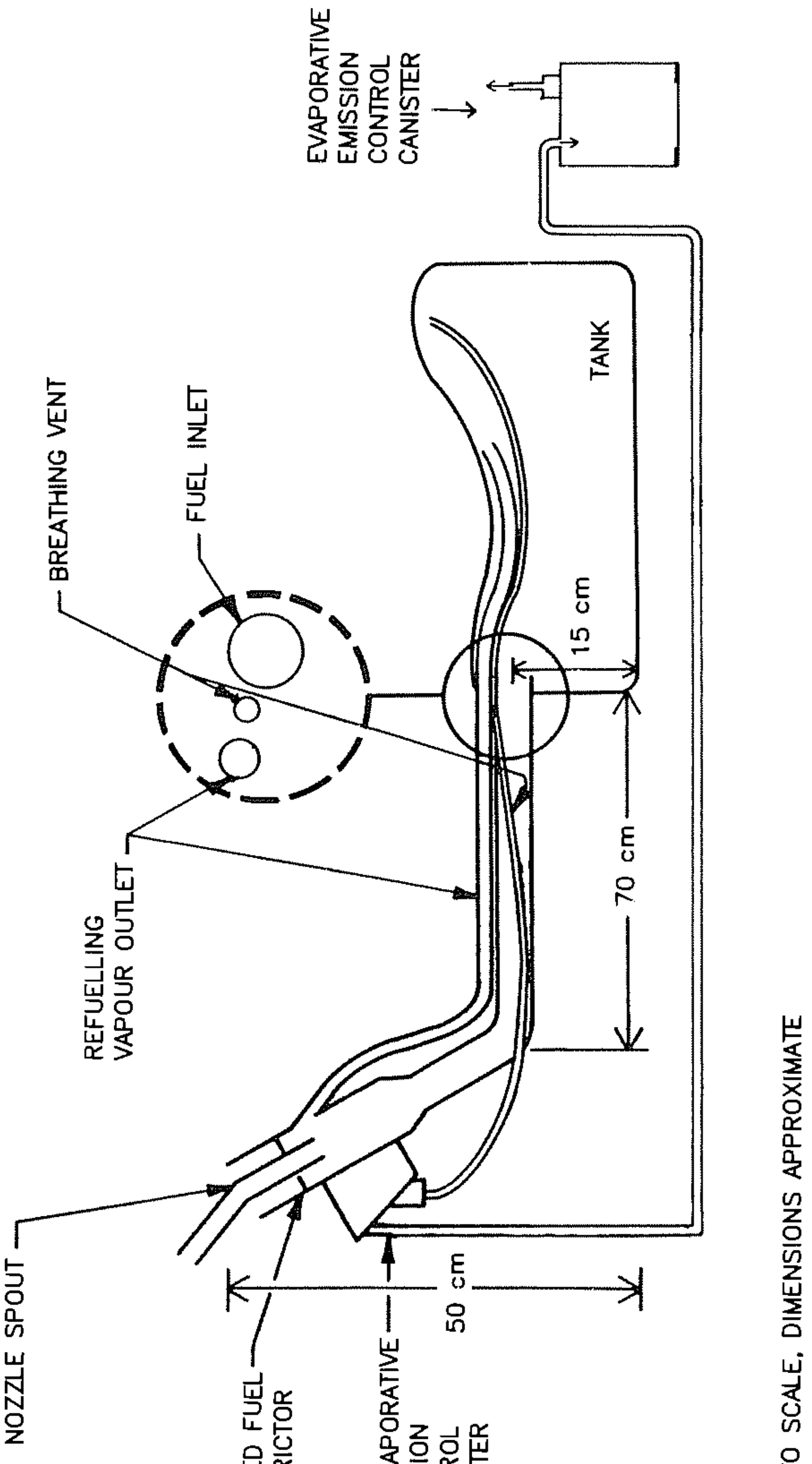
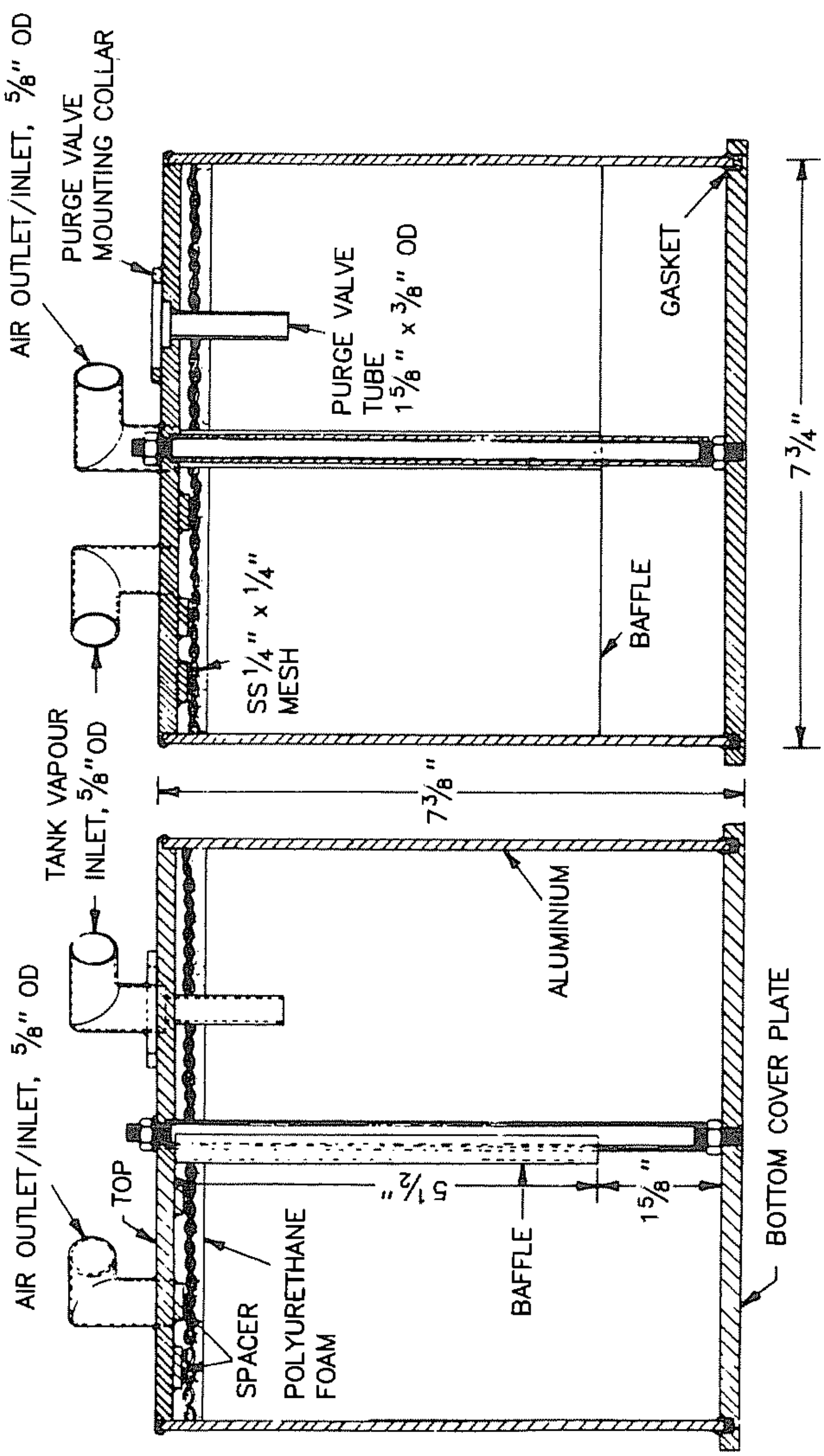


Fig. 4 On-board refuelling emission control canister 4.7 litres of carbon



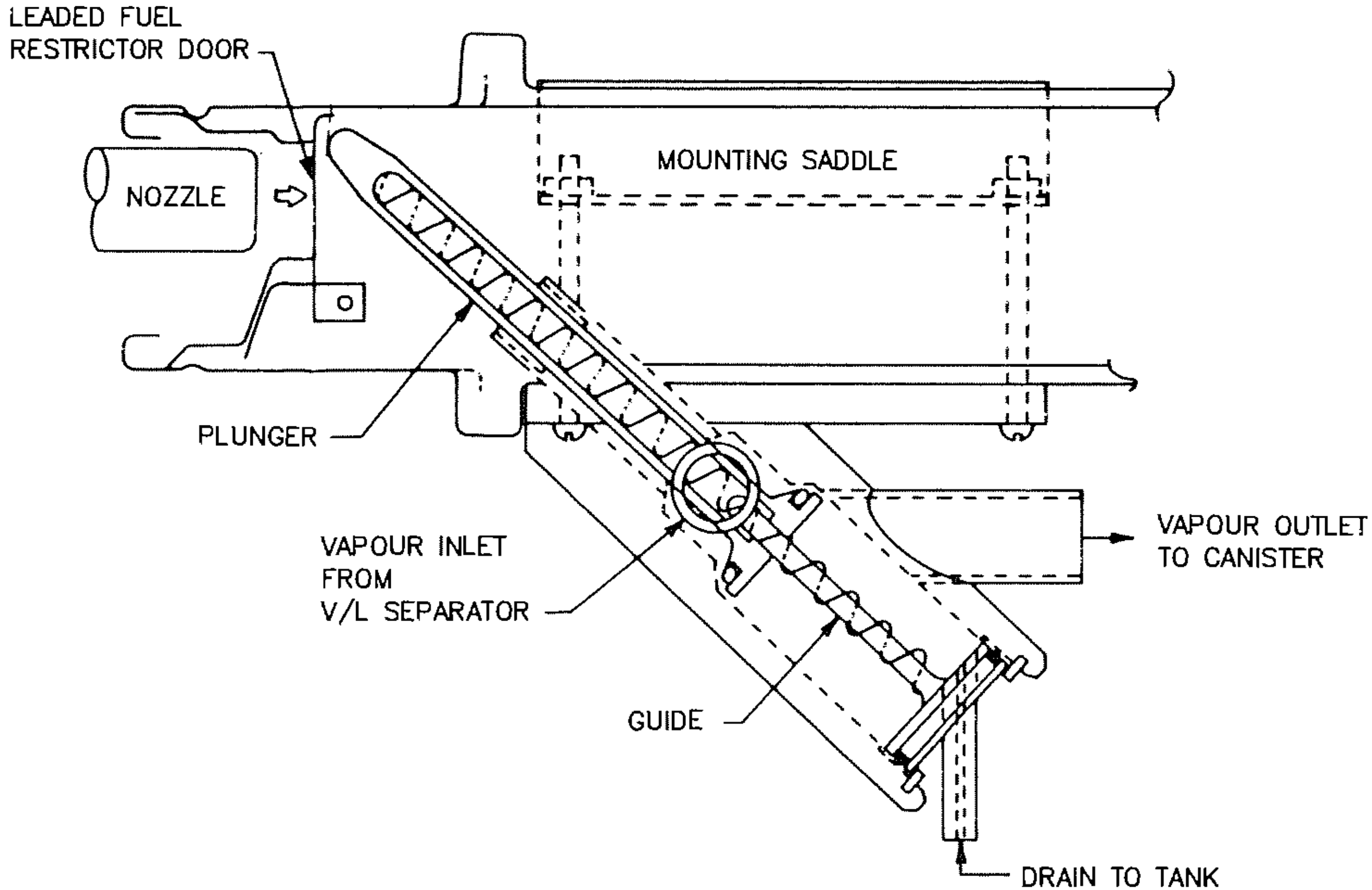
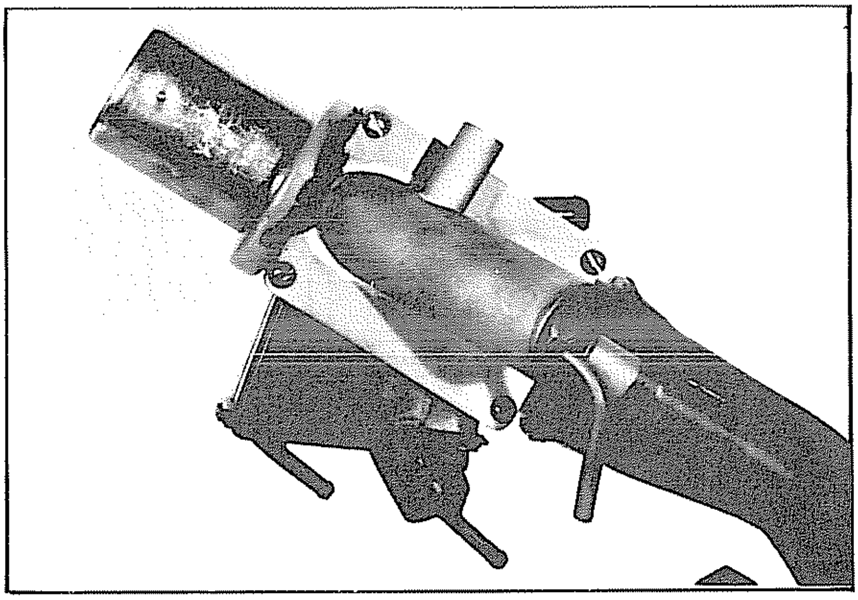


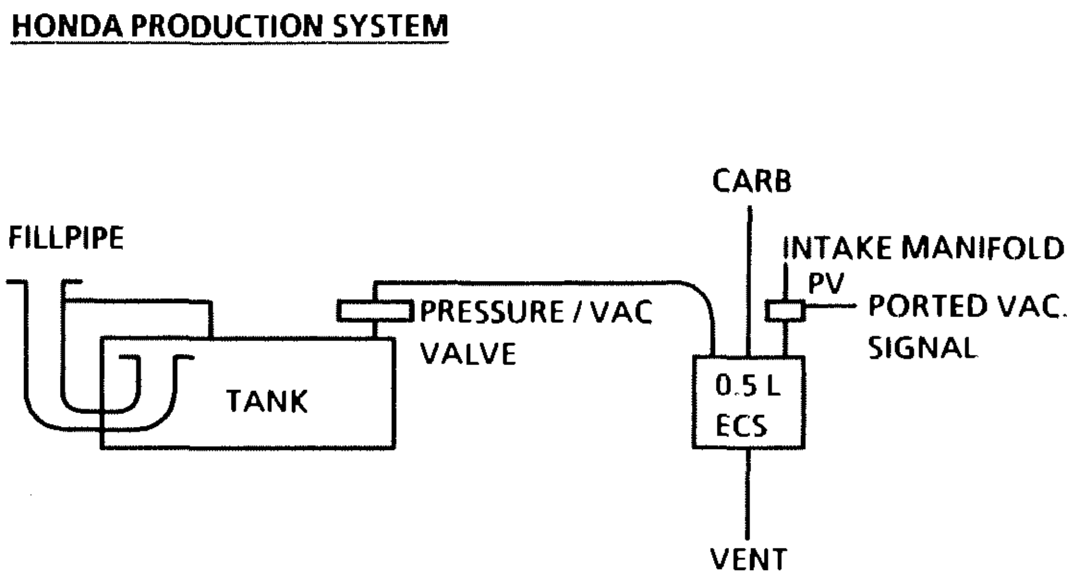
Fig. 5 Nozzle-actuated refuelling emissions vapour vent valve

Fig. 6 Nozzle-actuated vapour vent valve mounted on Opel Ascona fillpipe



SIDE VIEW OF FILLPIPE

Fig. 7 Honda Civic - installation of "on-board" system



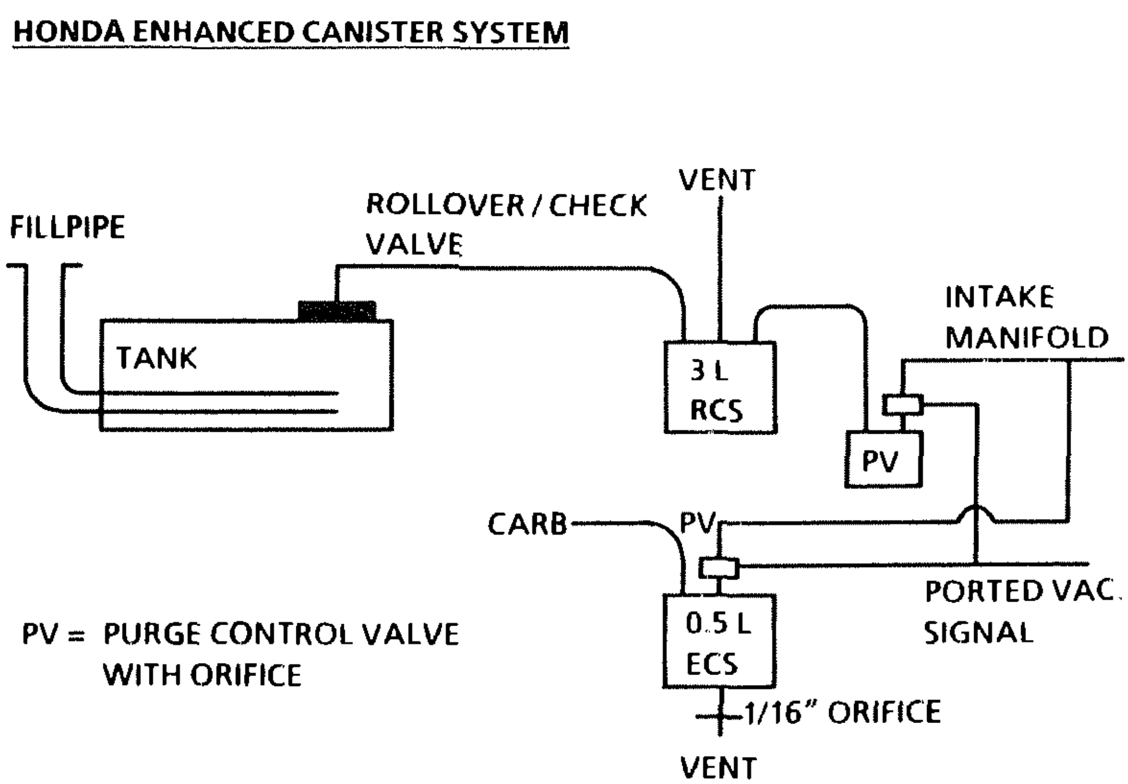


Fig. 8 Honda Civic carbon canister

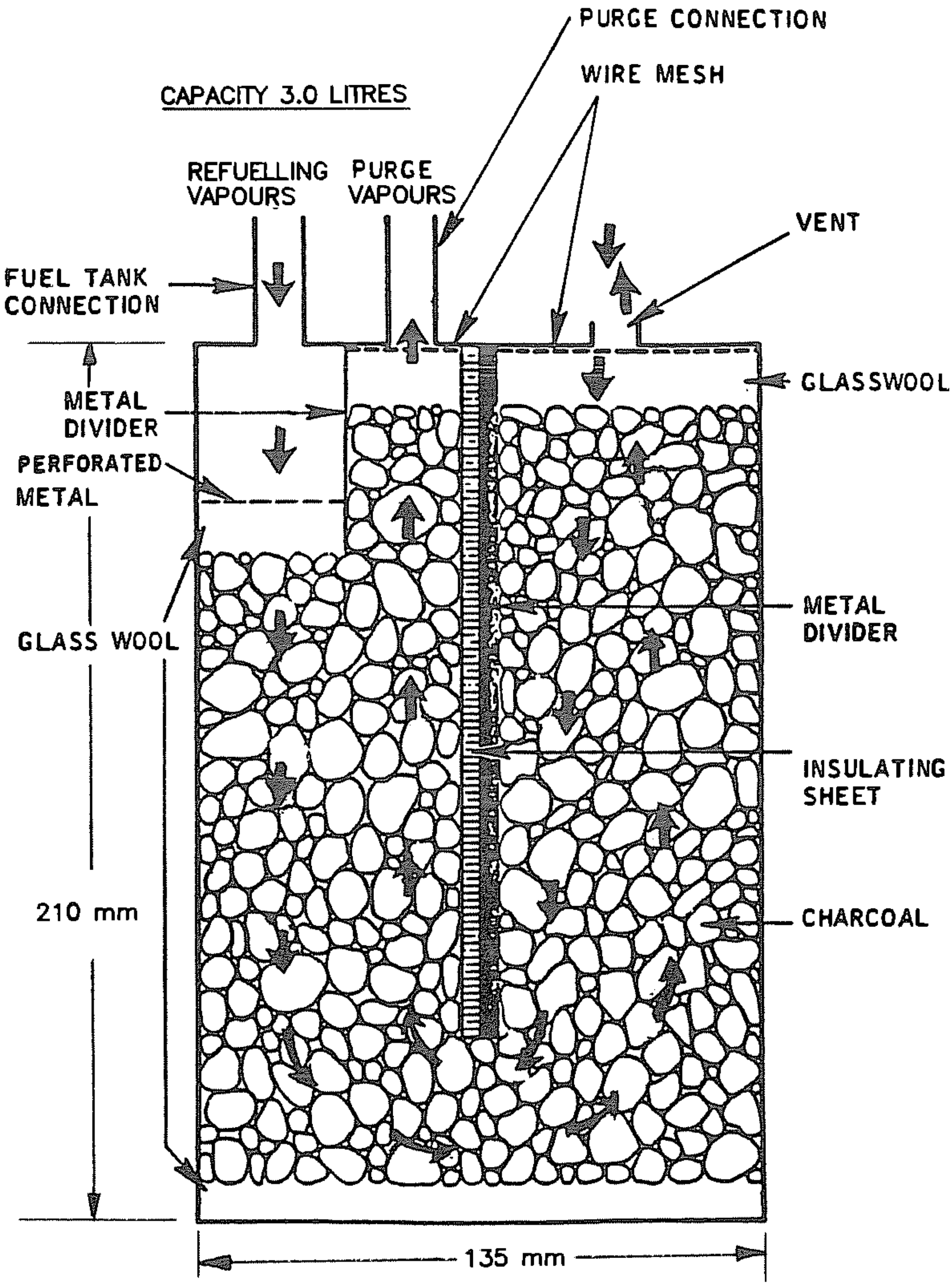


Fig. 9 Honda Civic refuelling emissions

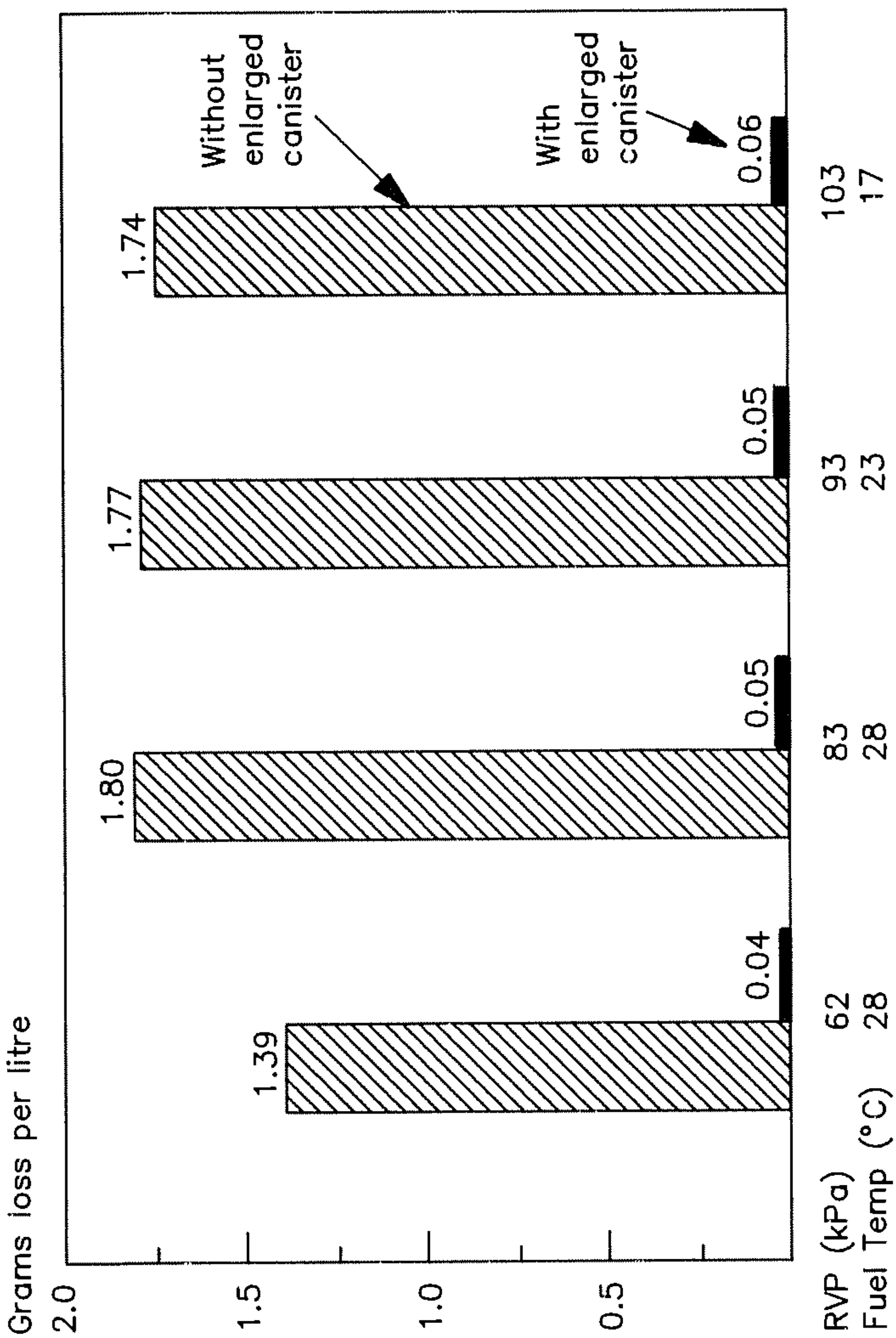


Fig. 10 Opel Ascona refuelling emissions

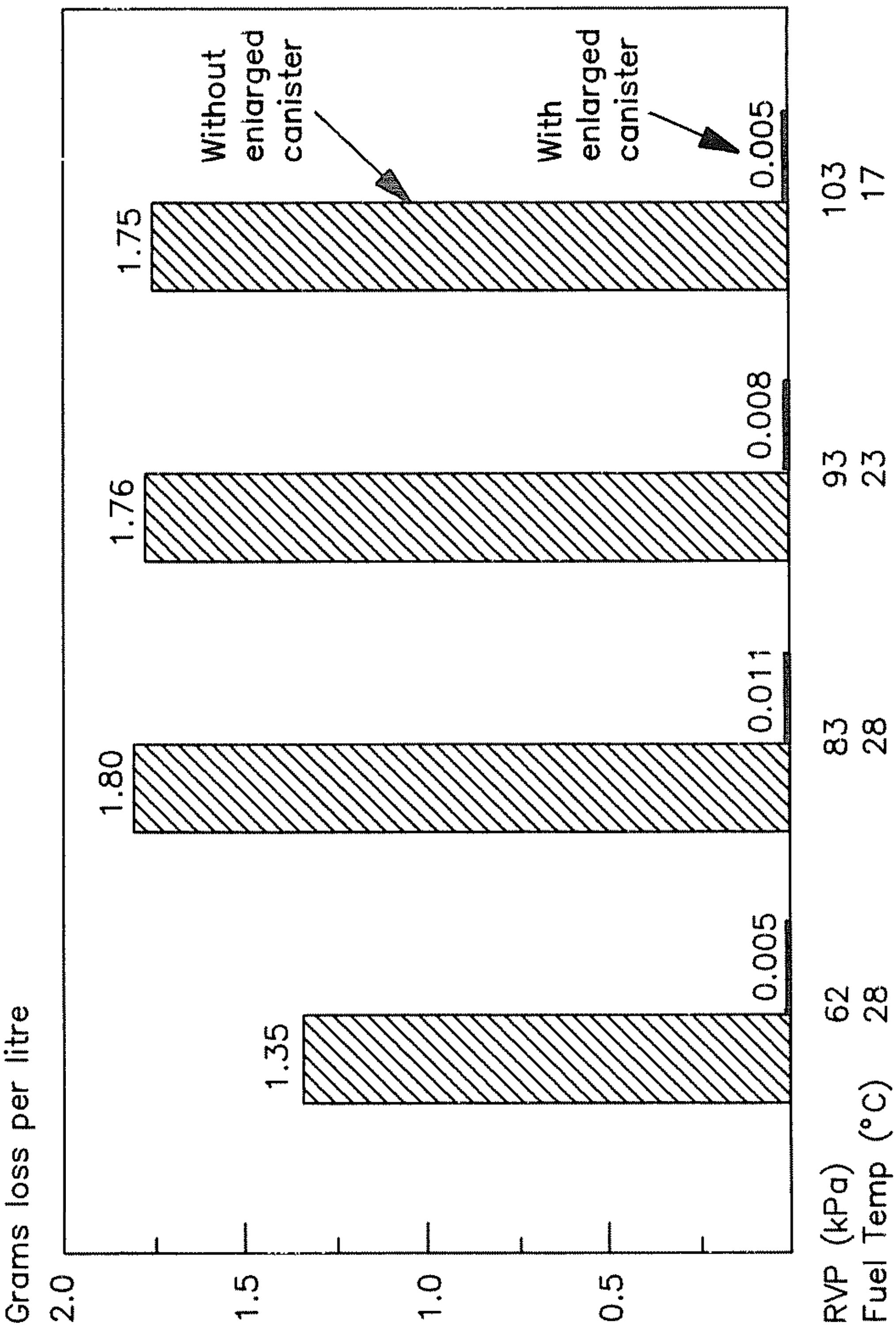
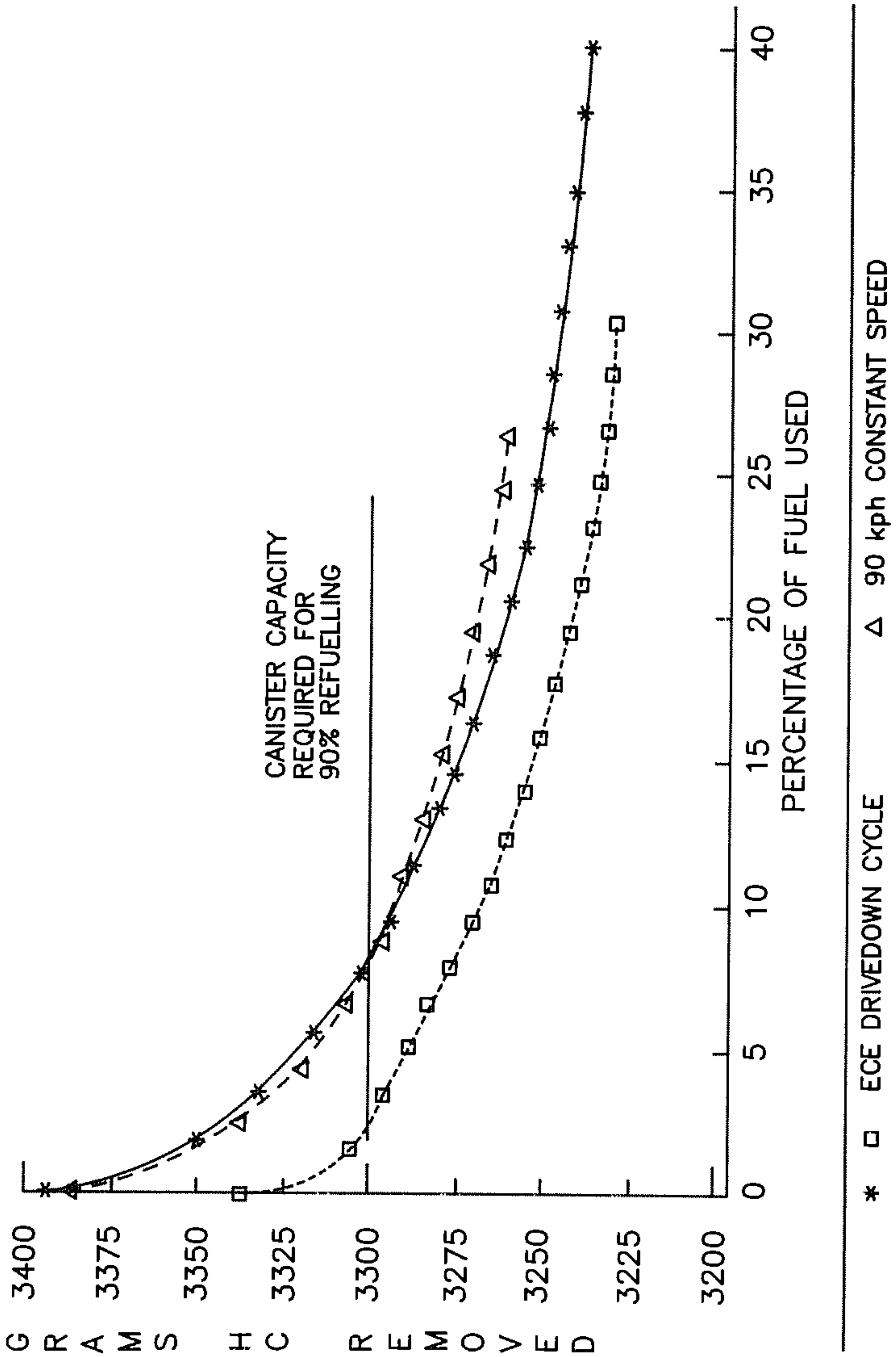


Fig. 11 Honda Civic canister weight during ECE and 90 km/h drivedown



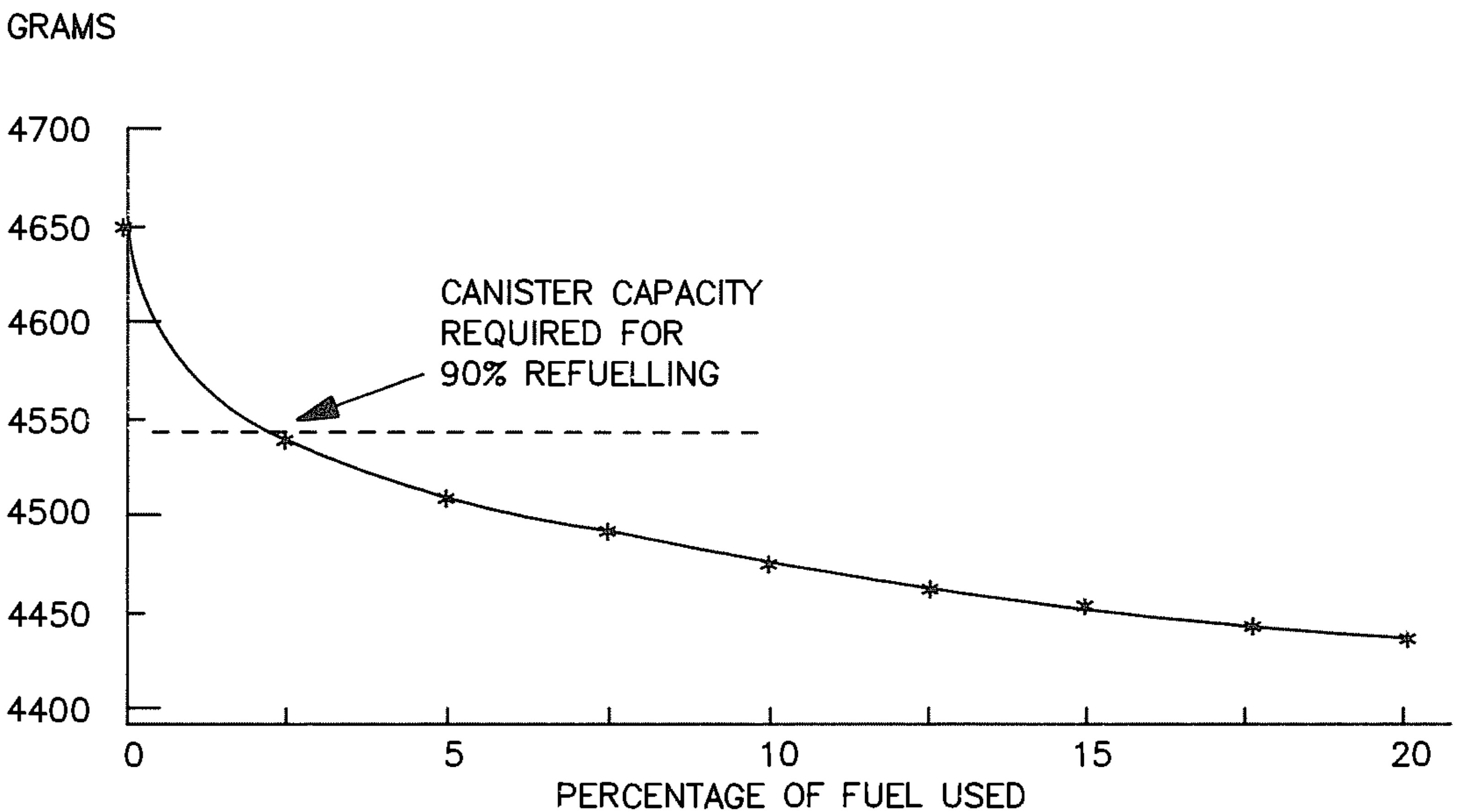


Fig. 12 Opel Ascona canister weight during ECE drivedown

APPENDIX A - TEST PROCEDURES FOR EVAPORATIVE AND REFUELLING EMISSIONS

These test procedures cover the determination of hydrocarbon losses by evaporation from the fuel system of gasoline engine vehicles, and losses during refuelling. The procedures summarized below are based on methods developed by CEC CF-11 (Reference RDF-73-83) and EPA.

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 5000 miles on the road in order to ensure that hydrocarbon evaporation from upholstery, tyres, underseal etc. has stabilized. The car should then be run at 35°C - 40°C for a period of 1-2 hours in order to minimize background hydrocarbon losses.

The fuel tank must be equipped with a thermocouple to allow temperature measurement of the test fuel, even when the tank is 10% full. Fittings and adaptors are necessary in order to ensure that the tank can be drained from the lowest point. Using repeated refuelling the maximum refuelling flow rate must be identified (controlled by the refuelling nozzle latch position) to avoid premature fuel shut-off.

I. Preconditioning

1. Refuel the vehicle in a SHED repeatedly until breakthrough on the enlarged carbon canister.

2. Disconnect carbon canisters, push vehicle outside SHED and drain fuel tank.

3. Ensure that the fuel tank is completely empty and then fill with ten litres of the appropriate test fuel. Weigh and reconnect canisters after fuelling.

4. 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.

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

6. 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.

II. Diurnal Test

The engine must not be started.

1. Disconnect the carbon canisters and drain the fuel tank.

2. Refill the fuel tank with a quantity of test fuel corresponding to 40% of the fuel tank capacity. The test fuel temperature must be between 8 and 12°C. Leave the filler cap off.

3. Weigh and reconnect carbon canisters. Push vehicle into SHED, connect thermocouples to record fuel tank temperature, and attach the heating blanket to fuel tank. Open vehicle luggage compartment and windows.

4. Heat fuel tank to 14-15°C with purge blower on. When temperature reaches 14.5°C replace filler cap, turn off purge blower, close and seal SHED doors.

5. When fuel temperature is 15°C start timer and measure SHED hydrocarbon concentration using the FID analyzer and recorder.

6. Increase fuel tank temperature from 15°C to 23°C over 60 minutes. Monitor to ensure tank temperature follows equation

$$T = 15 + 0.133 \times (\text{minutes})$$

to within ± 1°C.

7. At 60 minutes measure hydrocarbon concentration in SHED. Open doors, purge SHED and push vehicle out in preparation for exhaust emission test. Disconnect, weigh and reconnect carbon canisters. Do not start the engine.

III. Exhaust emissions test

One hour maximum is permitted between the end of the diurnal test and the start of the exhaust emission test.

1. Push the vehicle onto the chassis dynamometer.

2. 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.

3. Disconnect, weigh and reconnect the carbon canisters.

IV. Hot soak test

1. Switch on the SHED purge blowers.

2. Zero and span the FID hydrocarbon analyzer. 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 analyzer 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 tempeature in the chamber should remain within the range 26-30°C.

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

11. At the end of the hot soak, record the final hydrocarbon concentration in the SHED using the FID analyzer. 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. <u>Use a hydrocarbon face mask</u>.

14. Disconnect and weigh the carbon canisters.

V. Bench Rig Purge

1. Purge refuelling canister on bench rig or by driving to a predetermined weight. The appropriate weight is one which will allow one complete refuelling without breakthrough and which will exhibit breakthrough if a second refuelling is attempted. The appropriate canister weight for a given vehicle must be predetermined using repeated refuellings in the SHED.

VI. Refuelling test

1. Prepare the SHED. Circulate and heat the test fuel in the refuelling cart and pipework to obtain a fuel temperature of 28°C.

2. With the carbon canisters disconnected drain the vehicle fuel tank.

3. Fill the fuel tank to 10% full with the test fuel at 25 to 27°C. Leave the filler cap off.

4. Push vehicle into SHED, connect thermocouples to record fuel temperature and attach the heating blanket to the fuel tank. Open vehicle luggage compartment and windows.

5. Heat the fuel tank to 27°C with the purge blower on. Install the refuelling nozzle in the filler pipe with the latch on the highest acceptable setting to avoid premature shut-off.

6. Ensure that the recirculating fuel temperature is 28°C at the SHED wall. Weigh and reconnect the carbon canisters.

7. Switch off the purge blowers. Close and seal the SHED doors. Record the hydrocarbon concentration in the SHED.

8. With circulating fuel at 28°C start timer and start refuelling. Dispense fuel to auto shut-off (from 10% to approx 95% full) or to measured amount equivalent to 95% full. Note refuelling time.

9. Record FID until hydrocarbon concentration is stabilized.

10. Open SHED, disconnect and weigh canisters, disconnect thermocouples and heater blanket and push vehicle from SHED. Use hydrocarbon face mask.

If required a new test can now be started commencing with the preconditioning phase. All six test phases including the overnight preconditioning soak period can be carried out in a 24 hour sequence.

Calculation of evaporative emissions

Hydrocarbon losses captured in the SHED 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 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
= 2.33 for diurnal and refuelling losses

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