voc running losses from canister-equipped vehicles

Prepared for the CONCAWE Automotive Emissions Management Group, based on work carried out by the Special Task Force on emissions from gasoline powered vehicles (AE/STF-1)

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ABSTRACT

Six European vehicles fitted with carbon canisters have been tested under severe conditions to establish if evaporative losses of volatile organic compounds occur under European driving conditions - so called "running losses". The programme entailed the development of a point source measurement technique which has a number of advantages over other methods currently in use.

Following the development and validation of the measurement technique, the six vehicles were tested at 28°C over a range of driving cycles on a gasoline with a Reid vapour pressure of 90 kPa. None of the vehicles exhibited classical running losses, i.e. losses during higher-speed driving. This was due to the effectiveness of canister purging in these conditions.

However, significant volatile organic compound (VOC) losses were observed for several vehicles during idle after a period of driving had heated the fuel. Substantial car-to-car variation was observed in the losses obtained. The losses were always more severe over longer idling periods, and more severe than hot soak over comparable periods. This may have important implications for urban pollution.

Critical factors affecting running losses are fuel temperature and purging strategy. Higher fuel temperatures increase vapour generation and hence the canister charging rate. Purging rates must be sufficient to overcome the charging rate. Larger carbon canisters (LCC) were found to be more effective than small carbon canisters (SCC) in reducing running/idling losses because of the extra adsorbent capacity available. Mitigation of refuelling losses is an added benefit. Systems that combine the canister with a pressurized fuel tank, in order to limit VOC charging of the canister, were shown to run the risk of VOC losses from sources other than the canister vent.

KEYWORDS

Automotive emissions, carbon canister, emission test procedure, gasoline emission, hydrocarbon emission, measurement, running loss, test methods, VOC.

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SUMMARY

Measurements of running losses have been made for six European cars equipped with carbon canisters. Four of the vehicles were fitted with small carbon canisters (SCC) as standard equipment, the other two vehicles had been modified for previous CONCAWE studies and featured enlarged carbon canisters (LCC).

Identification of the driving conditions under which volatile organic compounds (VOC) running losses might occur was established by setting the fuel Reid vapour pressure (RVP)/ambient temperature combination at a realistic but severe European level and by starting the test with the carbon canister loaded. The main phase of work examined repeated (back-to-back) driving cycles, which provided a progressive increase in fuel temperature.

Doubts surround the validity of existing techniques for the measurement of VOC running losses. A point source measurement technique was therefore developed and validated for the project. This has permitted the detection of losses from the canister vent and other likely sources without affecting the performance of the canister. Only canister vent losses were monitored in this programme. However, some qualitative indication of other losses is still available as the background air quality in the dynamometer enclosure was also monitored.

None of the vehicles studied exhibited "classical" running losses, i.e. losses during higher-speed driving. This was due to the effectiveness of canister purging whilst the vehicle was being driven. However, significant losses were observed for several vehicles during idle after a period of driving had heated the fuel. Substantial car-to-car variation was observed in the losses obtained. The losses were always more severe over longer idling periods, and more severe than hot soak over equivalent times. This may have important implications for urban pollution.

The mass of VOC in the canister was found to reduce by purging during ECE, EUDC and constant speed driving cycles but increased sharply during idle, especially at higher fuel tank temperatures. Fuel temperature was increased particularly by fuel recirculation. It therefore seems likely that running losses are prevalent during periods of slow driving or idling (when the canister purge system is not operating) and after a period of driving has heated the fuel in the tank. The critical factors affecting running losses are therefore fuel temperature and purging strategy. Higher fuel temperatures increase vapour generation and hence the canister charging rate. Purging rates must be sufficient to overcome the charging rate. LCC were found to be more effective than SCC in reducing running/idling losses because of the extra adsorbent capacity available. Mitigation of refuelling losses is an added benefit.

Systems that combine the canister with a pressurised fuel tank, in order to limit VOC charging of the canister, were shown to run the risk of VOC losses from sources other than the canister vent.

1. INTRODUCTION

Previous work by CONCAWE[1,2,3] has demonstrated that carbon canister technology can provide an extremely effective means of controlling evaporative emissions from motor vehicles. However, experience in the US has demonstrated that this is not always the case. Inadequate canister system design and a mismatch between the volatilities of certification and marketed fuels can lead to poor efficiency and high in-service evaporative emissions. In particular, work carried out for the US EPA[4] has shown that running losses, traditionally defined as those hydrocarbon losses that occur during driving, can represent a major source of in-service evaporative emissions. Running losses occur via overloading of the canister, or through leaks in the fuel system.

The 1989 CONCAWE programme[3] determined running losses from a range of current uncontrolled European cars, but could not detect any losses from the canister-equipped vehicles that were tested. However, since there were doubts about the suitability of the test method for canister-equipped vehicles, it was not possible to conclude unequivocally that there were no losses. In view of the potential importance of, and interest in, running losses in a European context, it was decided to carry out a further investigation. The objectives of this programme were:

(a) to develop a suitable test method and
(b) measure running loss emissions from a range of canister-equipped European cars over a wide range of driving conditions.

2. TEST METHOD DEVELOPMENT

Measurement of VOC emitted from vehicles while they are being driven has been attempted previously using two different methods; adsorption in carbon traps, and the use of a dynamometer in a SHED (sealed housing for evaporative determination).

Measurement using carbon traps is simple and inexpensive, but may be inaccurate. If a carbon trap is attached to the vent of the vehicle's carbon canister, it can alter the canister back-pressure and therefore influence the losses. During purging of the vehicle's canister, the carbon trap may also be purged, causing an underestimation of the true loss. A carbon trap can only determine the total loss from a source over a given driving cycle element; it does not identify the point at which the losses occur within the cycle. Losses will only be recorded from those sources fitted with carbon traps. If there are losses from unexpected sources, such as leaks or from porous hoses, these will be missed by the carbon trap approach.

Measurement of losses using a SHED surrounding the dynamometer covers all sources (including leaks). However, the equipment is complicated and expensive. The key difficulty is ensuring sufficient air cooling. If the fuel tank temperature is higher than when driven on the road, the VOC losses will be exaggerated. The dynamometer-in-SHED technique detects when losses occur but does not identify the source of the loss.

The limitations of the above methods highlighted the need for a simple and accurate test method with the following characteristics:

- The test must not change the losses, i.e., it must not change the back-pressure at the vehicle's carbon canister.

- The method should identify when the losses occur in addition to measuring the total losses over any driving cycle element.

- The method should preferably indicate the source of the losses.

- The method should use existing equipment as far as possible, or at least be simple enough for laboratories to adopt it at reasonable cost.

It was decided to adopt a point source technique to best meet these requirements. Thus, losses could be measured from the canister vent and other likely sources if so desired (e.g. fuel filler cap and pressure relief valve) and integrated. For simplicity, only canister vent losses were monitored in this programme; however, some qualitative indication of losses from other sources was still available as the background air quality was also monitored. The option exists for losses from other sources to be measured using carbon traps.

Figure 1 depicts the prototype Microtunnel developed at Esso Research Centre, Abingdon, for measuring running losses. The vent from the vehicle's carbon canister is connected into the lower end of the vertical tunnel using wide-bore (19 mm diameter) hose. A slow flow of air through the Microtunnel transfers any vapours from the canister vent to the measurement system without changing the pressure conditions at the canister vent.

A hydrocarbon detector positioned near the top of the Microtunnel checks that the flow rate is sufficient to sweep all VOC losses into the measurement system. The hydrocarbons were measured with standard flame ionization detector (FID) apparatus, as used on a conventional constant volume sampler (CVS) emissions facility.

Optimization of sampling conditions was achieved using Car G which is fitted with a small carbon canister. Initially, the air flow through the tunnel was adjusted to 2 l/min and directed straight into the FID. However, this flow rate was insufficient to prevent hydrocarbon losses from the top of the Microtunnel when this vehicle was idling. Under these conditions, the concentration of the hydrocarbons entering the FID caused it to read off-scale. The method was modified by increasing the total flow through the Microtunnel to 10 l/min, and this air/hydrocarbon mixture was then further diluted by injection into a standard constant volume sampler (CVS) exhaust sampling system.

Hydrocarbon emissions during the test were determined from a bag sample in the conventional way and corrected for the hydrocarbon content of the ambient air bag. Instantaneous hydrocarbon levels in the tunnel were recorded to determine the time and driving cycle conditions under which the canister started to vent hydrocarbons (the breakthrough point).

With a flow rate of 10 l/min, no vapours escaped from the top of the Microtunnel. The flow rate was varied between 0 and 15 l/min and showed no influence on pressure at the canister vent.

On transfer of this testing method to Shell's Thornton Research Centre, the approach was further modified so as to provide:

- Increased flexibility in handling the large range of hydrocarbon losses possible.
- An alternative to the use of a CVS.

These features were incorporated in the Dual Microtunnel (see **Figure 2**), whereby the hydrocarbons leaving the canister vent were still sampled with pressure equalization at the top of the first Microtunnel. However, by judicious choice of flow rates, it was possible to accommodate any amount of hydrocarbon loss while still maintaining good detection sensitivity. Under some low loss conditions, the second Microtunnel was not required.

The first tunnel was typically operated at 12 l/min. A further dilution factor of at least 20 was readily available by splitting the flow from the first tunnel and drawing air into the second at approximately 10 l/min. Unwanted diluted gas from the first Microtunnel was vented away.

Checks similar to those described previously were again carried out in fixing test conditions, notably ensuring that hydrocarbons were not lost from the top of either Microtunnel.

Hydrocarbon analysis was carried out by NDIR (non-dispersive infra-red spectrophotometry) using the HORIBA MEXA 544. Output from the experiments was relayed to a data-logging facility and thus time-resolved information on hydrocarbon loss was generated as a function of driving cycle. From the flow rates, dilution factors and elapsed times, mass emissions of hydrocarbon were then calculated.

The point-source technique described above is, in fact, very similar to that developed for use in the US Auto/Oil programme on gasoline reformulation[5].

Where practicable, the results were supplemented with measurements of vehicle canister weight at set points during the test. This extra information is of particular relevance in tests where hydrocarbon losses from the canister vent are not observed. Canister weight indicates how close the canister is to breakthrough under a given set of conditions, and thus is useful for ranking purposes.

3. CHOICE OF TESTING PARAMETERS

The study was set up to test vehicles with a range of canister systems at one fixed combination of fuel RVP/ambient temperature, but over a range of driving patterns. Earlier work has shown that RVP is by far the most important fuel parameter influencing evaporative losses. The fuel RVP/ambient temperature combination was therefore set at 90 kPa/28°C, and the test was started with the canister loaded. Under these realistic but severe European conditions it should be possible to establish under what driving regimes VOC losses occur. It should also be possible to determine the factors promoting such losses.

Table **1** gives general technical details for the vehicles used in the programme. Cars E and F are vehicles that have been used in previous CONCAWE work[2]; both have been equipped by CONCAWE with refuelling emission control systems based on the large carbon canister (LCC). The remaining vehicles chosen represent a range of technologies currently available in European markets, with evaporative control systems based on the small carbon canister (SCC). Information on the evaporative loss control systems is given in Table **2**.

Key properties of the fuels used in both the preliminary and main phases of the work are shown in Table **3**. It should be noted that these fuels were used quite separately in the two independent phases of the work and so the differences in the detailed fuel characteristics are of no consequence.

Considerable thought was given to the question of canister pre-conditioning. In the event, purging the canister off the car overnight, followed by charging with test gasoline vapours (see **Figure 3**), at a known flow rate to a known condition (i.e. breakthrough) was chosen. Thus, after overnight purging, the canister was loaded at a flow rate of 5 l/min until breakthrough was detected using an MSA explosimeter. This was seen to be a convenient and effective way of achieving a constant baseline condition that offered fair comparison, and was used generally in the programme.

Vehicle conditioning prior to testing was carried out as follows:

DAY 1: Disconnect canister for purging off-car. Drain fuel tank and refill to 40% capacity with fresh test fuel.
Leave to soak overnight at test temperature (28°C).

DAY 2: Load canister to breakthrough. Weigh and refit loaded canister.
Drive chosen cycles.

Because of the expected link between increased fuel temperature and canister charging, the effect of driving cycle on hydrocarbon losses was examined with due regard to fuel warming. Accordingly, the choice (as well as the effect) of the experimental cycles formed an important part of the study.

4. RESULTS

In the preliminary phase of the work, carried out at the Esso Research Centre, Abingdon, the effect of nine different driving cycles on canister loading/running losses was investigated. Test cars F and G were employed, using a 90 kPa RVP gasoline at an ambient temperature of 26°C.

Car F (fitted with the LCC) showed no losses under any of the driving cycles tested. Car G only showed losses during the idle portion of the driving cycles (see **Table 4**). Results for the hydrocarbon running loss, the time to canister overloading, changes in fuel tank temperature and canister weights, are given in Tables **5** (Car G) and **6** (Car F).

As shown in Figure **4**, canister weight is influenced by both the driving cycle (which affects purging) and the fuel temperature (which influences the hydrocarbon loading). Measurement of the canister purge rates showed that neither car purged at idle or low speeds and that Car G was unusual in exhibiting very high purge rates (45 l/min) at higher speeds. This model was fitted with an electronic system which allows intermittent purging at intermediate engine speeds.

Canister weight is reduced by purging during ECE, EUDC and constant speed (90 kph) driving cycles but increases sharply during idle, especially at higher fuel tank temperatures. Fuel temperature is increased particularly by fuel recirculation. Therefore, it seems that running losses are most likely to occur during periods of slow driving or idling (when the canister purge system is not operating) and after a period of driving has heated the fuel in the tank.

The main phase of work, carried out at Shell's Thornton Research Centre, therefore examined repeated (back-to-back) driving cycles. The standard test adopted was five repeated (ECE15 + EUDC + 15 min idle), which is illustrated in **Figure 5**. The repetition of driving cycles in this way provided a progressive increase in fuel temperature while still allowing specific sections of the overall driving cycle (e.g., idle, hot-soak etc.) to be compared for their individual contribution to the running losses observed.

The full range of driving cycles examined is given in Table **7**. These were not necessarily examined for all six vehicles, but each vehicle was tested over a number of different driving cycles (see Tables **9** to **11**). Note that, under the constraint of 40% initial fill, only 4 back-to-back (90 kph/30 mins + 5 min hot soak) cycles could be driven.

Table 8 gives values for the VOC loss observed in each case. The data include both the overall total (i.e. 5 cycles), and the contributions from successive individual cycles. **Tables 9** to **11** show quantified running loss behaviour, as a function of varying driving cycle, grouped according to vehicle. These results also indicate the point at which any running loss was first observed. Canister weights were noted at convenient points in the overall driving cycle whenever this was possible. In practice, this provided good comparative data at the start and end of each driving cycle element. The combination of information provided by the weight profiles, time-resolved hydrocarbon trace (see **Figure 6**), and quantified hydrocarbon loss is substantial. This type of output was available for all experimental runs listed in Tables **8** to **11**.

These results show clearly that classical running losses (i.e. those associated with moderate to high-speed driving) are not readily observed under the conditions of this study. Losses repeatedly occurred during idle after a period of driving. Only Car D exhibited losses during a driving phase, and then only for repeated low-speed driving in which some idling was incorporated.

For the standard test condition, notable running losses were observed for three out of the six vehicles. The largest losses were seen for Car D and these were substantially greater than for Cars B and E, though these latter losses were also significant. Although losses for Car C were minimal or zero, the standard fuel/temperature/driving cycle combination clearly provided borderline behaviour (see Figure 7). This figure also demonstrates that increased temperatures increase running losses. For cars A and F, no losses were observed. Running loss performance was not solely determined by test car canister capacity (but see later).

For all cars, shortening the idle period from 15 mins to 5 mins reduced the severity of the test. This could be seen as a reduction in either running losses or canister loading. The diminished severity of this test condition is due to the reduced overall fuel temperature increase and to the more limited time for canister charging.

Similarly, replacing the 5 min idle by a 5 min hot soak always reduced losses (or the tendency towards losses) even further. Again, losses were not observed during higher speed driving.

Car D gave canister vent running losses under all conditions investigated. These always arose first during the idling or hot-soak parts of the overall cycle. Cars A and F exhibited no canister vent hydrocarbon loss in any experimental run.

Whether running losses occurred or not, comparison of the canister weight profiles yields important information. In cases where running losses were not actually observed, they also provide a means of ranking the severity of the different parts of the overall cycle. Figure 8 (for Car F) shows that a longer idle is more severe than a shorter one. Figure 9 (for Car E) shows idling is a more severe condition than hot-soak. Figure 10 (also for Car E) provides a useful comparison between the emission cycle and the 90 kph condition in promoting losses under the subsequent hot-soak conditions.

Figure 11 (for Car A and Car C) reflects the effectiveness of canister purging under the constant high speed (90 kph/30 mins) driving condition. This, coupled with some restriction on canister charging, is presumably the key to controlling running losses in these vehicles under such conditions. This is despite clear indications that fuel temperature increases substantially. Note that Car C does not charge the canister under hot-soak conditions.

Before the canister weight profiles can be used as an absolute indicator of running losses, it is necessary to recognise the fact that the condition described as "breakthrough" for canister loading off-the-car is different (as far as canister weight is concerned) from that experienced on the vehicle. This is because the loading conditions are different in respect of flow rates and temperatures. Table 12 shows the relationship found between the two weights during this work. It is evident that on-the-car loading allows higher quantities of hydrocarbon to be retained by the active carbon, in line with nominal canister capacity.

Some experiments were carried out for a 90% initial fuel fill condition (rather than the normal 40%). Results are shown in **Figures 12** and **13**, and **Table 13**, covering idling and hot-soak conditions. It was always found that those runs carried out under the 40% condition tend to produce any losses much earlier in the overall cycle, while those done with a 90% initial fill do so much later. Runs that did not produce a running loss showed the same trend, i.e. greater charging of the canister towards the end of the cycle when a 90% fill was used.

Variations in the driven part of the overall cycle concentrated on comparing (ECE15+EUDC) with 90 kph constant speed over 30 minutes. It is evident from the canister weight profiles that purging is generally more effective for the 90 kph constant speed condition than for (ECE15+EUDC). This finding is in accordance with purge rate data collected for all the test vehicles, shown graphically in **Figure 14**. It can be seen that, with the exception of the specially-adapted Car E, purging operates only beyond a certain pre-set engine speed, and increases to high values around 90 kph. Furthermore, it is interesting to note the variety of purging strategies displayed within this particular group of vehicles.

Table 14 shows the maximum fuel temperatures achieved during these tests, reflecting the severity of each individual run. One clear finding from these results is that Car D and Car E generate the highest fuel temperatures in any given testing regime. The results for 5 (ECE15+EUDC+15 min idle) are in line with the observed running losses, i.e. highest fuel temperatures correlate with highest running losses. This trend is repeated for the other driving patterns based on emission cycles.

When the higher speed (90kph/30 mins) cycle is used, running losses are not observed in most cases in the subsequent hot soak. This illustrates the importance of purging in these cases. However, Car D does show losses under this condition.

Comparison of equivalent data for 40% and 90% fill shows how the reservoir of hydrocarbon is just as important as fuel temperature in realising running losses.

Throughout this work, Car D has been shown to be the most susceptible to running losses. The calculations in **Table 15** demonstrate the effect of fitting Car E's larger carbon canister to Car D under the conditions in which Car D underwent its greatest losses. Despite the higher hydrocarbon loading that would be imposed by the set procedure used for canister preconditioning, the incremental weight increase plus the accumulated running loss, is always less than that required to produce a running loss from the LCC. Thus, the extra capacity offered by this larger carbon canister would be sufficient to control canister vent hydrocarbon losses.

The calculation assumes no change to the charging and purging rates on Car D. Note that the calculation takes into account the fact that the difference between the canister breakthrough weight for charging on-the-car and for charging off-the-car is greater for the LCC than the SCC. However, the LCC starts from a more highly loaded point, a feature of the comparison that discriminates against the LCC.

Some ancillary observations made during the testing of Cars A and C are also of interest. Under the conditions tabulated in **Table 16**, the dilution air taken from the dynamometer working cell showed an increase in background air hydrocarbons over the duration of the run. The source of this increase was traced to the fuel tank area of the cars in question. It would appear that, under certain conditions, gasoline vapours are prevented from transferring from the tank to the canister - which in turn suggests that the fuel tank pressure is increased. Thus, assessing the true running loss performance of these two SCC/pressurised tank/switched charging systems may require caution.

A brief comparison was made of the canister loading achieved by using the full CEC procedure and the bench loading technique used generally in the present work. This was done for Cars A and B. In the case of Car B, the observed loading by each method was exactly the same. The Car A canister was loaded less severely by the CEC method (by 10 g). Therefore, the bench loading method appears to provide an initial canister loading condition that is at least as demanding as that obtained via the time-consuming and relatively inconvenient CEC alternative.

Standing losses from the open-base canister fitted to Car G were also investigated. Weight loss was measured hourly from a loaded canister disconnected from the vehicle; 11.5 g of hydrocarbon was lost over a twenty-two hour period before the canister weight stabilized:

Hours standing	1st	2nd	3rd	4th	5th	6th	7th to 22nd
VOC loss per hour, g.	4.2	2.1	0.7	1.0	0.5	0.2	0.175 (Av.)

The standing loss in the first few hours may be reduced in the proposed legislative hot soak test. If the SHED temperature (proposed 25 to 31 °C) is lower than the fuel tank temperature, cooling of the fuel tank vapour space can produce back-purging of the canister and reduce the initial standing losses.

5. DISCUSSION

The results presented above provide clear indications that VOC losses deriving from canister overloading during vehicle operation can arise in a number of ways. This also makes it necessary to clarify the terminology to be used in this discussion. The term "running loss" describes losses that occur generally when the engine is running. However, the term "idling loss" refers specifically to idling conditions and "hot-soak loss" refers to evaporative losses when the engine is off.

It is clear that the most critical factors favouring running losses are those that promote higher fuel temperatures (and therefore higher VOC loading) and lower rates of canister purging (thereby reducing remaining canister capacity). Consequently, the consistent finding that VOC losses are not associated with high speed driving can be explained on the basis that canister purging is effective enough to overcome the high loading rate, even with the realistic but severe fuel RVP/temperature combination chosen. Accordingly, it is the fine balance between charging and purging that determines whether running losses occur. That is, the purge rate has to be sufficient to counteract the VOC charging rate.

This greatly simplifies interpretation of the individual results. The observation that repeated (ECE15 + EUDC + 15 min idle) produces high fuel temperatures together with long periods of no canister purging is consistent with its ranking as a very severe condition in the study. The equivalent driving cycle with the shorter idle provides reduced periods of no purge, and reduced fuel temperatures. Substitution of hot-soak for idle again reduces the fuel temperature because return of hot fuel to the tank ceases. The most important driving cycle factor promoting VOC loss under the conditions of this study is thus the idle. Idling losses are therefore very important.

Care must be exercised when interpreting the results involving the 90 kph/30 mins constant high-speed driving element (rather than the emission cycle). It is clear that canister purging during this constant speed condition is more effective on most cars. However, it is crucial to make the correct comparison in evaluating the real effect of 90 kph/30 mins compared with ECE15 + EUDC. In the present study, this is best done for tests having 5 mins hot soak as the non-driving sector. Results indicate that the 90 kph/30 mins element is marginally more likely to promote VOC losses than the ECE15 + EUDC. They further indicate, however, that the combination of more moderate driving patterns with significant idling is much more likely to cause canister overload than this constant speed/hot soak regime. Clearly, there is cause to expect that the longer idle following constant higher-speed driving is likely to produce greatest potential for canister overloading. Whether running losses are realised in any particular set of the present experimental circumstances is a complex function of many variables, notably:

- overall driving cycle
- purge rate/strategy
- canister capacity
- canister charging potential or controls (if any)
- fuel temperature and volatility
- the proportion of fuel returns to the tank
- the quantity of fuel on board.

Cars D and E regularly generate the highest fuel temperatures. They have no extra controls on canister charging (unlike Cars A and C). Car D does not exhibit particularly good purging performance to counteract the regular heavy loading of its canister. Car E often has the canister capacity to counteract the high charging rates imposed by its fuel tank venting system but its real weakness may lie in relatively low purge rates at higher speeds. The fact that Car D is overall a much worse performer than Car E must, however, be attributed mainly to the size of the canister, as evidenced by the calculation of Table 15.

Car B performs better than Car D because it produces lower fuel temperatures, and shows better purging performance (though very similar purging strategy).

Car F performs well because it combines a large carbon canister with good purging performance and low fuel temperatures associated with its carburetted fuel system. Higher speed driving brings about good purging rates while fuel temperatures are still kept down. The high canister capacity was more than adequate under the conditions of this study, even at 90% initial fuel fill.

Cars A and C generate intermediate fuel temperatures. The purging system on Car C is not quite as effective overall as that on Car A. With a small canister, the main control of canister vent losses is effected directly by severely restricting the flow of VOC vapours to the canister under certain conditions, Car C being more severe in this respect than Car A. The combined result of these measures is much the same, but an undesirable consequence is the release of some (unquantified) evaporative losses other than from the canister vent.

The results on the effects of varying initial fill make the important point that fuller fuel tanks can be expected to give higher losses. This is because the effect of the greater reservoir of light ends outweighs that of lower fuel temperature. Thus, the VOC losses at 40% initial fill will be readily exceeded if higher fuel loads are involved. This is particularly demonstrable for Car B Table 9.

The above detailed consideration for each test vehicle allows informed comment on the importance of canister size and purge strategy in relation to evaporative control system performance. If the purging regime for a particular vehicle cannot counterbalance the VOC charging rate, then increasing the canister capacity must improve the position, as this work shows. Thus large carbon canisters, as used to control refuelling emissions, have an inherent advantage due to their larger absorbent capacity. However, since canister capacity is not the only factor controlling running losses, there is a clear need for optimization of the engineering of evaporative control systems if the full available benefits are to materialise. This issue is particularly relevant, given the fact that VOC losses to the atmosphere during longer idle periods will tend to occur in city centre environments.

6. CONCLUSIONS

1. A reliable and repeatable method for the measurement of running losses has been developed and demonstrated.

2. Under the conditions of this study, the vehicles tested did not exhibit classical running losses, i.e. losses during higher-speed driving, due to the effectiveness of canister purging in these circumstances.

3. Significant VOC losses were observed for several vehicles during idle after a period of driving had heated the fuel; most cars do not purge during idle. This may have important implications for urban pollution.

4. While there is substantial car-to-car variation in the losses obtained, idling is more severe over longer periods, and more severe than hot soak over equivalent times.

5. Critical factors affecting running losses are fuel temperature and purging strategy. Higher fuel temperatures increase vapour generation and hence the canister charging rate. Purging rates must be sufficient to overcome the charging rate.

6. The initial fuel fill level can have a major effect on the observed running loss behaviour. A greater quantity of fuel delays the onset of running losses but may give an increased overall loss because of the greater reservoir of hydrocarbons available.

7. Larger carbon canisters (LCC), of themselves, are more effective than small carbon canisters (SCC) in reducing running/idling losses because of the extra adsorbent capacity available. Mitigation of refuelling losses is an added benefit. However, it is crucial that the charging/purging system is based on optimized engineering, consistent also with the control of exhaust emissions.

8. Systems that combine a carbon canister with a pressurized fuel tank, in order to limit VOC charging of the canister, run the risk of exhibiting VOC losses from sources other than the canister vent. This is because the increase in fuel tank pressure may inadvertently result in VOC losses from some point, or points, in the fuel system.

9. A simple canister preconditioning procedure has been successfully implemented in this study. This is more convenient but no less severe than the time-consuming CEC procedure.

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Table 1 Running losses - general technical data for test vehicles

CAR	A	B	C	D	E	F	G
DISPLACEMENT cc	1598	1272	1392	1781	1796	1342	1998
COMPRESSION RATIO	9.2	9.5	8.5	10.0	8.9	8.7	-
RATED POWER kW/rpm	55/ 5200	40.5/ 5200	53/ 5500	84/ 5400	73.5/ 5800	45/ 5500	-
FUEL SYSTEM TYPE	SPI	MPI	SPI	MPI	MPI	carb	MPI
FUEL RECIRC?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FUEL TANK CAPACITY, l.	61	42	42	55	61	46	-
EXHAUST GAS CATALYST?	3WC	3WC	3WC	3WC	3WC	-	3WC

Table 2 Running losses - evaporative control details for test vehicles

CAR	A	B	C	D	E	F	G
					Opel Ascona	Honda Civic	
FUEL SYSTEM TYPE	SPI	MPI	SPI	MPI	MPI	Carb	MPI
CANISTER	SCC	SCC	SCC	SCC	LCC	LCC	SCC
CAPACITY, l (approx)	1	1	1	1	4.7	3	1
PRESSURISED FUEL TANK	Yes*	No	Yes*	No	No	No	No

* In these 2 cases, canister charging is independently triggered in the warmed-up condition and is probably subject to tank pressure control.

Table 3 Key properties of test fuels

Preliminary Phase		Main Phase
91.2 kPa	RVP	89.8 kPa
22°C	IBP	26°C
36.7%	E70	28.5%
57.6%	E100	43%
90.1%	E150	80.5%
97.7%	E180	95%
197°C	FBP	212°C

Table 4 Running losses - preliminary work; overall summary

	Car G (SCC)	Car F (LCC)
ECE+EUDC legislative cycle	NO LOSSES	NO LOSSES
ECE+EUDC, then 15min idle	LOSSES DURING IDLE	NO LOSSES
90 kph/30 mins	NO LOSSES	NO LOSSES
90 kph/30 mins, then 15 min idle	LOSSES DURING IDLE	NO LOSSES
2 cycles(90 kph/30 mins, 15 min idle)	LOSSES DURING IDLE	NO LOSSES
130 kph/30 mins*	NO LOSSES	NO LOSSES
130 kph/30 mins, then 15 min idle**	LOSSES DURING IDLE	NO LOSSES
90 kph/30 mins, then 30 min idle	LOSSES DURING IDLE	NO LOSSES
130 kph/30 mins, then 30 min idle	LOSSES DURING IDLE	NO LOSSES

Fuel RVP 90 kPa Ambient Temp 26°C

* CEC hot driveability specification

** CEC hot driveability test condition

Table 5 Running losses - preliminary phase; typical results, car G

Test	Drive Cycle	Running Loss (g)	Fuel Tank Start	Temp End	Time to Breakthro'	Canister Weight (g)
1 A	90 kph/30 min	0	27.2	37.7		
B	Idle 15 min	36.9	37.7	40.0		
2 A	ECE15	0	25.1			862.7 start
B	EUDC	0				
C	Idle 15 min	36.2		35.4		876.2 end
3 A	90 kph/30 min	0	25.3	36.2		861.5 start
B	Idle 15 min	46.5	36.2	37.3	0min 35sec	
C	90 kph/30 min	0	37.3	39.5		
D	Idle 15 min	43.3	39.5	40.5	3min 00sec	879.1 end
E	130 kph/30 min	0	40.5	43.1		
F	Idle 15 min	43.2	43.1	45.2	4min 18sec	893.2 end
G	ECE15	2.9	45.2	45.6		
H	EUDC	0.5	45.6	45.1		
I	Idle 15 min	44.1	45.1	47.2	7min 53sec	906.5 end
J	130 kph/30 min	0		46.5		
K	Idle 15 min	28.3	46.5	48.6	9min 20sec	879.7 end

Each test involves cumulative driving and so the data obtained represent cumulative effects.

Table 6 Running losses - preliminary phase; typical results, car F

Test	Drive Cycle	Running Loss (g)	Fuel Tank Temp Start	Fuel Tank Temp End	Canister Weight (g)
1A	ECE15	0	26.0		4215.0 start
B	EUDC	0		26.3	
C	Idle 15 min	0	26.3	27.6	
D	Idle 15 min	0	27.6	29.8	
E	90 kph/30 min	0	30.5		
F	Idle 15 min	0		34.4	
G	90 kph/30 min	0	34.4		
H	Idle 15 min	0			
I	Idle 15 min	0		37.0	4136.1 end
2A	130 kph/30 min	0	33.3		4135.2 start
B	Idle 15 min	0		38.6	
C	Idle 15 min	0	38.6	37.0	4124.7 end

Data for each test are cumulative

Table 7 Running losses - main test conditions examined

PRECONDITIONING OF CANISTER: Purge overnight with air off-the-car. Load using equipment of Fig.3 just prior to driving.
FUEL RVP/AMBIENT TEMPERATURE: 90 kPa RVP/28°C INITIAL FUEL FILL: 40% as standard; some work at 90%. DRIVING CYCLE VARIATIONS: 5(ECE15+EUDC+15 min idle) 5(ECE15+EUDC+5 min idle) 5(ECE15+EUDC+no idle) Continuous ECE 5(ECE15+EUDC+5 min hot soak) 4(90 kph/30 mins+5 min hot soak)

Table 8 Running losses - hydrocarbon losses observed in standard test

Car	Total Loss, g	During Cycle 1	2	3	4	5
A	0					
B	20	2	8	8	2	
C	<5					
D	106	9	22	12	41	22
E	35			17	11	7
F	0					

Driving Cycle 5(ECE15 + EUDC + 15 min idle)

All losses generated at idle

40% initial fuel fill

Temperature 28°C ; Fuel RVP 90 kPa

Losses as hexane equivalent

Table 9 Running losses - test carried out on car A and car B

Cycle	Losses (g)	First Observed
[CAR A]		
5(ECE15 + EUDC + 15min idle)	0	
5(ECE15 + EUDC + 5min hot soak)	0	
4(90kph/30mins + 5min hot soak)	0	
[CAR B]		
5(ECE15 + EUDC + 15min idle)	20	During Idle 1
5(ECE15 + EUDC + 5min idle)	0	
5(ECE15 + EUDC + no idle)	0	
Continuous ECE	0	
5(ECE15 + EUDC + 15min idle)*	89	During Idle 2
5(ECE15 + EUDC + 5min hot soak)	0	
5(ECE15 + EUDC + 5min hot soak)*	5	End of Hot Soak 4
4(90kph/30mins + 5min hot soak)	0	

* 90% initial fill
Otherwise 40%.

Table 10 Running losses - test carried out on car C and car D

Cycle	Losses (g)	First Observed
[CAR C]		
5(ECE15 + EUDC + 15 min idle)	<5	
5(ECE15 + EUDC + 15 min idle).31C	7	End of Idle 2
5(ECE15 + EUDC + 15 min idle).25C	0	
5(ECE15 + EUDC + 5 min hot soak)	0	
4(90 kph/30 mins + 5 min hot soak)	0	
[CAR D]		
5(ECE15 + EUDC + 15 min idle)	106	During Idle 1
5(ECE15 + EUDC + 5 min idle)	51	During Idle 3
5(ECE15 + EUDC + 5 min hot soak)	10	End of Hot Soak 3
Continuous ECE	25	5th (ECE15)
4(90 kph/30 mins + 5 min hot soak)	19	During Hot Soak 1

Table 11 Running losses - test carried out on car E and car F

Cycle	Losses (g)	First Observed
[Car E]		
5(ECE15 + EUDC + 15 min idle)	35	During Idle 2
5(ECE15 + EUDC + 5 min idle)	0	
5(ECE15 + EUDC + 5 min hot soak)	0	
4(90 kph/30 mins + 5 min hot soak)	0	
[Car F]		
5(ECE15 + EUDC + 15 min idle)	0	
5(ECE15 + EUDC + 15 min idle)*	0	
5(ECE15 + EUDC + 5 min idle)	0	
5(ECE15 + EUDC + 5 min hot soak)	0	
4(90 kph/30 mins + 5 min hot soak)	0	

* 90% initial fill
Otherwise 40%.

Table 12 Running losses - differences in canister loading for off-the-car and on-the-car conditions

	VOC Charge at Breakthrough for Off-the-Car Loading (g)	Extra VOC Charge at Breakthrough for On-the-Car Loading (g)
CAR A	45	>5 #
CAR B	40	10
CAR C	45	25
CAR D	40	17
CAR E	100	165
CAR F	65	>30 #

This extra charge cannot be determined more accurately from the present work since no running losses were observed.

Table 13 Running losses - comparison of 40% fill vs 90% fill car B; (ECE 15 + EUDC + 5 min hot soak)

Test Point of Canister	40% fill Relative Weight of Canister	90% fill Relative Weight	40% fill Fuel Temp	90% fill Fuel Temp
End 1(ECE15+EUDC)	-13.2	-14.2	31.5	29.3
End hot soak 1	-4.8	-12.0	32.0	29.6
End 2(ECE15+EUDC)	-10.4	-17.9	36.2	33.0
End hot soak 2	+0.8	-14.7	36.9	33.5
End 3(ECE15+EUDC)	-7.9	-15.0	39.0	36.0
End hot soak 3	+7.1	-5.3	39.3	36.3
End 4(ECE15+EUDC)	-4.2	-5.5	40.4	37.9
End hot soak 4	+8.1	+11.5	41.1	38.3
End 5(ECE15+EUDC)	-6.5	+1.2	41.5	39.4
End hot soak 5	+1.9	+17.6	41.7	39.4

Canister weights relative to off-the-car breakthrough weight

All weights in grams

All temperatures in °C

Table 14 Running losses - maximum recorded fuel temperatures (°C)

a) 5(ECE15+EUDC+15min idle), 40% fill		
CAR A		44
CAR B		45
CAR C		44
CAR D		48
CAR E		49
CAR F		39
b) 5(ECE15+EUDC+5min hot soak), 40% fill		
CAR A		41
CAR B		42
CAR C		44
CAR D		47
CAR E		46
CAR F		38
c) CAR B vs. CAR D		
	CAR B	CAR D
5(ECE15+EUDC+15min idle)	45	48
5(ECE15+EUDC+5min idle)	45	49
5(ECE15+EUDC+5min hot soak)	42	47
Continuous ECE (6xECE15)	41	45
4(90kph/30mins+5min hot soak)	44	52
d) CAR E		
5(ECE15+EUDC+15min idle)	49	
5(ECE15+EUDC+5min idle)	48	
5(ECE15+EUDC+5min hot soak)	46	
4(90kph/30mins+5min hot soak)	53	
e) CAR B; 40% Fill vs. 90% Fill		
	40%	90%
5(ECE15+EUDC+15min idle)	45	42
5(ECE15+EUDC+5min hot soak)	42	39

Table 15 Running losses - calculated losses for car D fitted with LCC from car E

5(ECE15 + EUDC + 15 min idle)

Test Point	Canister Weight vs Off-car Loaded Weight	Obs'd SCC RL	Total#	Threshold for LCC RL	LCC RL ?
End of Idle1	+8	+9	+17	+165	NO
End of Idle2	+24	+22	+55	+165	NO
End of Idle3	+30	+12	+73	+165	NO
End of Idle4	+37	+41	+121	+165	NO
End of Idle5	+43	+22	+149	+165	NO

Note that total hydrocarbon figure necessarily includes all accumulated running losses (RL). It is therefore derived by adding up all previous and present RL to the canister weight, e.g., for the End of Idle3 it is 30+9+22+12 = 73 g.

All weights in grams.

The breakthrough point for off-the-car loading of the LCC ex Car E is about 60 g higher than for the SCC ex Car D.

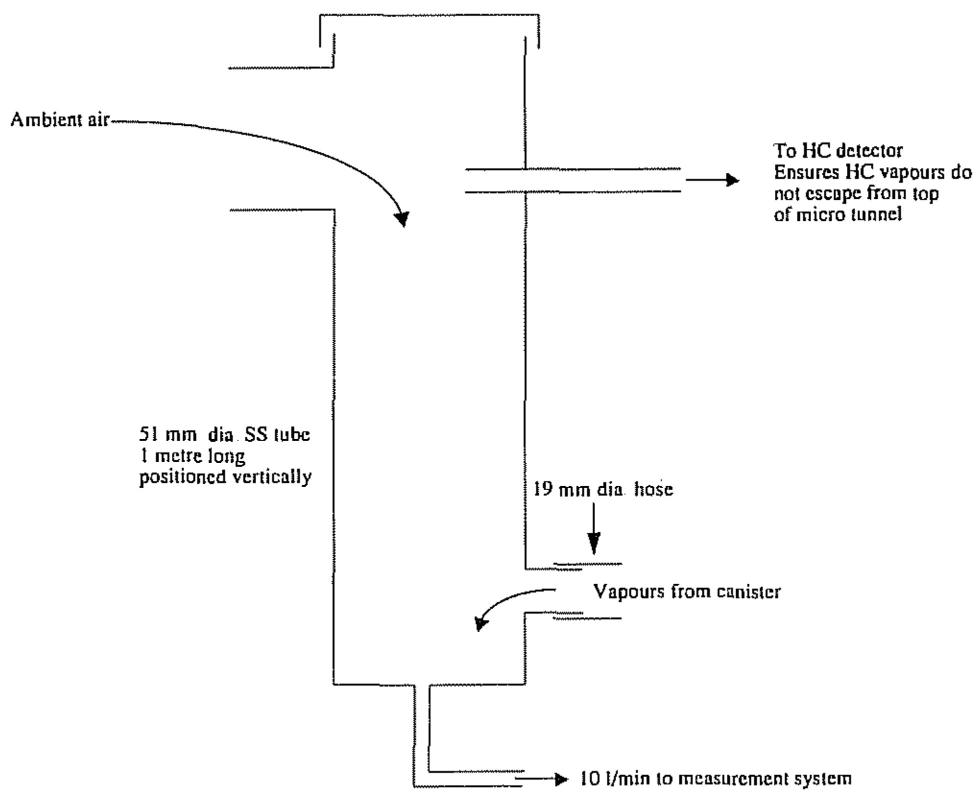
Table 16 Running losses - conditions giving increases in background air VOC

CAR A
5(ECE15 + EUDC + 15 min idle) 5(ECE15 + EUDC + 5 min hot soak)

CAR C
5(ECE15 + EUDC + 5 min hot soak) 4(90 kph/30 mins + 5 min hot soak)

Both vehicles are equipped with a control system that limits VOC charging of the canister under specific conditions.

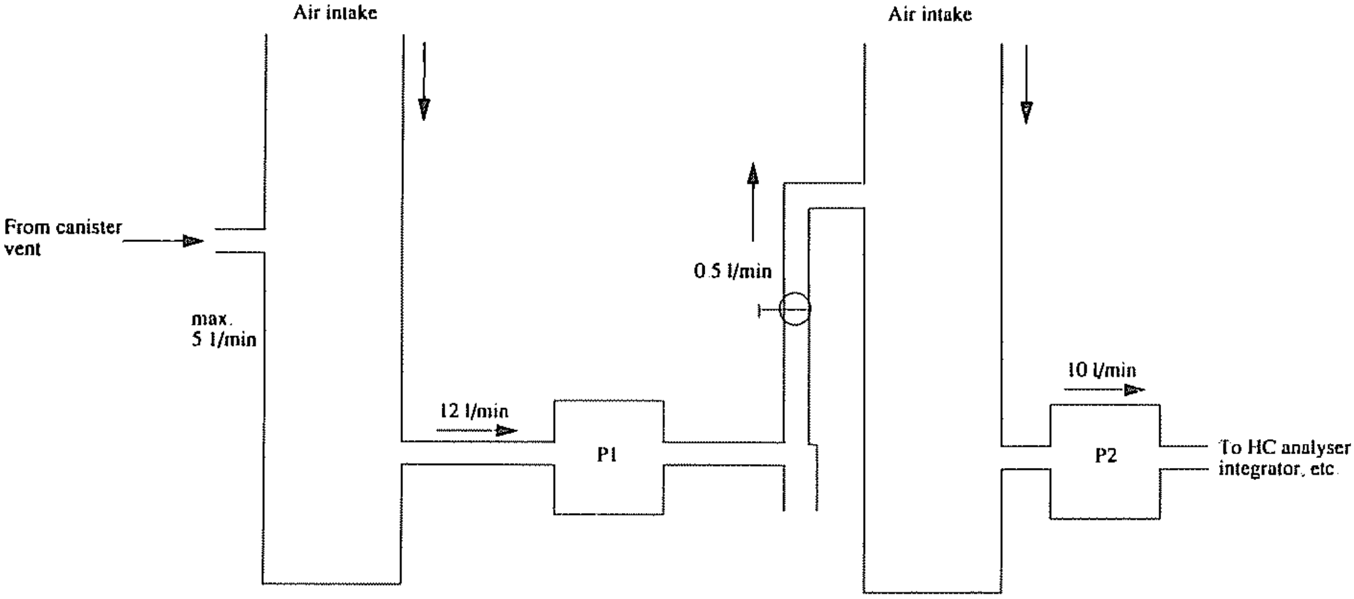
Figure 1 Running loss microtunnel (schematic)



Slow flow of air through micro tunnel transfers any vapours from canister vent to measurement system without changing pressure conditions at canister vent

HC = hydrocarbon

Figure 2 Running loss dual microtunnel



HC = hydrocarbon

Figure 3 Schematic diagram of apparatus used to load carbon canister to breakthrough

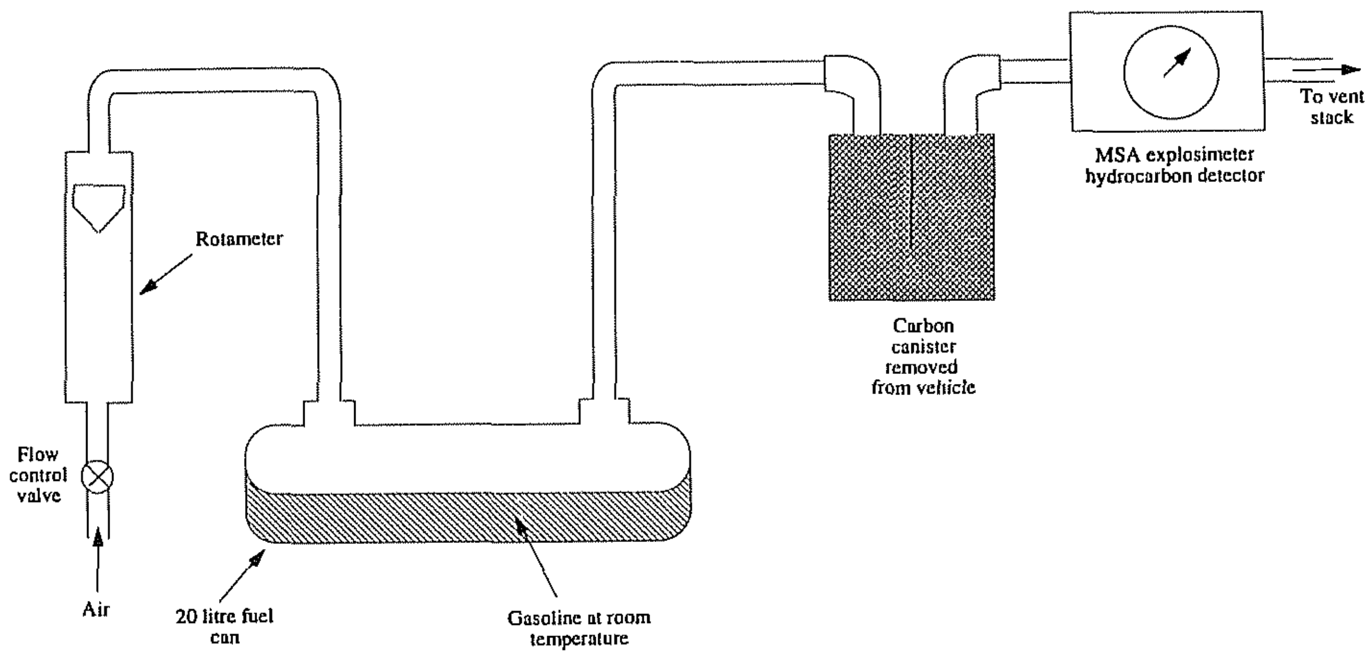


Figure 4 Effect of drive cycle or canister weight

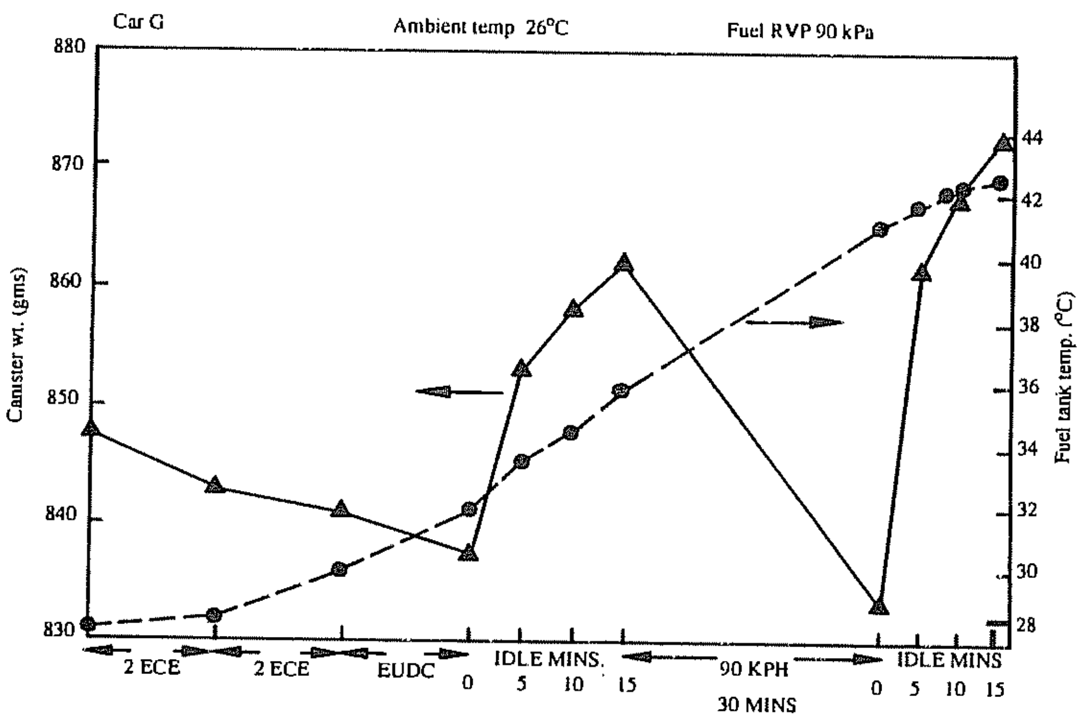


Figure 5 Standard test cycle: 5(ECE 15 + EUDC + 15 min idle)

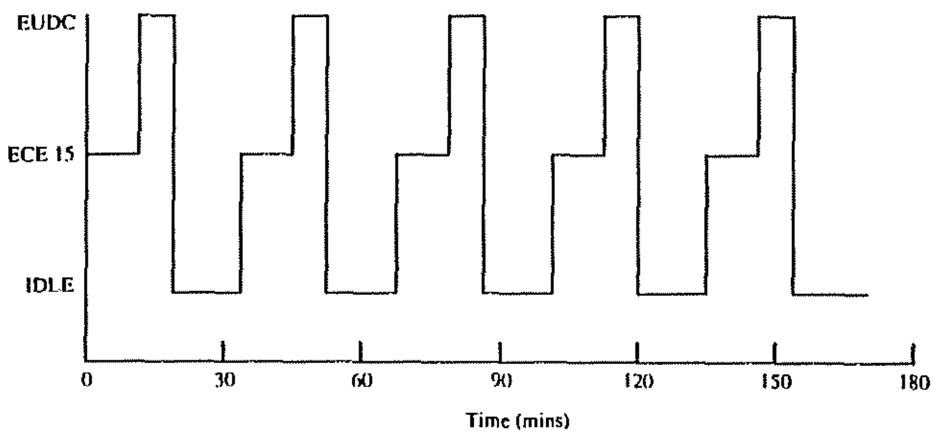
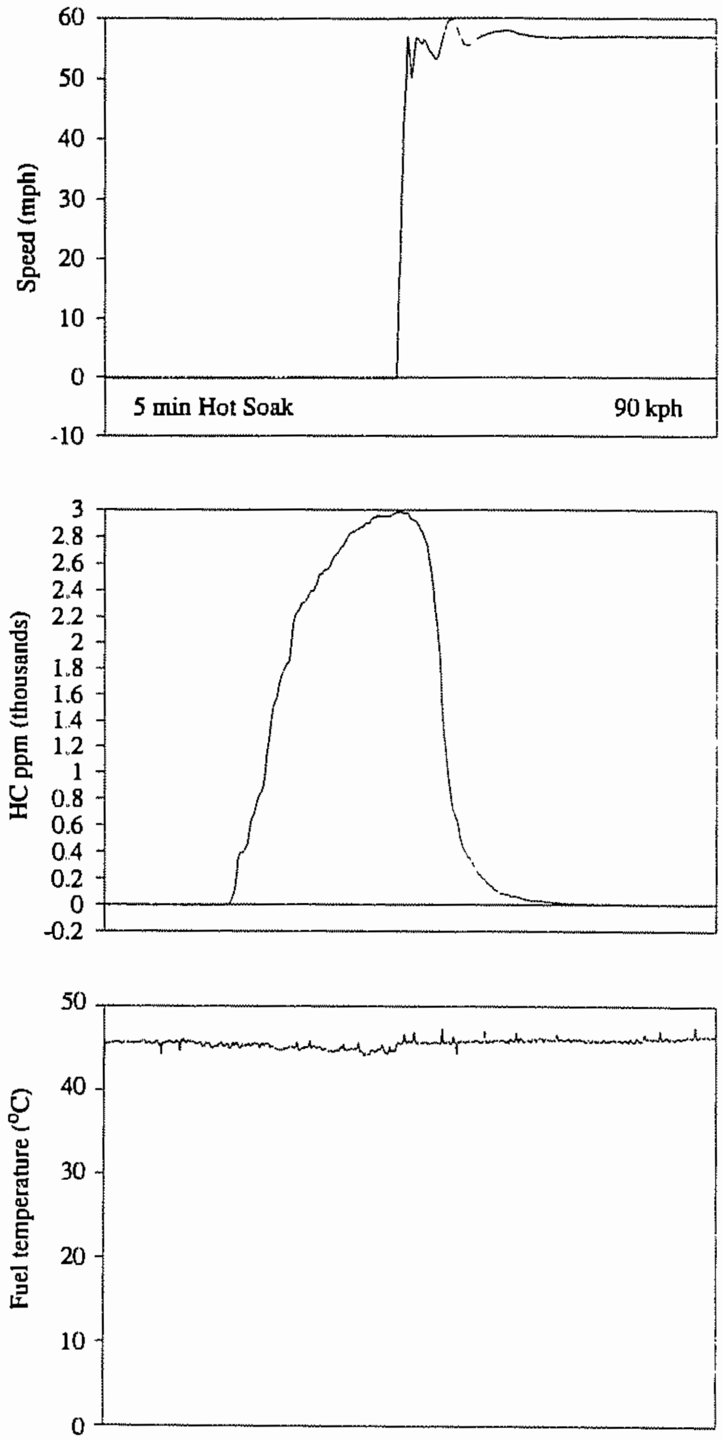


Figure 6 Snapshot from running loss test for Car D during repeated (90 kph for 30 mins + 5 mins hot soak)



N.B. Losses observed during hot soak were reduced when purging was activated in the 90 kph sector, despite increasing fuel temperature

Figure 7 Effect of ambient temperature on running losses in standard test cycle - Car C

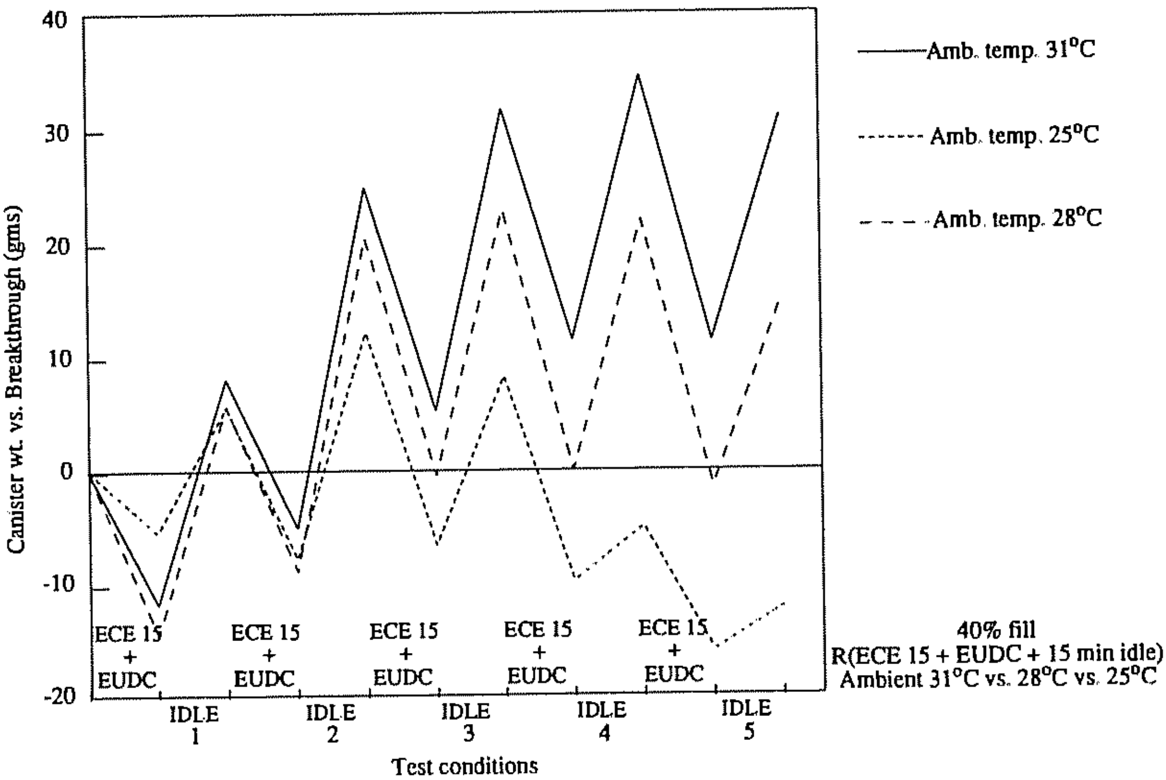


Figure 8 Effect of idling period for ECE 15 + EUDC driving element - Car F

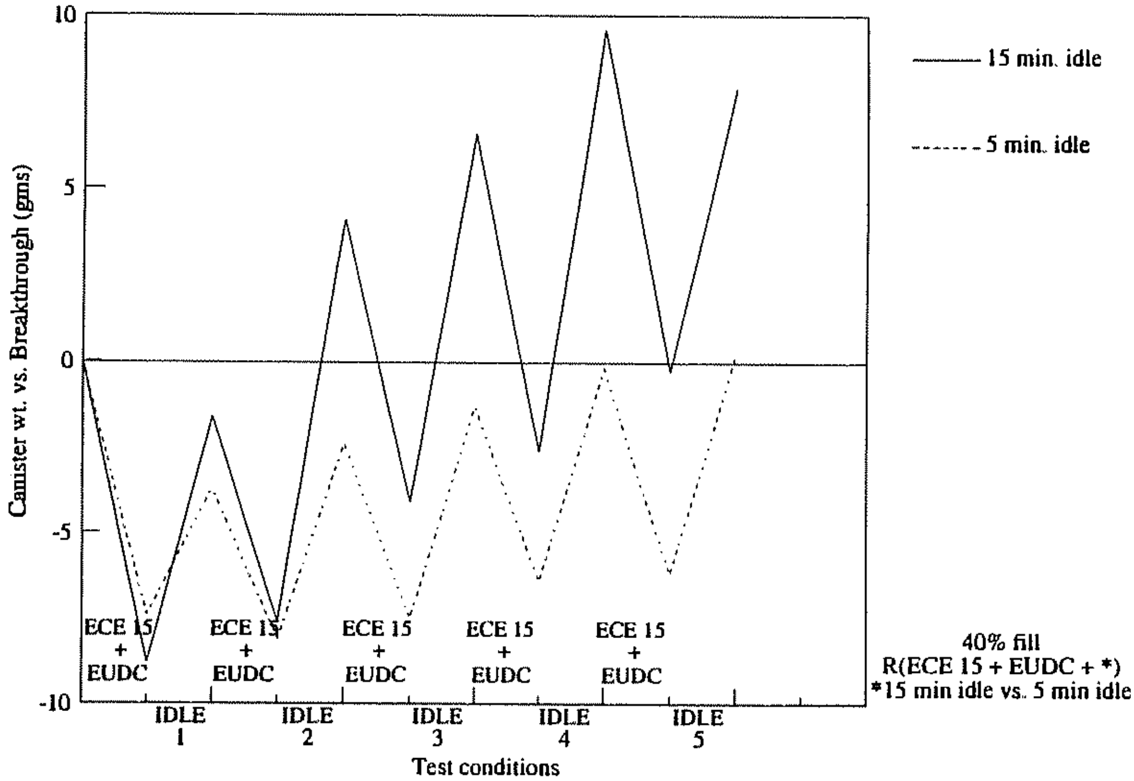


Figure 9 Comparison of idle and hot soak for ECE 15 + EUDC driving element - Car E

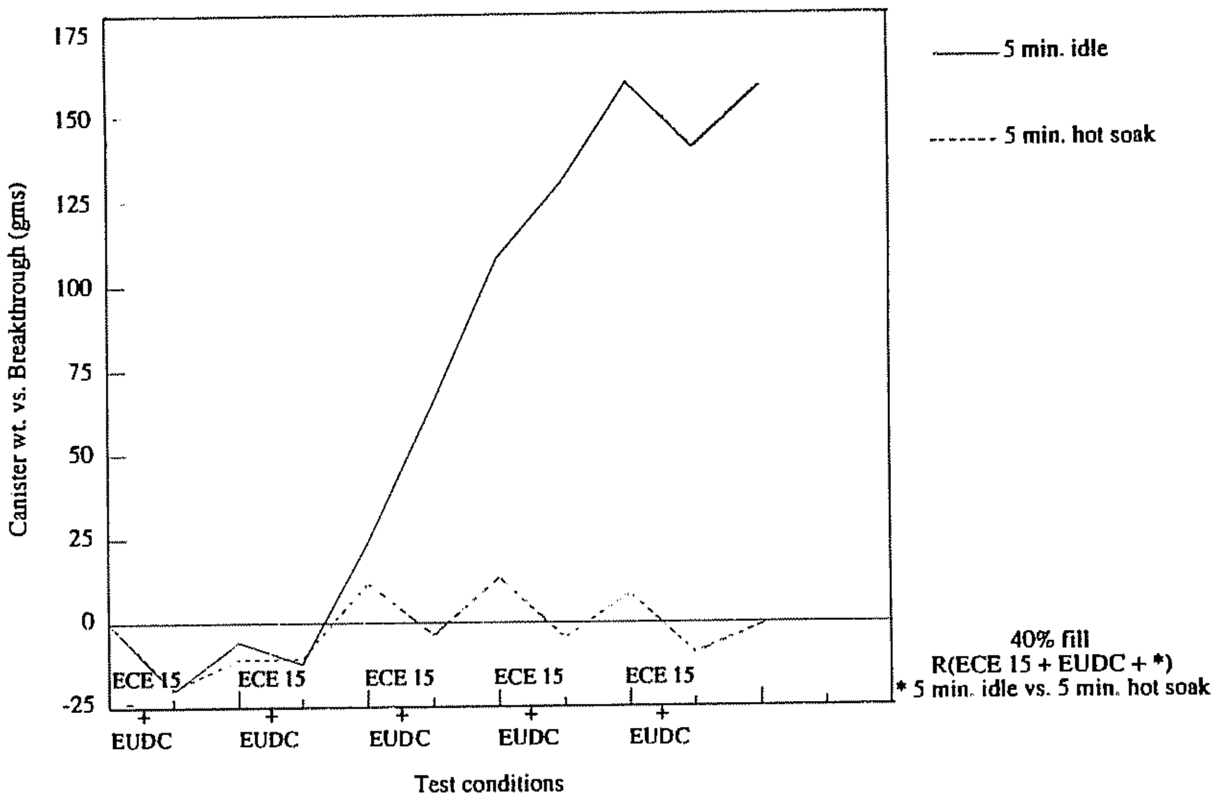


Figure 10 Comparison of 90 kph driving element with ECE 15 + EUDC for hot soak conditions - Car E

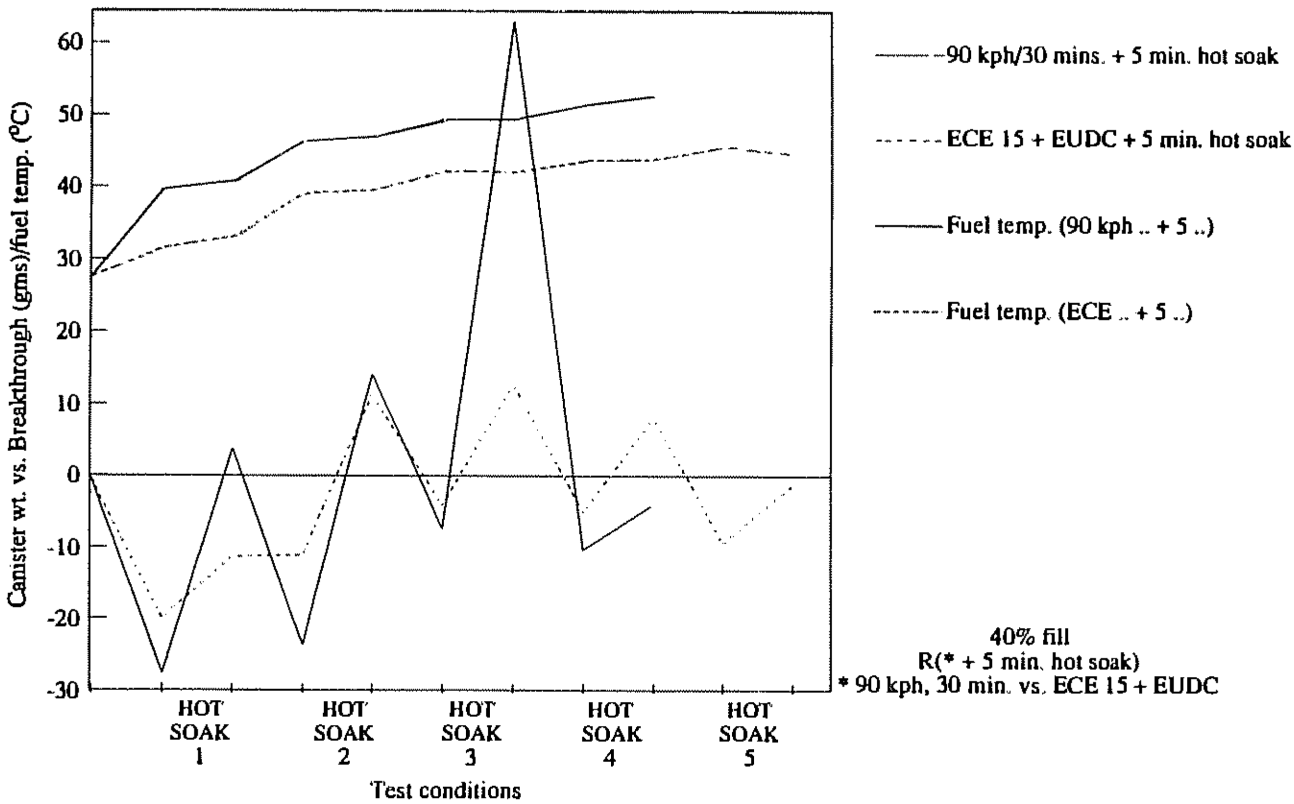


Figure 11 (a) Comparison of 90 kph driving element with ECE 15 + EUDC for hot soak conditions - Car C

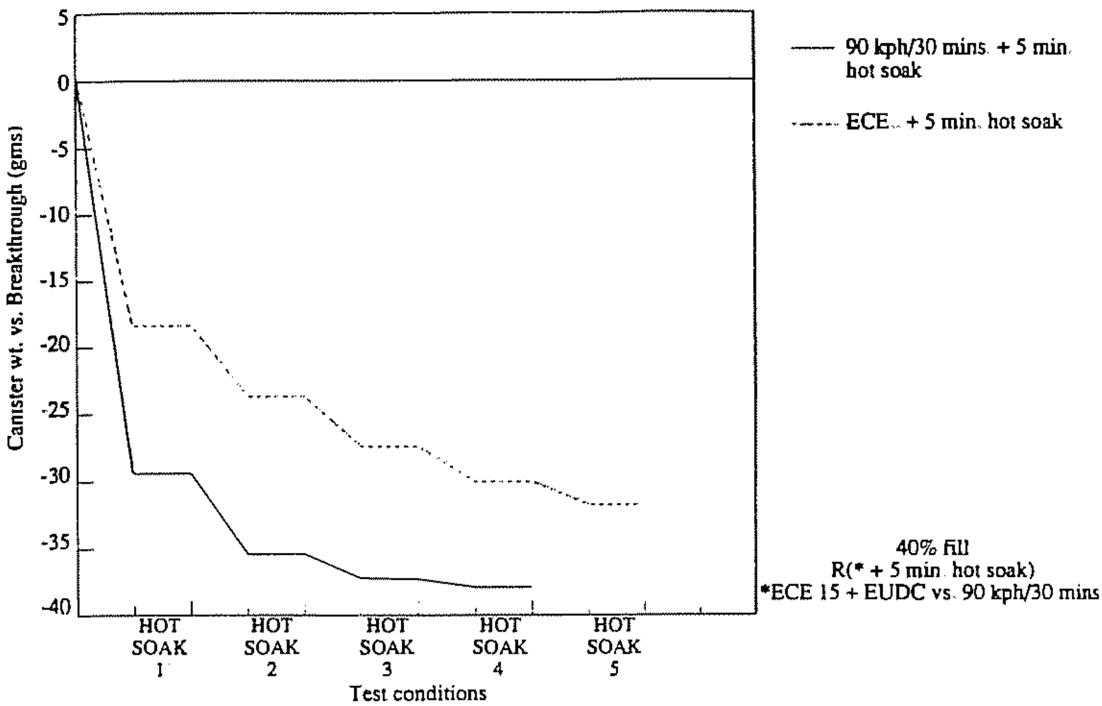


Figure 11 (b) Comparison of 90 kph driving element with ECE 15 + EUDC for hot soak conditions - Car A

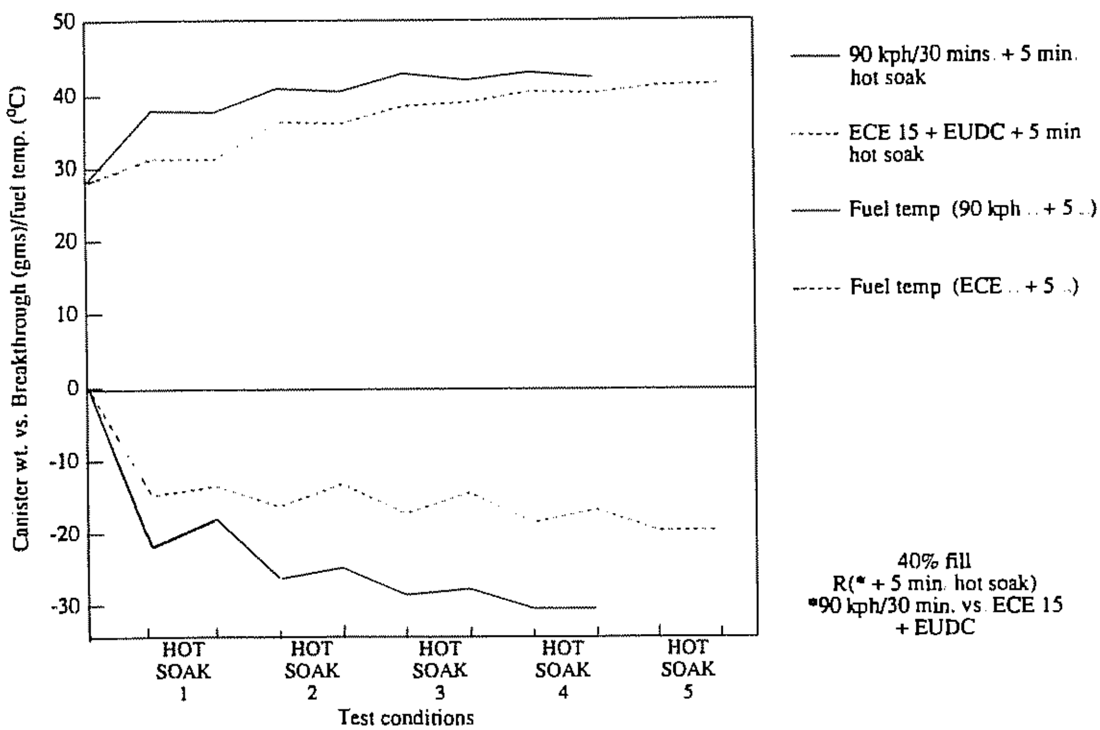


Figure 12 Effect of 40% fill versus 90% fill for standard test conditions - Car B

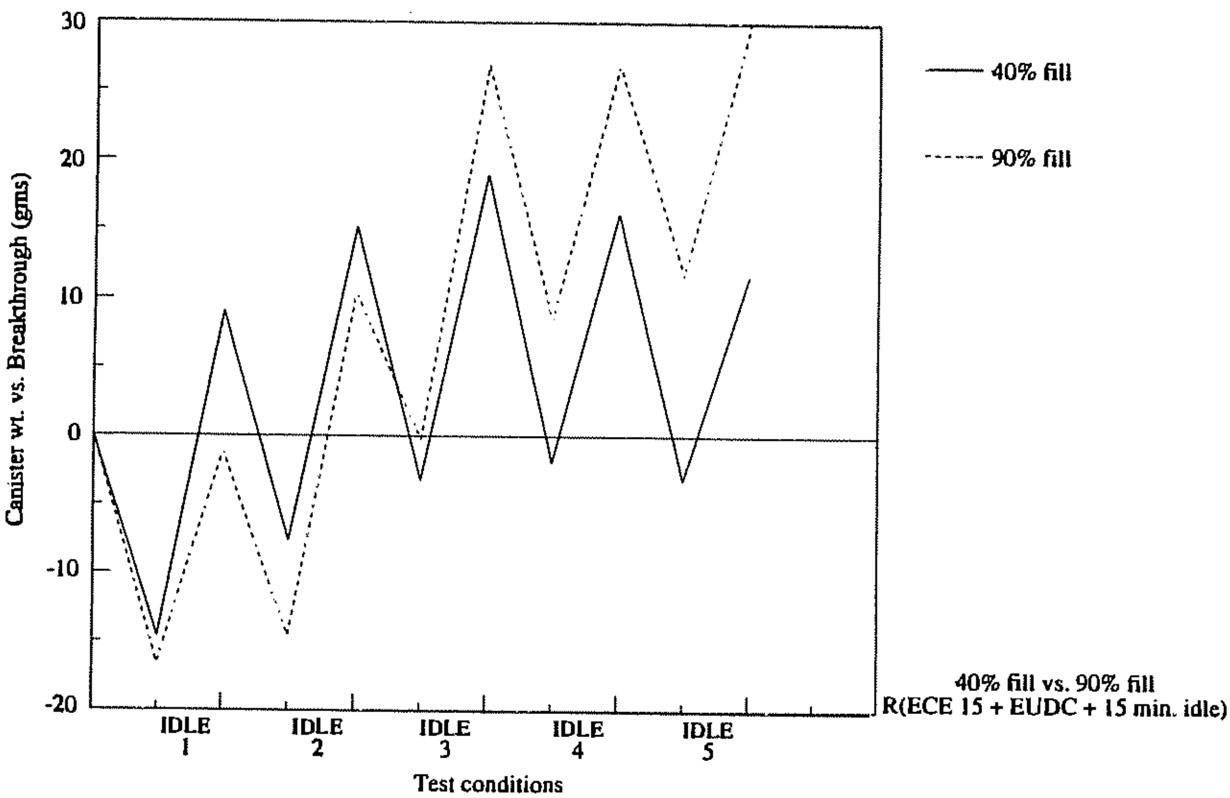


Figure 13 Effect of 40% fill versus 90% fill for standard test conditions - Car F

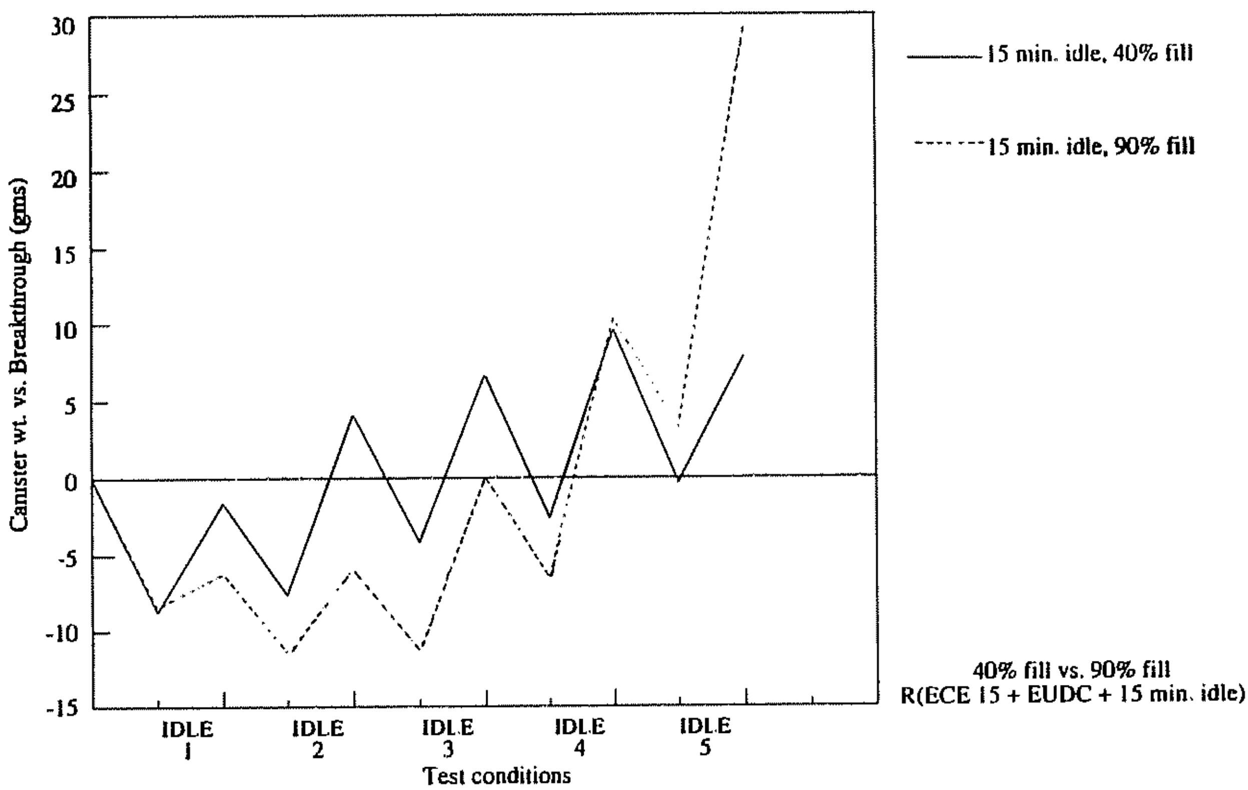


Figure 14 Carbon canister purge rates