MOTOR VEHICLE POLLUTION IN AUSTRALIA

Supplementary Report No. 2

Petrol Volatility Project

prepared by the

Environment Protection Authority of Victoria

for

Environment Australia

&

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To all of you, our sincere thanks.

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Contents

EXECUTIVE SUMMARY

GLOSSARY

Page

MAIN REPORT

APPENDICES (ARE ON SEPARATE DOCUMENTS)

Appendix I	Contributors and Contractors
Appendix II	Managing Authority and Phases of the Project
Appendix III	Evaporative Emissions Control System
Appendix IV	Testing Phase Detail
Appendix V	Vehicle and Fuel Specifications

LIST OF FIGURES AND TABLES

FIGURES

TABLES

EXECUTIVE SUMMARY

INTRODUCTION

Motor vehicle usage contributes significantly to the presence of volatile organic compounds (VOC) and oxides of nitrogen (NOx) in urban airsheds. These substances react chemically in conducive meteorological conditions and this reaction can lead to the formation of photochemical oxidant, commonly known as "photochemical smog". Although there is evidence of some improvement in the incidence of photochemical smog as various control strategies take effect, it is reasonable to expect that it will remain an issue in Australia's urban areas as vehicle usage continues to grow.

The Federal Office of Road Safety (FORS) National In-service Vehicle Emissions Study (NISE Study) raised a number of serious concerns about "real world" levels of evaporative emissions from motor vehicles. Evaporative emissions are hydrocarbon vapours which emanate from a motor vehicle as a result of evaporated fuel and oil. The concerns raised by the NISE Study related both to the volatility of commercial fuel and to the durability of evaporative emission control systems fitted to cars.

METHOD AND OBJECTIVES

Environment Australia (EA) commissioned the Environment Protection Authority of Victoria (EPA (Vic)) to undertake the Petrol Volatility Project to further investigate these evaporative emission concerns raised by the NISE Study. The Federal Office of Road Safety provided overall financial and project management for the project.

The Petrol Volatility Project primarily involved a modest vehicle testing program, emissions and air quality modelling and costing assessments for both the petroleum and automotive industries. In the testing program 4 vehicles were tested using a range of fuels with different levels of volatility, and another 9 vehicles were tested before and after the installation of a new carbon canister (the carbon canister is a device fitted to the fuel system of vehicles to prevent fuel vapours being emitted to the atmosphere).

KEY FINDINGS

The key findings from each element of the Petrol Volatility Project are discussed below.

Volatility Component

Lowering the volatility of petrol reduced the evaporative emissions from the four vehicles tested. The relationship was not linear, rather there was a tailoring off in the magnitude of this effect as the fuel approached the lowest volatility. The greatest reduction in evaporative emissions for successive drops in volatility occurred between the baseline (highest volatility) fuels (74kPa for leaded, 77kPa for unleaded) and the next most volatile fuel (70kPa). On average, this reduction was of the order of 45%.

The effect of lowering petrol volatility was marked for the diurnal breathing loss phase for three of the four vehicles tested. For these vehicles, the diurnal breathing loss results contributed the higher proportion to the total evaporative emission results. The hot soak results for these three vehicles were not affected by changes in volatility. One pre-1986 vehicle did not follow these results. The hot soak result was the component that responded to changes in volatility and was larger than the diurnal results.

All vehicles were able to show compliance with their respective Australian Design Rule (ADR) evaporative emission limit when tested on the lowest volatility petrol. These fuels were close in Reid Vapour Pressure (RVP) specification to that of the ADR certification test fuels. It was encouraging that these vehicles were capable of meeting their original design requirements despite the passage of time.

Exhaust emissions and fuel consumption were not noticeably affected by the changes to petrol volatility.

Canister Component

Replacing the carbon canister led to a decrease in evaporative emissions for seven of the nine vehicles tested for this component. On average, this decrease was of the order of 55% for the seven vehicles. Two vehicles had extremely high evaporative emission results, consistent with a system fault, and did not show appreciable reductions with canister replacement.

The new canisters were not conditioned through a controlled load and unload cycle in this project. Consequently, the results represent a conservative or ‘best case’ benefit that can be achieved in replacing a canister. It was not possible to estimate the durability of this benefit.

One of the test vehicles had had a canister replaced during the NISE study. There had been approximately two years between the NISE study and testing for this project. The results were almost identical in both instances.

The net benefit (in grams) in evaporative emissions from replacing the carbon canisters on seven of the test vehicles is summarised in Figure 1 (below). The two leaded vehicles that had system faults are not included in this figure.

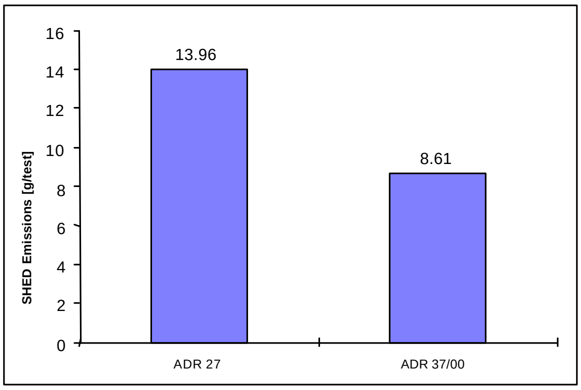


Figure 1 **Total SHED Emissions Saved by the Replacement of Canisters**

For the two leaded vehicles that gave results consistent with a fault, one vehicle's fuel filler neck was found to be leaking. The fault with the other vehicle could not be isolated. These vehicles gave disproportionately high evaporative emission results and replacing the canister had no appreciable effect on evaporative emissions. To realise any air quality benefits from a canister replacement program, vehicles with faulty evaporative system components should be identified. It is recognised that the identification of vehicles with such faults would be difficult in practice.

Carbon Iso-therm Testing

None of the canisters showed significant mechanical degradation or weathering of their carbon granules over time.

It was estimated that fresh carbon could adsorb about 35% by weight of hydrocarbons. Carbon from the old canisters were found to have significant amounts of adsorbed material ranging from 5.4% to 25.7% by weight with an average value of 16.4%. The capacity to adsorb hydrocarbons of these canisters was thus diminished. The presence of adsorbed hydrocarbons reduced the capacity for further adsorption in an approximately proportional manner. Removal of such hydrocarbons by purging restored the adsorptive capacity also in a proportional manner. Carbon canisters can thus be rejuvenated through adequate purging.

Analysis of the unpurgeable material recovered by solvent extraction was shown to consist mainly of C_9 to C_{11} hydrocarbons, 30 - 40% of which was aromatic in nature. The experiments also allowed measurement of the rates of desorption of butane, hexane and benzene. These became slower the less volatile the adsorbate. It is suggested that these heavier end hydrocarbons will not be fully desorbed in the purge time available to an urban motor vehicle. Under these circumstances there would be a slow build up of the heavy ends on the carbon of canisters.

Inventory Modelling

The inventory modelling used the existing motor vehicle inputs for the inventory model of the South East Queensland Region (SEQR) rather than the experimental results from this modest test program.

Two "day specific" scenarios were modelled, an average summer day (20-31^{o}C) and a high oxidant day (20-37^{o}C), using Reid Vapour Pressure (RVP) fuel of 63.5 and 68.5 kPa. The existing motor vehicle evaporative volatile organic compounds (VOC) emissions inventory of SEQR was based on a fuel RVP of 73.5 kPa. The results of the inventory modelling estimated the total magnitude of the evaporative motor vehicle emissions for varying RVP. The reduction in total fleet emission (exhaust and evaporative) was 12% and 17% from a RVP of 73.5 kPa to 68.5 and 63.5 kPa respectively for a summer day. The equivalent reduction for a high oxidant day was 8% and 15%.

Table 1-1 Impact on Total Motor Vehicle Emissions (Exhaust and Evaporative) from the Vehicle Fleet in SEQR, 1993 from changes in petrol volatility

RVP kPa	Summer day (tonnes/day)	High oxidant day (tonnes/day)
63.5	101	131
68.5	107	142
73.5	121	154

Replacement of 50% of the carbon canisters on the Brisbane vehicle fleet was estimated to produce a reduction in evaporative emissions of 24 % for both the summer and high oxidant day with a fuel RVP of 73.5 kPa. The reduction in total vehicle emission (exhaust and evaporative) was 11 % and 13 % for a summer and high oxidant day respectively.

Table 1-2 Total Motor Vehicle Emission (Exhaust and Evaporative) from the Vehicle Fleet in SEQR, 1993 from replacement of canisters (50%)

Canister Action	Summer day (tonnes/day)	High oxidant day (tonnes/day)
No replacement	121	154
50% Replacement	108	134

Photochemical Smog Modelling

The photochemical smog modelling exercise took as its input the inventory modelling results (refer above). The base case or 'status quo' for this modelling used a fuel RVP of 73.5 kPa and a "high oxidant day" scenario. To estimate the effect of reducing petrol volatility, the base case model results were compared to the model results obtained using the estimated emissions inventory for a 63.5 kPa fuel. Coupling the high oxidant day scenario with the lowest RVP fuel was likely to illustrate the greatest reduction in peak ozone concentrations. A separate photochemical smog modelling exercise was not undertaken for the canister replacement component because the percentage change to total motor vehicle VOC emissions (13%) accorded with that of the percentage change for the reduction in fuel volatility from 73.5 kPa to 63.5 kPa (15%). Thus the modelling exercise undertaken would be appropriate for both the volatility and canister components.

The modelling results suggest that a reduction of evaporative emissions in reducing the RVP of fuel from 73.5 kPa to 63.5 kPa would lead to a 2-6% reduction in peak ozone concentrations. The maximum reductions were found to occur early in the development of the photochemical smog plume, where smog production is most sensitive to the concentration and reactivity of the VOC's. However, peak ozone concentrations present in the airshed later in the day, were not predicted to change significantly.

These results suggest that for the modelled conditions, the RVP reduction or canister replacement strategies will result in reductions to the peak concentrations of photochemical smog of the order of 2-6%. This reduction represents a less than proportional response if the peak ozone concentrations are assumed to develop primarily from a motor vehicle dominated anthropogenic source. The existence of a significant biogenic VOC component and the possibility that peak ozone concentrations are controlled by the availability of oxides of Nitrogen (NOx) may be the principal factors responsible for reducing effectiveness of the VOC reduction strategies. However, it was cautioned that both of these factors are likely to be enhanced in SEQR by the presence of high ambient temperatures and solar radiation flux.

Petroleum Industry Costings

The Australian Institute of Petroleum, through its member organisations, provided estimates of costs associated with reducing the volatility (RVP) of petrol from all Australian refineries by 5 and 10 kPa from that which is currently supplied to the various marketing regions. The costs estimates were made on the basis of a reduction for a two month period (initially February and March) but with allowances for extensions to this time period.

The costs were different for each refiner, with one refiner being able to manage the reduction by increased operating costs and short term storage. Should the period be significantly extended, however, this would not be feasible. All the other refiners would require some capital investment, mostly of the order of $5 million per company, with one exception. One refinery would need to install a butamer plant to remove C4s from the pool in order to achieve the 10 kPa reduction.

The industry costs (Australian dollars), estimated by the AIP, are tabulated below:

Table 1-3 Estimated Petroleum Industry Costs associated with reducing petrol volatility by 5 and 10kPa

Capital Costs, $M		**Operating Costs, $M/y**	
- 5 kPa	**- 10 kPa**	**- 5 kPa**	**- 10 kPa**
13	255	7.1	15.9

Automotive Industry Costings

An industry survey conducted by the Federal Chamber of Automotive Industries (FCAI) gave indicative costs for replacing evaporative emission control components. The average costs are tabulated below:

Table 1-4 Canister Replacement Costs

Component/system	**5yr. old car**	**10 yr. old car**	**15 yr. old car**
canister	$ 117	$ 121	$ 80
purge system/hoses/ connections	$ 172	$ 105	$ 92
fuel fill cap	$ 31	$ 28	$ 27

The range of costs for all vehicle ages surveyed was between

- $ 36 and $ 260 for canisters;
- $ 34 and $ 635 for purge systems; and
- $ 8 and $ 49 for fuel filler caps.

Locally produced components and systems were found to be cheaper than those imported.

SUMMARY

The testing program for this project was modest and caution needs to be exercised in attempting to draw definitive conclusions. Rather the results from this project provide useful indications of trends and possibilities for further investigation. The following is a summary of the key findings (not prioritised):

1. Lowering the volatility of petrol significantly reduced the evaporative emissions of the test vehicles (by an average 45%). Most of the emission reductions are delivered by the initial reduction in the volatility of the fuel to around 70kPa with smaller benefits from further reductions.

2. When the emission reductions from lower fuel volatility in 1. are modelled in the South East Queensland Region airshed, it suggests that reductions around 12 - 17% in airshed evaporative emissions from motor vehicles are achievable.

In reducing the fuel volatility, producers and suppliers of petrol will need to consider vehicle drivability. Although drivability aspects of fuel composition were raised during the project they were not specifically investigated as fuel volatility is already adjusted widely throughout Australia to cope with seasonal and regional variations.

3. Reducing the volatility of petrol resulted in a 2-6% reduction to the peak concentrations of photochemical smog for the modelled conditions in the South East Queensland Region. Further modelling would be required to investigate the smog changes in other Australian cities through reductions in petrol volatility (or canister replacement).

4. The petroleum industry costs (capital and operating) associated with reducing petrol volatility are dependant on the level of reduction specified. Industry estimates that a 5kPa reduction can be addressed at a relatively modest cost ($13m capital, plus $7m pa operating) while the costs for achieving a 10kPa reduction would be much higher ($255m capital, plus $16m pa operating). Proposals to reduce the volatility of petrol would need to take account of these costs and the timeframes needed by industry to commission plant where necessary.

5. Replacing canisters lead to a significant reduction (average 55%) in evaporative emissions from the test vehicles, provided the evaporative emission control system was functionally intact. It was not possible to determine the durability of the new canisters.

6. The photochemical smog reductions attributable to replacing 50% of canisters in South East Queensland Regions was

expected to be of the same order (2-6%) as that resulting from the petrol volatility modelling.

7. The evaporative emissions from two motor vehicles whose evaporative emission control systems were not functionally intact were very high. This suggests that the identification and rectification of faulty systems should be given priority in the management of “real world” motor vehicle hydrocarbon emissions.

8. The average costs to be associated with a canister replacement proposal would be high depending on the frequency of replacement and the age of the vehicles. By way of example, the one off cost of replacing the canisters on 50% of cars on Australian roads is estimated at $545 million, compared to $255 million in capital outlay for a 10 kPa reduction in fuel volatility and $16 million per annum.

9. While the physical structure of the carbon granules within the canisters tested by CSIRO had not deteriorated over time, the uptake of heavy hydrocarbons (C_9 to C_{11}) and other contaminants reduced their absorptivity. It was suggested that these hydrocarbons would not be fully desorbed in the purge time available to an urban motor vehicle. The purge flow design features of a vehicle’s evaporative system has a determining influence on the performance of a canister. The vehicles with the lowest purge flows had the larger reductions in evaporative emissions when their canisters were replaced.

10. Regular artificial purging and servicing of carbon canisters would be an effective means of rejuvenating the adsorptive capacity of the carbon in vehicle canisters.

11. Servicing requirements for canisters vary for different manufacturers. The maintenance and upkeep of the components of evaporative emission control system, especially the carbon canister, hoses and connections, and filler cap, are important elements in reducing evaporative emissions.

12. Overfilling of petrol tanks increases the possibility of flooding canisters with liquid fuel which may permanently reduce adsorptivity of the canister. Unless a flooded canister is properly purged or replaced, the adsorptive capacity of the carbon remains greatly diminished which may result in higher in-service evaporative emissions. Although not investigated in this project, system design considerations could possibly overcome this concern. Education of motorists to discourage overfilling of tanks may also be useful.

GLOSSARY

AAA	Australian Automobile Association
ADR	Australian Design Rule
ADR27	Australian Design Rule on emissions control for Light Vehicles. For this report ADR27 incorporates 27A, 27B and 27C as well as the original ADR27.
ADR37/00	Australian Design Rule on emissions control for light vehicles for vehicles built from 1986
AIP	Australian Institute of Petroleum Ltd
CO	Carbon Monoxide - a criteria pollutant in exhaust emissions testing
EECS	Evaporative Emissions Control System
EA	Environment Australia (formerly Environment Protection Agency (Commonwealth))
EPA(VIC)	Environment Protection Authority (Victoria)
FCAI	Federal Chamber of Automotive Industries
FORS	Federal Office of Road Safety
FVI	Flexible Volatility Index
GMH	General Motors - Holden Automotive Ltd.
HC	Hydrocarbon - a criteria pollutant in the measurement of exhaust and evaporative emissions
NISE	National In-Service Vehicle Emissions Study conducted by FORS
NOx	Oxides of Nitrogen - a criteria pollutant in the measurement of exhaust emissions
NSW EPA	New South Wales Environment Protection Authority
RVP	Reid Vapour Pressure
SEQR	South East Queensland Region
SHED	Sealed Housing for Evaporative Determination
VOC	Volatile Organic Compounds

MAIN REPORT

1. INTRODUCTION

Photochemical oxidant, commonly known as "photochemical smog", is a challenging urban air pollution issue. It has been a concern for State and Federal governments, particularly over the last two decades. It remains an issue notwithstanding evidence of some improvement as various control strategies take effect.

Photochemical oxidant, of which the principal component is ozone, is a "secondary" pollutant. Ground level ozone is generated in the urban airshed by the chemical reactions in the atmosphere between volatile organic compounds (VOC) and oxides of nitrogen (NOx) , which are forced by ultra-violet radiation, in conducive meteorological conditions of air temperature and wind speed. Motor vehicle usage contributes significantly to anthropogenic emissions of VOC and NOx.

The Federal Office of Road Safety (FORS) National In-service Vehicle Emissions Study (NISE Study) raised a number of serious concerns about "real world" levels of evaporative emissions from motor vehicles. Evaporative emissions are hydrocarbon vapours which emanate from a motor vehicle as a result of evaporated fuel and oil. The NISE Study concerns related both to the volatility of commercial fuel and to the durability of evaporative emission control systems fitted to cars.

Figure 1-1 summarises the NISE study evaporative emission results. For both categories of Australian Design Rule 27 (ADR 27) and ADR 37/00 vehicles, the average evaporative emission results were well above their original certification requirements. Although both categories responded positively to tuning, the post tune results remained well above the respective limits.

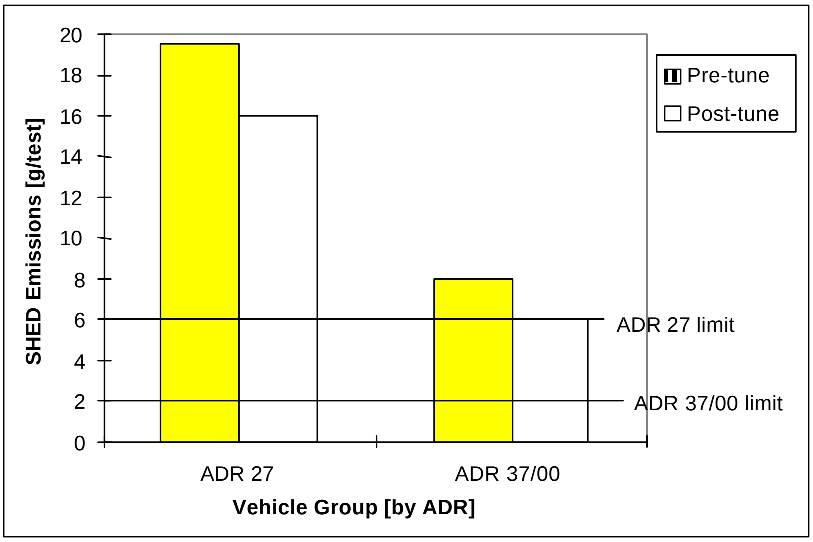


Figure 1-1 **Evaporative emissions Pre and Post tuning** [From the NISE report page viii]

Environment Australia (EA) (formerly the Commonwealth Environment Protection Agency) provided funding for the Petrol Volatility (PV) Project to further investigate the evaporative emission concerns raised by the NISE Study. In particular, to investigate the sensitivity of motor vehicle evaporative emissions to changes in petrol volatility and carbon canister performance. The Environment Protection Authority (Victoria) (EPA(VIC)) was engaged by the Federal Office of Road Safety (FORS) to undertake and manage the Petrol Volatility Project.

The PV Project complements the NISE Study by revisiting a subset of the vehicles tested and using, as baseline test fuels, the leaded and unleaded fuels in the NISE Study.

1.1 OBJECTIVES

The objectives of the Petrol Volatility project were:

1. to undertake a literature review into previously published material on motor vehicle evaporative emissions and their sensitivity to changes in fuel volatility;
2. to carry out an initial relatively small test program for evaporative emissions (ADR 37 SHED) using a range of fuels of different volatility. This is directed towards identifying the relationship between fuel volatility and evaporative emissions;
3. to make a preliminary assessment of the photochemical smog changes of nominated reductions in fuel volatility;
4. to obtain, with the assistance from the petroleum refineries via the Australian Institute of Petroleum, advice on the costs of specified changes to petrol volatility;
5. to determine the evaporative emissions from a small number of vehicles with known or suspected deteriorated carbon canisters and with the canister replaced;
6. to provide indicative information on likely performance of carbon canisters, photochemical smog consequences of deterioration and costs of regular replacement.

2. BACKGROUND

The PV Project investigated the sensitivity of motor vehicle evaporative emissions to changes in both petrol volatility (Volatility Component) and carbon canister performance (Canister Component). This investigation was undertaken using 13 vehicles previously tested as part of the NISE Study. These vehicles were tested in accordance with ADR 37/00 test procedures (with the exceptions noted below).

2.1 EVAPORATIVE EMISSIONS

The factors which influence evaporative emissions from motor vehicles are fuel volatility, ambient temperature, vehicle design and driving conditions (Morrell *et al.*, 1995). It is appropriate to categorise the evaporative emission sources as follows:

- Diurnal loss - the evaporative emissions generated from parked vehicles as a result of changes in ambient temperature (Haskew *et al.*, 1990).
- Hot soak loss - the emission of fuel vapour immediately (less than an hour after vehicle shut down) after the vehicle has been operated (Haskew *et al.*, 1990).
- Running loss - vapour which occurs while the vehicle is in use. The emissions are mainly due to the rate of fuel vapour formation exceeding the capacity of the carbon canisters to store and purge the vapour. Running loss evaporative emissions occur when the vehicle is driven irregularly, especially if it is parked for long periods of time, or when it is driven for very short trips. Typical sources of running losses include the vapour canister vent, the fuel cap and fuel tank pressure relief valves (Brooks *et al.*, 1992). Losses can also occur when warm fuel is recirculated from the engine to the fuel tank (Concawe, 1990).
- Resting loss - the evaporation due to permeation through various non-metallic fuel system components (Adamcyzyk *et al.*, 1986), design features and actual fuel leaks.

Two further sources of evaporative loss are:

- Refuelling losses - evaporative emissions caused by liquid fuel displacing vapour as vehicle tanks and petrol station tanks are refuelled and from the pump nozzles, including spills (Reddy, 1989).
- Crankcase losses - evaporative losses through the crankcase of early model vehicles without positive crankcase ventilation systems. Losses in this case occur throughout the operation of the vehicle (Morrell, *et al.* 1995).

2.2 EVAPORATIVE EMISSIONS CONTROL

Evaporative emissions are caused by the petrol vapour which escapes the vehicle before combustion. Currently evaporative emissions are managed by an evaporative emissions control system (EECS). Typically, an EECS will consist of a fuel cap, hoses and connections, carbon canister, and a purge control valve. For a diagram of a typical evaporative emissions control system used on Australian motor vehicles refer to Appendix III, Diagram A-III.1.

2.2.1 Carbon canister

The carbon canister is integral to the control of fuel vapours from the petrol tank. It is also a potential source of hydrocarbon vapours. Carbon canisters utilise activated carbon to adsorb and desorb fuel vapours. When the engine is running the “loaded carbon” is desorbed by air being drawn through the canister. This vapour laden air is introduced into the intake manifold and subsequently utilised in the engine’s combustion. It is likely that the working capacity of the carbon in the canister may decrease over time. An understanding of this would be valuable in developing strategies for the control of evaporative emissions from in-service motor vehicles.

3. AUSTRALIAN DESIGN RULES

All vehicles (except for a few pre-1974) are required, when new, to comply with an emissions performance standard. In Australia, the performance standard is called the Australian Design Rule (ADR). This standard limits the exhaust emissions of hydrocarbons (HC), oxides of nitrogen (NOx) and carbon monoxide (CO). It also sets a maximum limit for evaporative emissions of hydrocarbons. The ADR for light duty and passenger vehicles manufactured between 1976 and 1986 are covered by ADRS 27, 27A, 27B, 27C (in this report referred to simply as ADR 27). For those vehicles manufactured between 1986 and 1996 inclusive, the standard is ADR 37/00.

3.1 TEST CYCLE - EXHAUST EMISSIONS

To demonstrate compliance with the relevant ADRs, exhaust emissions are measured using a chassis dynamometer. This is capable of simulating engine load and speed conditions similar to those found in normal driving conditions.

The urban drive cycle is tightly constrained with fixed rates of acceleration and deceleration and periods of cruising and idling. This is to simulate driving in on-road conditions and is repeatable. The ADR37/00 drive cycle simulates a driving distance of approximately 17.8 km, with a maximum speed of 91.2 km/hr.

3.2 TEST CYCLE - EVAPORATIVE EMISSIONS

Evaporative emissions are measured in two phases using a sealed enclosure (**SHED** -Sealed Housing for Evaporative Determination). The first phase is the diurnal breathing loss ("heat build"). This measures the evaporative emissions caused by the controlled heating of the petrol tank that has been filled with chilled fuel. The second phase is the hot soak where the evaporative emissions are measured from a vehicle after being parked at the end of a journey. The total evaporative emissions test result (in grams) is obtained by adding the results from the two phases (Diurnal and Hot Soak results, in grams). The specification of the test fuel is defined in the ADR. ADR 37/00 low octane fuel is unleaded and represents a fuel that is on the lower end of commercially available unleaded fuel in terms of Reid Vapour Pressure (RVP). It is an artificial fuel not commercially available in Australia.

3.3 AUSTRALIAN DESIGN RULES

Motor vehicles tested in this study came from two ADR categories. Motor vehicles with build dates pre-1986 were designed to meet the ADR 27 standard and operate using leaded petrol. Those made from-1986 were designed to meet the ADR 37/00 standard and use unleaded petrol.

Table 3-1 details the emission limits for ADR 27 and ADR 37/00 category vehicles.

Table 3-1 ADR emissions limits (adapted from the NISE report)

Standard	HC (g/km)	CO (g/km)	NOx (g/km)	Evap (g/test)
ADR 27 *	2.1	24.2	1.9	6.0**
ADR 37/00	0.93	9.3	1.93	2.0
ADR 37/01 ***	0.26	2.1	0.63	2.0

* From 1/7/76 only (test between 1/1/74 and 30/6/76 was based on UN ECE R15 and cannot easily be correlated with FTP test protocol)
** From 1/1/82 only (different test method prior to that date)
*** Phased in from 1/1/97

4. STUDY OUTLINE

4.1 SCOPE

The PV Project involved undertaking a literature review, a modest test program of evaporative emissions testing of 13 privately owned vehicles (4 vehicles for the volatility component and 9 vehicles for the canister component), inventory and photochemical smog modelling assessments, carbon isotherm testing, and costing assessments for both the petroleum industry and the automotive industry.

A project Steering Committee was established to guide and oversee the project. Representatives from EA, FORS, EPA (Vic), AIP, FCAI, and AAA made valuable contributions to the committee. For further details of the roles and responsibilities of the participating organisations refer to Appendix II.

4.2 PHASES OF THE PETROL VOLATILITY PROJECT

Table 4-1 below details the various phases of the PV Project. The report was delivered in March 1997 following its review by the Steering Committee members:

Table 4-1 Timetable of PV Project Phases (1996)

Task	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1. Agreement MOU	■								
2. Literature Review		■							
3. Volatility Testing			■	■					
4. Canister Testing				■	■				
5. Compiling Results					■	■	■		
6. Isotherm Test					■	■	■		
7. Modelling							■	■	■
8. Refinery Costs							■	■	■
9. Canister Rep. Costs						■	■		
10. Final Report					■	■	■	■	■

4.2.1 Agreement MOU

FORS engaged EPA(Vic) to manage and undertake the project through a Memorandum of Understanding.

4.2.2 Literature review

Almost 70 articles and reports, and 10 verbal communications, were considered as part of the literature review. The broad conclusions from the review were:

Petrol Volatility

There was consensus that reducing petrol volatility would reduce evaporative emissions. Halberstadt (1989, page 862) probably summarises it best: *'the control of fuel volatility will have an immediate positive effect upon evaporative emissions, refuelling emissions and running loss from all vehicles on the road'.*

Canister Maintenance

It proved difficult to locate research and published material on carbon canister maintenance, replacement or deterioration. Literature on controlling evaporative emissions by the use of carbon canisters primarily focused on optimum sizing and purge flow rates.

4.2.3 Volatility and Canister testing

Test Fuel

The baseline test fuels used for the PV Project were the same as those used for the NISE Study. These fuels (leaded and unleaded) were typical of pump-grade fuel. For the volatility component the NISE fuels were modified by Mobil Australia Ltd. The Flexible Volatility Index (FVI) of the respective fuels was reduced over a controlled range, which correlated to comparative changes in RVP. Lower volatility was achieved by the controlled stripping of light ends from the baseline fuels. Octane testing carried out on the most “weathered” fuels ensured that no degradation occurred in the Research Octane Number (RON) of the fuels. Appendix V contains the analysis reports for each of the fuels used in this project.

Table 4-2 summarises the target FVIs and those actually achieved through the controlled weathering process. The corresponding RVPs of the fuels are given. In this report, the RVPs have been rounded.

Table 4-2 Summary of Test Fuels Specifications

Fuel Type	Target FVI	Actual FVI	Actual RVP	Round RVP
Leaded	100	99.7	73.5	74
	95	95	69.5	70
	90	91	66.0	66
	85	85	62.5	63
Unleaded	100	102.8	76.5	77
	95	94	69.5	70
	90	91	67.2	67
	85	84	61.7	62

Vehicle Selection and Sourcing

Vehicles for this part of the project were selected by examining the records of vehicles tested by the NISE project in both the Ford Motor Co. and EPA(VIC) laboratories.

For the volatility component, vehicles with low and/or complying evaporative emission results were targeted, on the assumption that their, evaporative emission systems that were functioning correctly. The purge results from the IM240 tests from the NISE study were also factored into the evaluation of a particular vehicle's appropriateness.

For the canister component, vehicles with relatively high evaporative emissions (within 10 to 20 grams of the vehicles original certification limit) and low purge flow values were chosen. Consideration was not given to any vehicle with extremely high SHED results as these possibly indicated vehicles with faulty evaporative emission control systems that may not have been repairable in the timeframes available for this project. For the details of the vehicles selected for this project refer to Appendix V.

At the time of sourcing or pick up of all test vehicles, the filler cap was opened to check for pressure release as a quick and preliminary indication of the integrity of the evaporative control system.

Those vehicles that underwent the Canister Component were returned with a new replacement canister.

Part Replacement (Canister, Filler cap)

For the canister testing, all canisters were replaced. The replacement canisters were the manufacturer's specified part. Due to time constraints the canisters were matched in model but not in carbon type/source. One vehicle was found to have a poorly sealing filler cap (Vehicle 4) which was replaced.

Testing Sequence

The motor vehicle testing was undertaken at EPA(Vic)'s Vehicle Testing Station in Altona. The Testing Station is NATA accredited for ADR 37/00 testing and all calibration and quality assurance measures were routinely followed during this project.

Each vehicle was tested in accordance with ADR 37/00 testing procedure, with the following exceptions: a surface mounted resistance temperature detector was used, the canister was weighed after the diurnal breathing loss phase of the test, and the with differing specifications to certification test fuels were used. The baseline fuels (leaded and unleaded) were the same fuels used for the NISE Study.

Four vehicles (2 pre-1986 & 2 post-1986) were tested as part of the volatility component of the project. The first test was undertaken using the lowest volatility fuel. Successive tests were undertaken using progressively higher volatility fuel until the baseline fuels were used.

Nine vehicles (4 pre-1986 & 5 post-1986) were tested as part of the canister component of the project. The NISE Study fuels (leaded and unleaded) were used for testing in this component.

Other details which were tested in both components were:

- purge flow rate of the vehicle's EECS
- fuel cap pressure test and seal effectiveness
- canister weight before and after both the diurnal and hot soak phases of the evaporative emission test.

Diagrams A-IV.1 and A-IV.2 of Appendix IV shows the testing sequences followed in the volatility and canister components.

The following points are made in relation to the testing sequence:

- Purge flow was measured during the pre-conditioning drive using a purge flow meter, exact in specification to that used in the NISE study for the IM240 test.
- all canisters were removed from the vehicles on arrival at the testing station and artificially purged using laboratory compressed air (dried). Each canister's weight and HC concentration were measured every 15 minutes for up to 2 hours. This purging exercise was also undertaken on the

canisters at the completion of the testing sequence. This procedure gave details of canister weight and hydrocarbon loading changes. Appendix VII details the results from this purging regime.
- The canister (old or new) was weighed immediately after the heat build and hot soak phases of each evaporative emission test.

4.2.4 Compiling of Test Results

The raw data of the test results from both the volatility and canister components are presented in Appendix VI. The report was compiled using the NISE study as a structural guide. For confidentiality reasons, the test vehicles have been labelled accordingly: for the volatility component (vehicles A, B, C, D), for the canister component (vehicles 1, 2, 3, 4, 5, 6, 7, 8, 9).

4.2.5 Carbon Isotherm Testing

At the completion of emissions testing for the Canister Component, both the old and new canisters were sent to CSIRO Coal Division for carbon isotherm testing. CSIRO was engaged by EPA (Vic) to test the adsorption/desorption characteristic of the carbon in the canisters and to assess the carbon for attrition or obvious effects of ageing. For CSIRO's complete report on this work refer to Appendix VIII.

Upon arrival of the carbon canisters at CSIRO for carbon isotherm analysis, two aliquots were taken from the carbon of each canister. One aliquot was tested with a solvent to remove any build up on the carbon. The other aliquot was tested with different gasses at the two temperature levels to examine adsorptive capacity and the effect of ageing.

4.2.6 Emissions Inventory

The experimental data from the vehicle emissions tests was made available to EPA (Vic)'s Inventory Modelling Group. Rather than use the experimental data, the existing motor vehicle inputs to the South East Queensland Region (SEQR) Inventory Model were used. The experimental data did not correlate with the Reddy estimates used in the existing model for ADR 27 and ADR 37/00 vehicles. The purging of the canister used in the testing sequence would not be indicative of canister use in the "real world". If the experimental data had been used, this may have underestimated the evaporative component of the motor vehicle emissions.

Parameters and Assumptions - RVP Reductions

Two "day specific" scenarios were modelled, an average summer day and a hot (or "high oxidant") day, based on average temperature ranges for the Brisbane airshed region (defined region). The high oxidant day scenario was used as typical of days on which high levels of photochemical smog are produced.

For each day specific scenario, two RVP reductions were modelled, each of 5 kPa from the baseline RVP fuel. The baseline fuel used for EPA's Brisbane Inventory was 73.5 kPa. The NISE ULP was 76.5 kPa and the NISE LP was 73.5 kPa.

In summary, the modelling scenarios were as follows:

Fuel RVP (kPa)	**Average Summer Day**	**High Oxidant Day**
73.5 (baseline)	existing data	existing data
68.5	modelled	modelled
63.5	modelled	modelled

Parameters and Assumptions - Canister Replacement

The two day specific scenarios (average summer day and high oxidant day) were modelled and an estimate determined of the possible VOC reduction assuming a target of 50% of the <u>total</u> Brisbane fleet change canisters immediately. There is considerable uncertainty associated with this modelling exercise, not the least given the experimental results are derived from the use of new canisters (ie. non-conditioned) and hence uncertainties with the duration of the evaporative emission benefit from a new canister.

This modelling exercise involved the following (50% of fleet change canisters):

Canister Status (Fuel RVP 73.5 kPa)	**Average Summer Day**	**High Oxidant Day**
old canister	existing data	existing data
new canister-50%	modelled	modelled

4.2.7 Photochemical Smog Modelling

EPA (Vic)'s Centre for Air Quality Studies undertook the photochemical smog modelling using as its input the modified inventory files generated for the "high oxidant" day scenarios from the Inventory Modelling results (refer Inventory Modelling above).

Parameters and Assumptions - RVP reductions and Canister Replacement

A "high oxidant" day in Brisbane was modelled for photochemical smog formation using the modified inventory files. EPA (Vic)'s Brisbane model had been set up for the "high oxidant" event day (15 January 1987). The average summer day scenario was not modelled because of the significant reworking of the model this would have required. The high oxidant day is likely to highlight the greater changes as compared to the normal summer day. Caution needs to be exercised in trying to translate the results of this modelling exercise to other Australian cities. Although the high oxidant day of January is indicative of the timing of similar events in Sydney and Melbourne, the specific nature of the airsheds of these cities do not lend themselves to a direct correlation with Brisbane.

4.2.8 Assessment of Refinery Costs

The Australian Institute of Petroleum (AIP) undertook an analysis of cost implications for the refinery industry should petrol volatility be reduced.

The following considerations were taken into account in AIP's costing exercise:

- the marketing areas considered would include Brisbane, Sydney, Melbourne, Adelaide and Perth;
- the contiguous months of January and February were to be used for the timing for any reduction proposal;
- RVP reductions of 5 kPa and 10 kPa respectively were to be considered on petrol typically supplied to the above marketing areas for these months of the year;
- costings were to be in terms of capital costs and operating costs;
- the capacity, and therefore cost of national capital equipment expenditure, was to be conservatively sized to accommodate possible future extensions to the above time period;
- the length of time the industry would need to implement this strategy, should it be pursued as a policy option for air quality management.

For full details of AIP's costing exercise refer to Appendix XI.

4.2.9 Assessment of Canister Replacement

The Federal Chamber of Automotive Industries (FCAI) undertook a survey to determine the cost of replacing canisters. This was done over approximately 80% of the typical annual sales volume of new cars sold in Australia by companies. For full details of FCAI's costing survey refer to Appendix XII.

5. RESULTS

A summary of the results from the various phases of the project are presented in this chapter. The raw data and the various reports and submissions can be found in the appendices.

5.1 VOLATILITY COMPONENT

Lowering the volatility of petrol lowered the evaporative emissions from the four vehicles tested. The relationship was not linear, rather there was a tailoring off in the magnitude of this effect as the fuel approached the lowest volatility.

5.1.1 Evaporative Emission Performance

Figure 5-1 shows how the evaporative emissions of the vehicles decreased as the volatility of the fuel decreased.

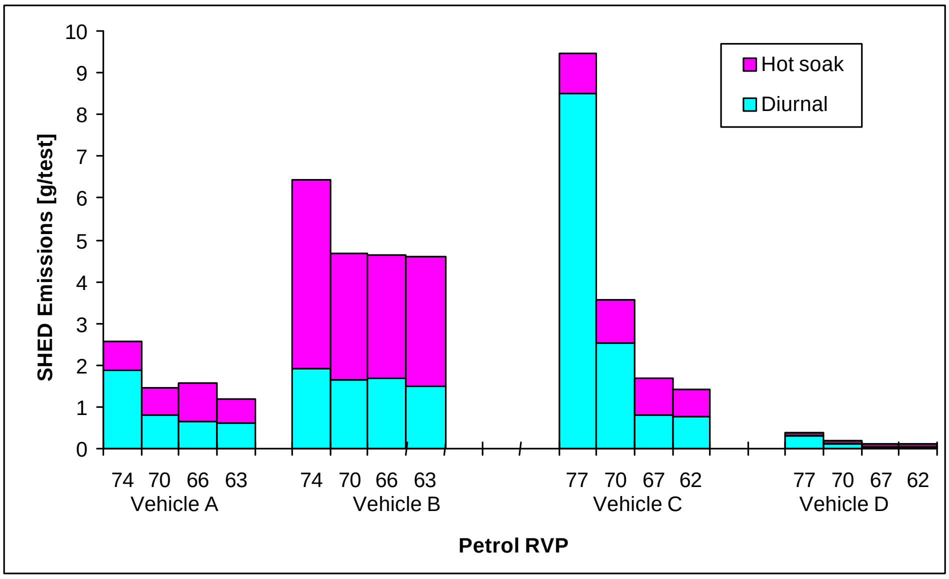
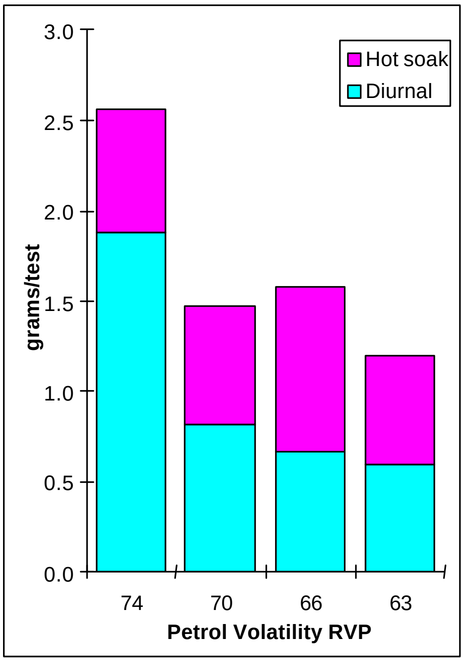


Figure 5-1 SHED emission results for the Volatility Component

For the individual vehicles the results are pictured in Figure 5-2 to Figure 5-5. [Note: for clarity, different scales are used in these four figures].



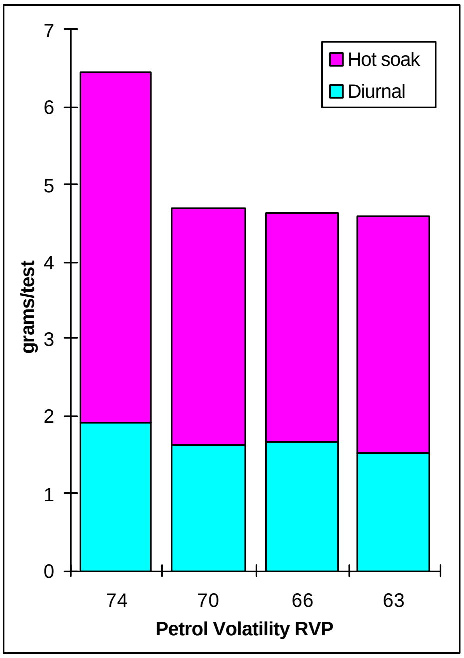
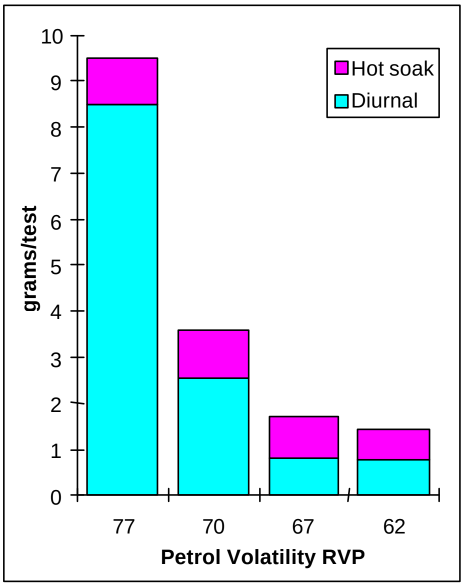


Figure 5-2 **SHED Results**
Vehicle A 1985
L (C) ADR 27

Figure 5-3 **SHED Results**
Vehicle B 1985
L (C) ADR 27



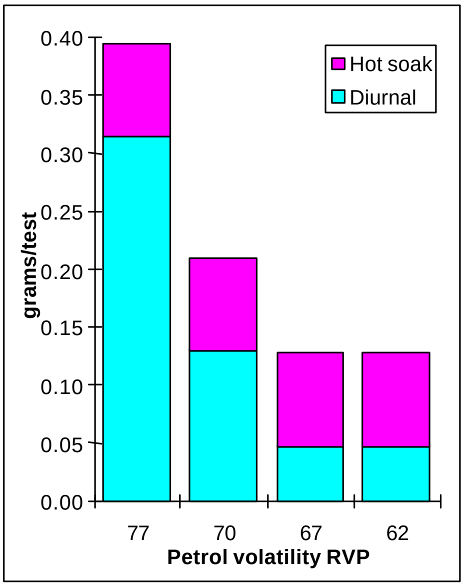


Figure 5-4 **SHED Results**
Vehicle C 1987
UL(C) ADR 37/00

Figure 5-5 **SHED Results**
Vehicle D 1989
UL (F/I) ADR 37/00

5.1.2 Canister and Engine size

The fuel tank capacity, engine size and purged canister weight are summarised for the four test vehicles in Table 5-1. It is instructive to keep these in mind when viewing the test results.

Table 5-1 Canister and Engine size

Vehicle	Model	Man. Year	Fuel Tank size (l)	Engine size(l)	Canister weight(g)
A	Toyota Corolla	1985	50	1.6	978
B	Ford Falcon	1985	53	4.1	1088
C	Mitsubishi Sigma	1987	45	2.6	524
D	Ford Laser	1989	66	1.6	724

5.1.3 Summary of Petrol Volatility Results

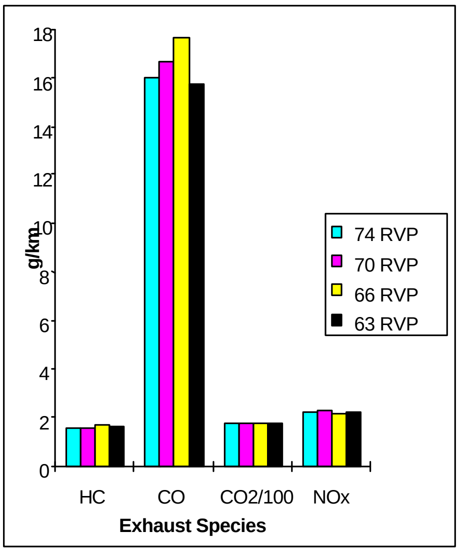
A summary of the results are presented in Table 5-2. The raw data can be found in Appendix VI.

Table 5-2 Summary table of Petrol Volatility Testing results

Vehicle	RVP	HC	CO	CO2	NOx	Fuel cons.	Diurnal	Hot Soak	Total SHED	Purge (total flow)	Sniff
		g/km				L/100km	g			l	ppm
A	**63**	1.63	15.7	177	2.2	8.9	0.60	0.60	**1.2**	>274	25
	66	1.66	17.7	174	2.1	8.9	0.67	0.92	**1.6**	>265	266
(LP)	**70**	1.58	16.6	178	2.3	9.0	0.82	0.66	**1.5**	>274	6
(1985)	**74**	1.59	16.0	177	2.2	9.0	1.88	0.68	**2.6**	>275	>3000
B	**63**	1.63	17.2	285	1.5	13.7	1.51	3.07	**4.6**	60	14
	66	1.61	16.6	284	1.5	13.6	1.70	2.94	**4.6**	33	100
(LP)	**70**	1.61	16.4	282	1.5	13.5	1.63	3.05	**4.7**	57	126
(1985)	**74**	1.56	16.4	280	1.5	13.4	1.92	4.52	**6.4**	45	1600
C	**62**	0.32	8.9	232	1.3	10.6	0.77	0.66	**1.4**	238	70
	67	0.31	9.0	231	1.3	10.6	0.80	0.90	**1.7**	256	>1000
(ULP)	**70**	0.32	9.0	231	1.3	10.6	2.54	1.04	**3.6**	256	>3000
(1987)	**77**	0.32	8.4	231	1.3	10.6	8.50	0.99	**9.5**	236	>3000
D	**62**	0.24	3.6	207	1.3	9.2	0.05	0.08	**0.1**	>296	16
	67	0.25	3.7	207	1.3	9.2	0.05	0.08	**0.1**	>286	9
(ULP)	**70**	0.22	2.9	205	1.3	9.1	0.13	0.08	**0.2**	>280	233
(1989)	**77**	0.24	3.7	205	1.2	9.1	0.32	0.08	**0.4**	>289	82

5.1.4 Exhaust emissions performance

Figure 5-6 to Figure 5-9 summarise the exhaust emission results for the four vehicles tested for the Volatility Component. No trend is apparent, indicating exhaust emissions remained unchanged across the range of petrol volatilities. Carbon monoxide does exhibit the test to test variations shown below when the same test fuel is used for each test.



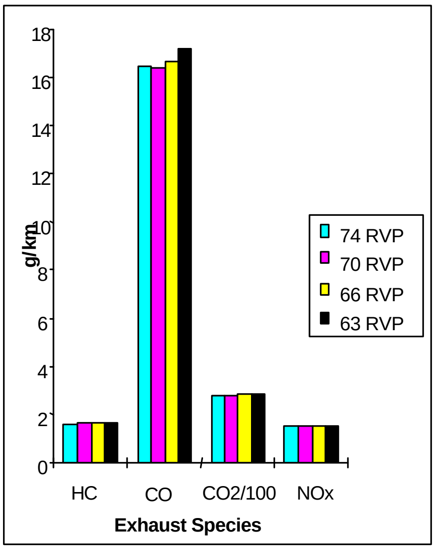
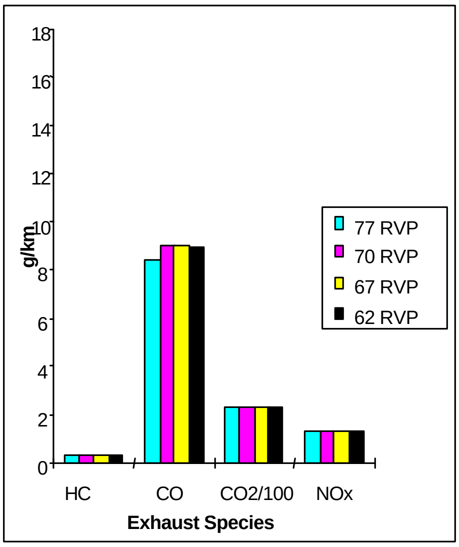


**Figure 5-6 Exhaust Results
Vehicle A 1985 L (C)
ADR 27**

**Figure 5-7 Exhaust Results
Vehicle B 1985 L (C)
ADR 27**



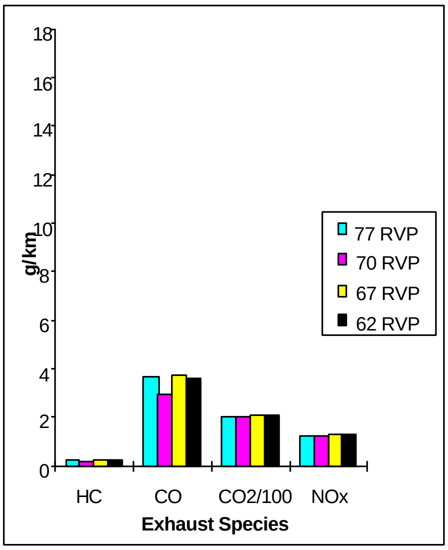


**Figure 5-8 Exhaust Results
Vehicle C 1987 UL
(C)ADR 37/00**

**Figure 5-9 Exhaust Results
Vehicle D1989 UL
(F/I) ADR 37/00**

5.1.5 Purge Flow

Figure 5-10 shows the purge flow results from the pre-condition drive using the purge flow meter (similar to that used for the IM240 test during the NISE Study). Petrol volatility changes do not effect the purge flow of the vehicles. It is interesting to note that Vehicle B's purge flow design is significantly lower than for the other three vehicles. This vehicle's hot soak diurnal results were proportionately higher than the other three vehicles.

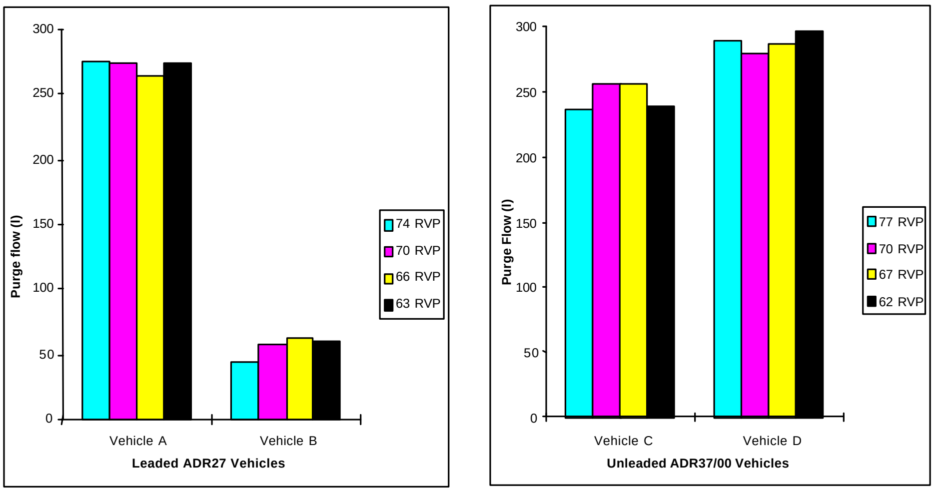


Figure 5-10 Petrol Volatility Purge Flow Results

5.1.6 *Fuel Consumption*

Figure 5-11 shows the results of fuel consumption for the four vehicles tested as part of the Volatility Component. Fuel consumption was calculated for the vehicles, despite not being an element of ADR testing. The fuel consumption figures determined do not accord with Australian Standard 2877, but have been included in this report and indicate that fuel consumption is largely unaffected by changes to petrol volatility.

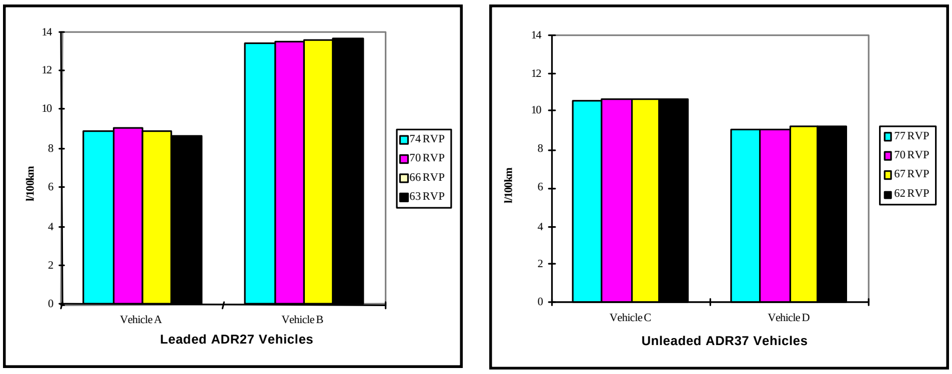


Figure 5-11 Fuel consumption results

5.1.7 *Sniff Test (Break Through)*

Three of the canisters clearly broke through (i.e. an increase of 300ppm HC or more on the sniff test). The fourth canister, vehicle D, increased emissions of hydrocarbons from 16ppm to a peak of 233ppm. This is a large increase and could be considered a breakthrough.

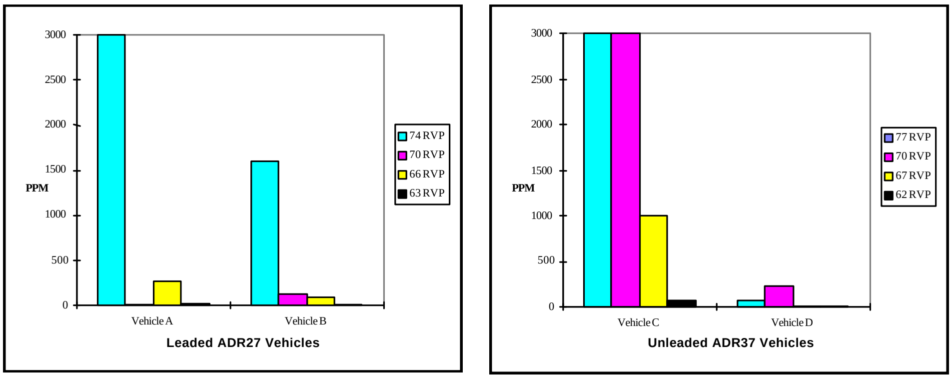


Figure 5-12 Sniff test results

5.1.8 Petrol Volatility Modelling Results

The estimated evaporative and total emissions from the motor vehicle fleet are presented in Table 5-3 and Table 5-4. The total emissions are the product of the emission factors and vehicle kilometres travelled (VKT) for the Brisbane car fleet. The VKT used was estimated by Morrell *et al.* (1995). The results show a reduction of evaporative emission on a summer day of 26% and 37 % when moving from a fuel RVP of 73.5 kPa to 68.5 and 63.5 kPa respectively. The equivalent reduction in evaporative emission of a high oxidant day was 14% and 26 %.

The exhaust emission used in the model was obtained from Morrell *et al.* (1995). It was assumed for this study that changes in fuel RVP has no effect on exhaust emissions. When considering both the exhaust and evaporative emission, the reduction from a fuel RVP of 73.5 kPa to 68.5 and 63.5 kPa were 12% and 17 % respectively for a summer day. The equivalent reduction for a high oxidant day was 8% and 15 %. Figures 5-13 and 5-14 show these results graphically.

Table 5-3 Estimated Evaporative Emissions from the Vehicle Fleet in SEQR, 1993

RVP (kPa)	Summer day (tonnes/day)	High oxidant day (tonnes/day)
63.5	34	64
68.5	40	75
73.5	54	87

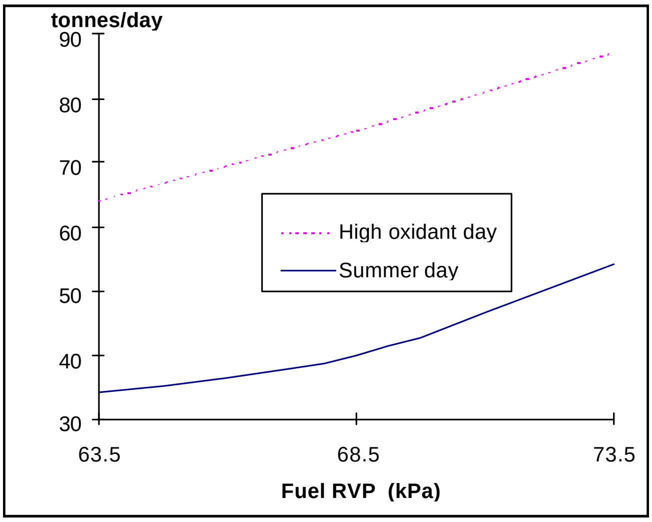


Figure 5-13 Change in SHED Emissions

Table 5-4 Total Motor Vehicle Emission (Exhaust and Evaporative) from the Vehicle Fleet in SEQR, 1993

RVP (kPa)	Summer day (tonnes/day)	High oxidant day (tonnes/day)
63.5	101	131
68.5	107	142
73.5	121	154

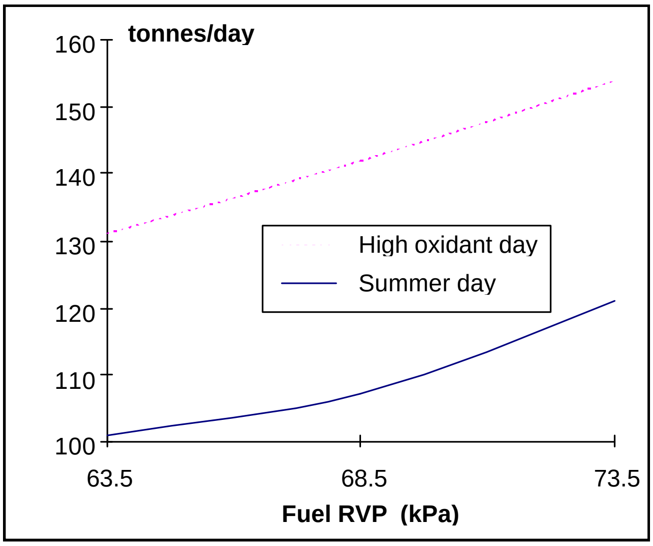


Figure 5-14 Change in Vehicle VOC Emissions

5.1.9 *Photochemical smog results*

The photochemical smog results suggest that, for the modelled conditions, a fuel volatility reduction or canister replacement strategy will result in a small reduction in peak concentrations of photochemical smog of 2-6%. This reduction represents a less than proportional response if the peak ozone concentrations are assumed to develop primarily from a motor vehicle dominated anthropogenic source. The existence of significant biogenic VOC component, and the possibility that peak ozone concentrations are controlled by the availability of NOx, may be the principal factors responsible for reducing the effectiveness of the VOC reduction strategy. However, the influence of the biogenic VOCs and the availability of NOx are likely to be exaggerated in the SEQR because of the presence of high ambient temperatures and solar radiation fluxes.

5.1.10 AIP costings

The Australian Institute of Petroleum, through its member organisations, provided estimates of costs associated with reducing the volatility (RVP) of petrol from all Australian refineries by 5 and 10 kPa from that which is currently available in the various marketing regions. The costs estimates were made on the basis of a reduction for a two month period (initially February and March) but with allowances for extensions to this time period.

The costs were somewhat different for each refiner, with one refiner being able to manage the reduction by increased operating costs and short term storage. Should the period be significantly extended, however, this would not be feasible. All the other refiners would require some capital investment, mostly of the order of $5 million per company, with one exception. One refinery would need to install a butamer plant to remove C4s from the pool in order to achieve the 10 kPa reduction.

The industry costs are tabulated below:

Table 5-5 Petroleum Industry Costs associated with reducing petrol volatility

Capital Costs $M		**Operating Costs $M/y**	
- 5 kPa	**- 10 kPa**	**- 5 kPa**	**- 10 kPa**
13	255	7.1	15.9

5.2 CANISTER COMPONENT

Replacing the canisters led to a decrease in evaporative emissions for seven of the nine vehicles tested. The two vehicles (Vehicles 1 & 4) which did not follow this trend had extremely high evaporative emission results, consistent with a system fault.

5.2.1 Evaporative Emission Performance

Replacing the canisters achieved an aggregate reduction of 13.96 grams in the three ADR 27 vehicles. Similarly, for the four ADR 37/00 vehicles, the aggregate evaporative emission reduction was 8.61 grams (Figure 5-15).

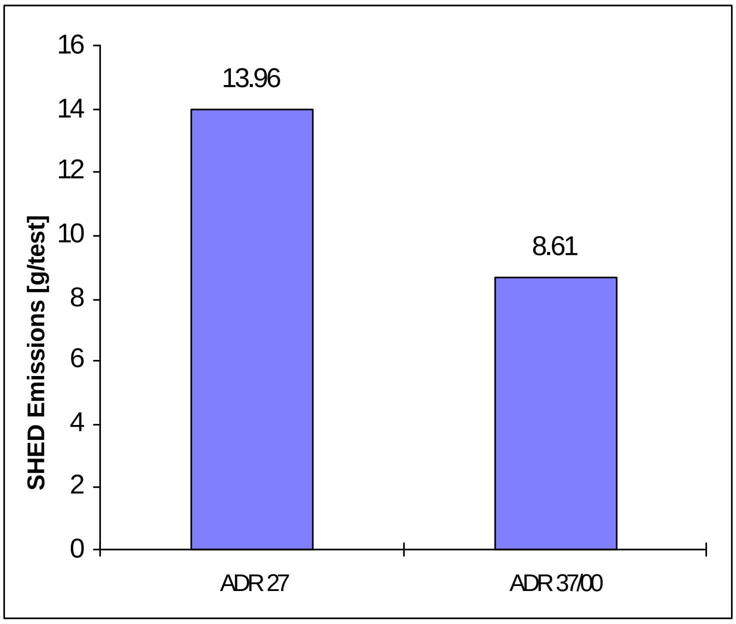


Figure 5-15 Total Evaporative Emissions saved by replacing the canister. (Vehicles 1 & 4 have been removed in generating the figures.)

Though five ADR27 vehicles were tested, only three were used in the analysis, because two of the vehicles gave uncharacteristically high evaporative results. The evaporative emissions results of all five ADR27 vehicles are shown below in Figure 5-16. The results for the ADR37/00 vehicles shown below were all used in the analysis. The results presented in Figure 5-17 clearly show that replacing the canister, in post 1986 vehicles, reduces evaporative emissions. These figures above show that the hot soak component does not change significantly.

NOTE: the differences in scale

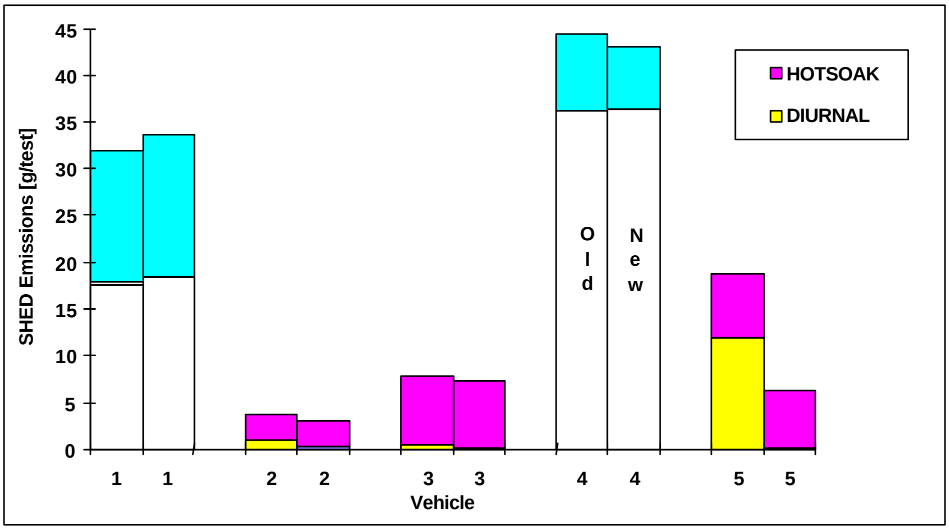


Figure 5-16 ADR27 Vehicle SHED results

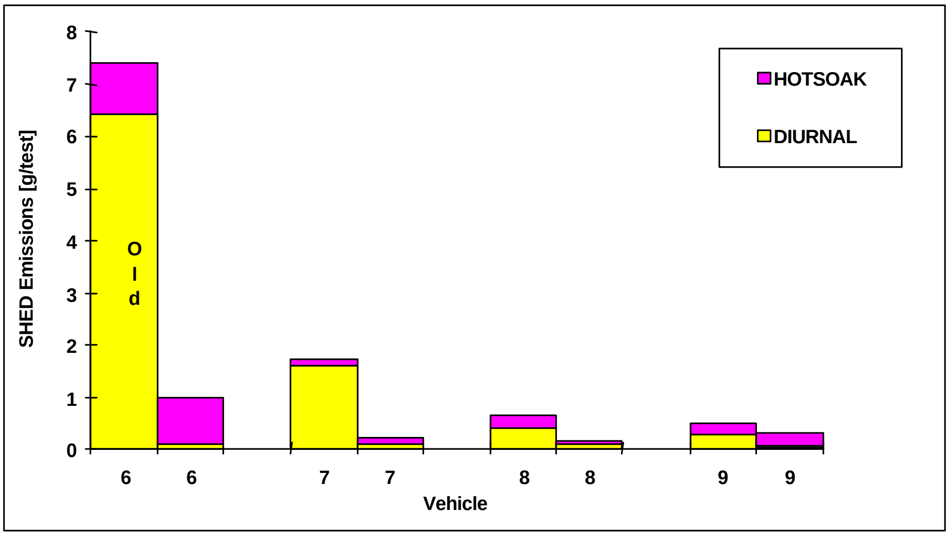


Figure 5-17 ADR 37/00 Vehicle SHED results

The exhaust, evaporative and purge flow results for all nine vehicles in the canister component summarised in Table 5.6.

Table 5-6 Canister Results Summary

VEHICLE	FUEL	YEAR	EVAP	HC	CO	CO2	NOX	Purge flow	Sniff test (ppm)
1	*LEADED*	*1980*	*31.7*	*1.3*	*10.5*	*224*	*3.1*	*207*	*283*
1	*LEADED*	*1980*	*33.7*	*1.3*	*11.7*	*220*	*3.2*	*201*	*83*
2	LEADED	1982	3.8	2.0	29.6	155	1.4	287	700
2	LEADED	1982	2.9	1.9	30.0	157	1.4	306	8
3	LEADED	1983	7.9	1.9	10.9	188	1.4	101	1000
3	LEADED	1983	7.4	1.9	10.2	183	1.4	98	5
4	*LEADED*	*1985*	*44.4*	*1.8*	*24.7*	*298*	*4.4*	*209*	*12*
4	*LEADED*	*1985*	*43.0*	*1.9*	*31.1*	*296*	*3.7*	*201*	*34*
5	LEADED	1985	18.8	1.8	15.9	169	2.2	30	2940
5	LEADED	1985	6.3	1.8	16.9	167	2.1	30	45
6	UNLEADED	1987	7.4	0.1	5.9	264	1.5	97	3000
6	UNLEADED	1987	1.0	0.2	6.6	267	1.5	110	3
7	UNLEADED	1989	1.7	0.3	3.9	285	1.1	122	300
7	UNLEADED	1989	0.2	0.3	3.6	287	1.1	132	2
8	UNLEADED	1990	0.6	0.3	5.6	264	1.6	303	3000
8	UNLEADED	1990	0.2	0.3	5.7	263	1.6	298	3
9	UNLEADED	1991	0.5	0.6	6.8	205	1.2	250	600
9	UNLEADED	1991	0.3	0.4	4.1	208	1.2	250	2

The purge flow is in litres per preconditioning drive which is 12km or 23 min

Results in italics not included in analysis

5.2.2 *Canister and Engine Size*

The vehicle make and model, year of manufacture, fuel tank capacity, engine size and canister size (old and new canister) are summarised for the nine test vehicles in Table 5-7. It is instructive to keep these design features in mind when viewing the test results.

Table 5-7 Vehicle Specifics for Canister Component

Vehicle	Model	Man. Year	Fuel Tank size (l)	Engine size (l)	Canister weight old/new (g)
1	Ford Cortina	1980	50	2.0	732/712
2	Nissan Pulsar	1982	50	1.5	570/600
3	Toyota Corolla	1983	50	1.3	856/731
4	Holden Commodore	1985	63	3.3	759/623
5	Mitsubishi Colt	1985	40	1.4	876/882
6	Mitsubishi Magna	1987	64	2.6	539/443
7	Holden Commodore	1989	68	3.8	461/406
8	Nissan Pintara	1990	60	2.0	557/564
9	Toyota Camry	1991	60	2.0	901/833

5.2.3 *Exhaust Emission Performance*

The carbon canisters were not expected to have a significant effect on exhaust emissions. Figure 5-18 below shows the difference between the exhaust emissions of the old and new canisters for vehicles 2,3,5,6,7,8 & 9. There was no consistant pattern in the results and the differences were relatively small.

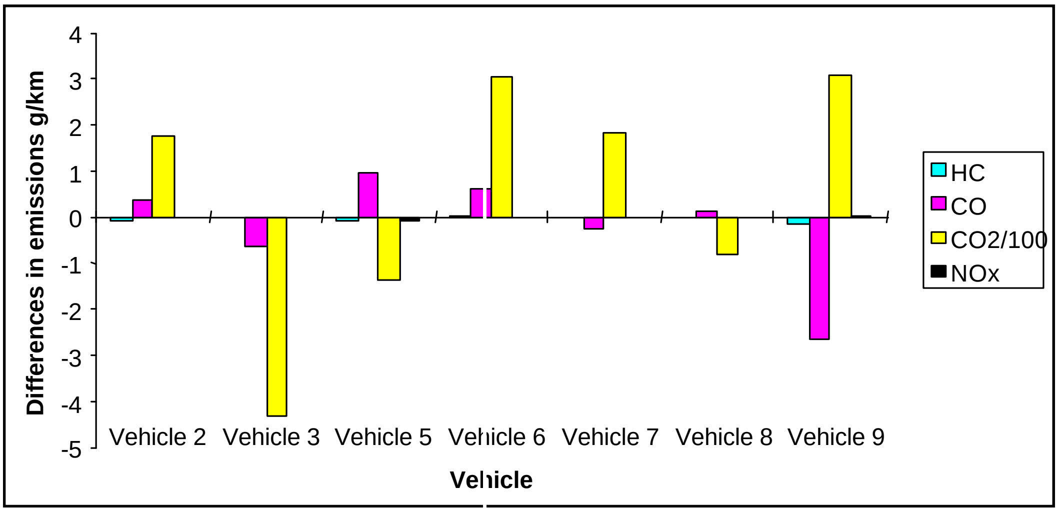


Figure 5-18 Summary of Difference in Exhaust emissions from old to new canisters

5.2.4 Purge Flow

The purge flow results shows a marked difference in canister purge flow design between vehicles. There was reasonable consistency with the old canister and new canister purge flow results, given the sensitivity of the purge flow measuring device.

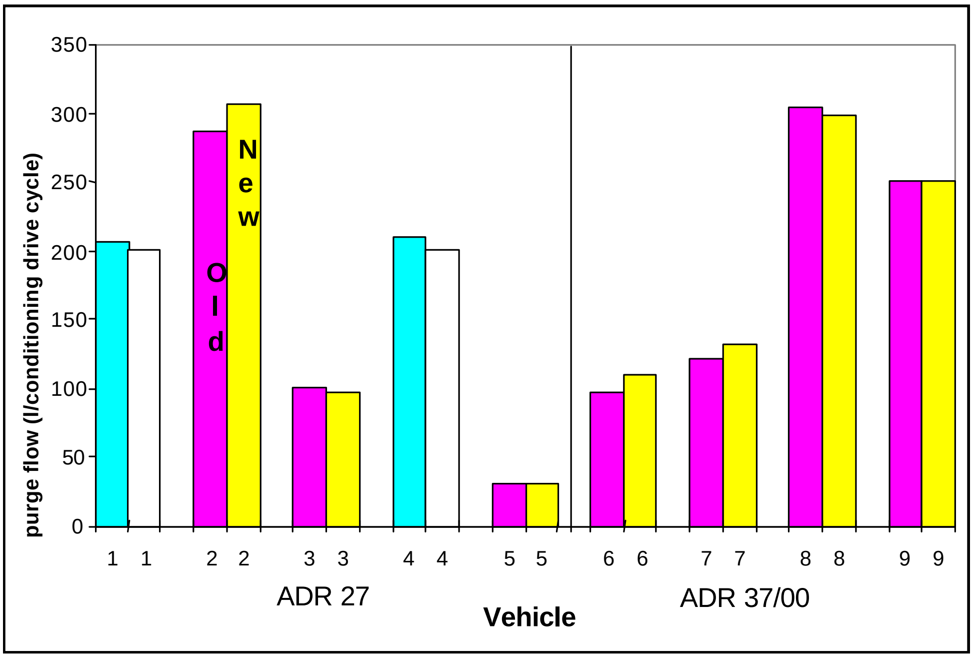


Figure 5-19 Purge flow results for the Canister tests

5.2.5 Fuel Consumption

It was not expected that canister performance would have an effect on fuel consumption. The results shown below (Figure 5-20) present a mixture of fuel consumption increases (negative values), and fuel consumption decreases (positive numbers). Overall, these results are negligible.

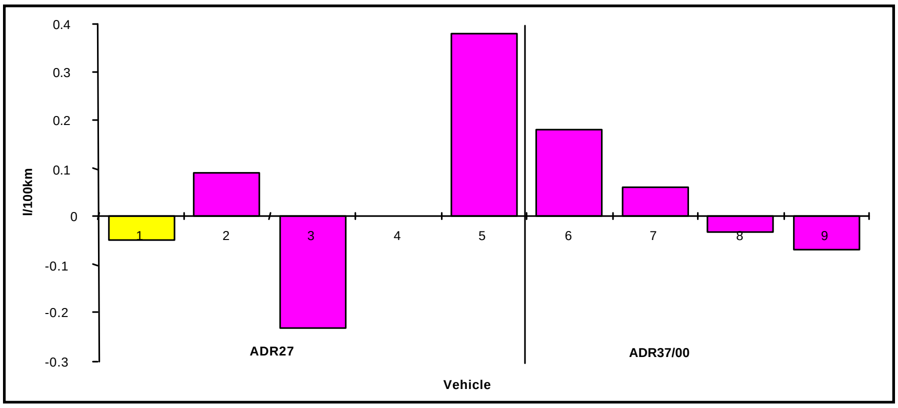


Figure 5-20 Fuel Consumption changes for the canister testing

5.2.6 Sniff Test (Break Through)

All of the original canisters broke through (ie. an increase of 300ppm HC or more on sniff test) except for Vehicle 1 & 4 canister which had system faults. Figure 5-21 compares the original and new canister performance.

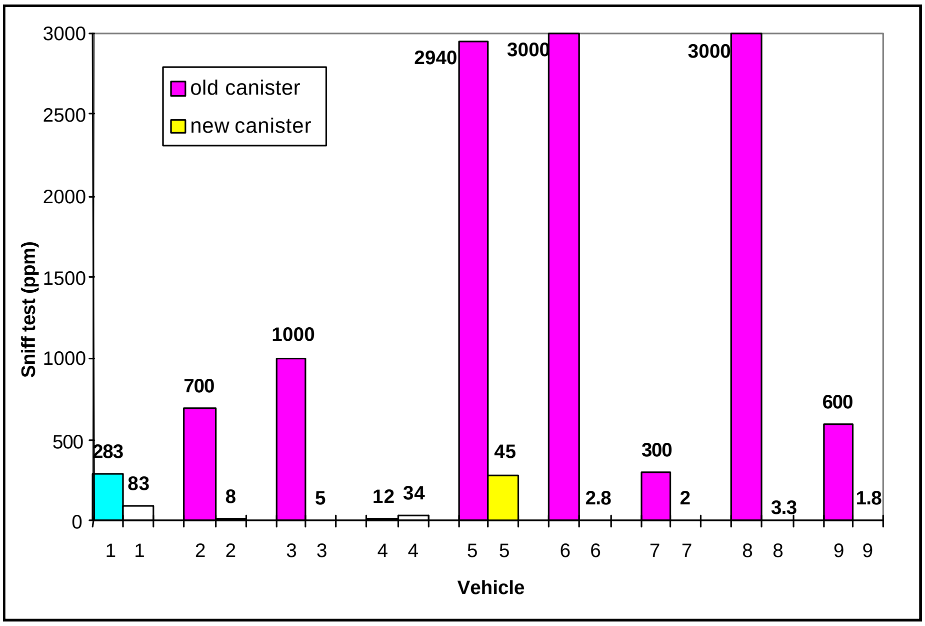


Figure 5-21 **Sniff test results for the original and new canisters**

5.2.7 Canister Isotherm Results

None of the canisters showed significant comminution of their carbon granules.

The adsorptive capacity of carbon from in-use and new replacement canisters was measured by exposure to known amounts of butane, hexane and benzene. The extent of contamination by low volatile organic compounds was determined by solvent extraction. Through this it was estimated that fresh carbon could adsorb about 35 % by weight of hydrocarbons.

In-use carbons were found to have significant amounts of adsorbed material ranging from 5.4% to 25.7%, by weight, with an average value of 16.4%. It was demonstrated that the presence of adsorbed hydrocarbons reduced the capacity for further adsorption in an approximately proportional manner and that removal of such hydrocarbons that could be achieved by purging restored the adsorptive capacity also in a proportional manner. Thus the adsorbed material found on the in-use carbons constitutes from 12% to 70% of the likely adsorptive capacity, averaging at 45%.

Analysis of the unpurgeable material recovered by solvent extraction was shown to consist mainly of C_9 to C_{11} hydrocarbons, 30 - 40 % of which was aromatic in nature.

The experiments also allowed measurement of the rates of desorption of butane, hexane and benzene. These became slower the less volatile the adsorbate. The data measured in this study strongly suggest that the heavier or less volatile components in petrol will not be fully desorbed in the purge time available to an urban motor vehicle. Consequently there will be a slow build up of the heavy ends on the canister.

Extensive purging with N_2 (10 m^3) at 74°C reduced the average amount 'permanent' adsorbate to 6.2% which represents about 16% of adsorptive capacity. In all probability, most if not all of the adsorptive capacity could be restored by purging at higher temperatures eg 150°C. The feasibility of purging at higher temperatures will depend on the materials used in the construction of the canister.

5.2.8 Emissions Inventory Modelling Results

The estimated emission for evaporative and total vehicle fleet are presented in Table 5-8 and Table 5-9. The reduction in evaporative emissions resulting from 50% canister replacement for a summer day was 24 % and for a high oxidant day was 23 %. The equivalent reduction in total vehicle emission (exhaust and evaporative) was 11% and 13 % for a summer and high oxidant day respectively.

Table 5-8 Evaporative Motor Vehicle Emission from the Vehicle Fleet in SEQR, 1993

Action	tonnes/day	
	Summer day	High oxidant day
No replacement	54	87
50% Canister Replacement	41	67

Table 5-9 Total Motor Vehicle Emission (Exhaust and Evaporative) from the Vehicle Fleet in SEQR, 1993

Action	tonnes/day	
	Summer day	High oxidant day
No replacement	121	154
50% Canister Replacement	108	134

5.2.9 Photochemical smog results

The photochemical smog modelling outcomes in replacing the canister are expected to result in small reduction in peak concentrations of photochemical smog of 2-6%, as was achieved through the modelling exercise for the reduction in petrol volatility.

5.2.10 Canister Replacement Cost Analysis

As a result of an industry survey conducted by FCAI, indicative costs relating to the replacement of canisters have been obtained from individual member companies. Collectively, these companies represent about 80% of the typical annual sales volume of new vehicles in Australia. The survey results are tabulated below.

Table 5-10 Results of evaporative system cost survey

	Age of car (years)		
Component/system	**5yr,old car**	**10yr, old car**	**15yr, old car**
Canister	$ 117	$ 121	$ 80
Purge system/hoses/conns	$ 172	$ 105	$ 92
Fuel fill cap	$ 31	$ 28	$ 27

The tabulated costs represent average values for all vehicle ages surveyed and in respect of :

- Canisters, the range was $36 and $260.
- Purge systems, the range was $34 and $635.
- Fuel filler caps, the range was $8 and $49.

Analysis of the figures indicated that the locally produced components and systems are cheaper than those imported from overseas sources.

6. DISCUSSION

This chapter discusses a number of issues that have arisen from this project.

6.1 DRIVEABILITY

A concern was raised by FCAI during this project, that reducing the volatility of petrol has been found within certain member companies to impact the driveability of some Australian vehicles. It was advised that this impact is likely to be more noticeable during the transition from summer to autumn months. The literature, however, did not support this. Stebar et al (1985) showed that RVP could be reduced to 9psi (63 RVP) without any driveability problems over a wide variety of conditions. AIP (1982) also showed that the driveability of Australian vehicles was insensitive to volatility reductions.

Of the four vehicles tested for this project, there were no noticeable impacts on vehicle operation. This was also reflected in the stability of the exhaust emission results across the range of volatilities. Nevertheless, driveability was not specifically assessed in this project. Should a reduction in RVP be pursued as a policy option, it is suggested that this should be done in conjunction with an assessment of driveability.

6.2 CANISTER CONDITIONING

The new canisters fitted to the test vehicles for the canister component of this project were not conditioned through a controlled load and unload cycle to account for the 'heel' of the canisters. EPA (Vic) did not have access to the specialised equipment needed to undertake this task. Consequently, the results from the canister component are likely to represent the best results possible from a canister replacement program. It was not possible to assess the likely duration of these maximum emission benefits.

6.3 INVENTORY MODELLING

6.3.1 Petrol Volatility Project Experimental Data

The previous SEQR inventory methodology was used in the modelling of fuel RVPs of 63.5 and 68.5 kPa. The diurnal emission was estimated by the Reddy equation which predicts uncontrolled tank vapour emissions. The Reddy equation has been verified against experimental data.

The experimental data did not correlate with the Reddy estimates for either ADR27 or ADR37/00. If the VTS data had been used, this may have under estimated the evaporative component of the motor vehicles. The average temperatures experienced in Brisbane summer in 1993 were 20 - 31° C. Since the SHED tests were conducted under standard conditions of 16 - 29.3 ° C, the experimental diurnal emissions from this project would under estimate the emissions in Brisbane.

Evaporative emissions are known to be affected by the state of saturation of the carbon canister which is dependent on trip history. The artificial purging of the canister in this project would not be indicative of a canister in the real world, which could explain the discrepancy between Reddy estimates and the experimental data from this project.

6.3.2 NISE Study Data

Although it would be desirable to use Australian test data, using the NISE study data would add a greater uncertainty to the evaporative emission estimates. From an emissions inventory point of view, the deficiency in the NISE study data is:

- the NISE study data for evaporative emissions was conducted at only two RVPs, ~60-63 and 76.5 kPa.
- limited sample size
- the data supplied with the NISE study contained total evaporative emission loss rather than diurnal and hot soak components separate. It is recognised that this break down of data would be available if requested.

The US data is more comprehensive than the NISE study data. The ADRs are derived from US Federal Test Procedures and therefore the US data is transferable to Australian conditions.

6.4 VOLATILITY RESULT ISSUES

The experimental data from this project showed that decreases in petrol volatility led to a decreases in the evaporative emissions of the four test vehicles without effecting exhaust emissions and fuel consumption results.

6.4.1 Evaporative Emissions Discussion

Most of the gains from reducing petrol volatility, seem to come from the reduction to 70 kPa (on average 35% for leaded vehicles and 55% for unleaded vehicles, see Table 6-1). This relationship was also noted by the American Petroleum Industry (1986),which found that when petrol volatility was reduced from 81.9 to 62.3 kPa, the greatest effect (73%) occurred between 81.9 and 75.6 kPa.

Table 6-1 summarises the average stepwise percentage reductions that were achieved from this project. The table indicates that the evaporative emission results for unleaded petrol vehicles showed a 55% reduction (on average) in dropping the RVP from 77 kPa to 70 kPa. Further reducing the RVP to 67 kPa, resulted in an average reduction in SHED emissions of 40%.

Table 6-1 Reduction in SHED emissions from reducing fuel volatility.

Decrease in Evaporative Emissions from base of 74/77 kPa (LP/ULP)	Average reduction in SHED emissions (%) (leaded vehicles)	Average reduction in SHED emissions (%) (unleaded vehicles)
70/70 kPa	35%	55%
66/67 kPa	-3%	40%
63/62 kPa	13%	8%

Influence of Petrol Reactivity

The petrol used in the PV project is considered to be of a relatively low reactivity (Challenger, personal communication 1996) and possibly not overly representative of the bulk of commercially available petrol in Australia. It is feasible that the real world gains from volatility reductions could be greater than those seen in this project.

6.5 CANISTER RESULT ISSUES

Replacing canisters on vehicles will lead to a reduction in a vehicle's evaporative emissions, so long as the evaporative system is functionally intact. For three ADR27 vehicles (2 faulty vehicles excluded) tested the cumulative reduction in evaporative emissions was 14 grams (46%) and for the four ADR37/00 the reduction was 9 grams (84%).

6.5.1 Evaporative emissions discussion

For both the ADR27 (2 faulty vehicles excluded) and ADR37/00 vehicles, there was a reduction in evaporative emissions in replacing an old canister with the new one recommended by the manufacturer.

ADR 27 Vehicle Results

The total SHED reduction for the ADR27 vehicles was 14 grams. This came from three of the five ADR27 vehicles tested. The vehicles that were not included had unusually high SHED results. One of the vehicles had damage to its filler neck.

Of the three ADR 27 vehicles used in this analysis, vehicle 2 remained under its ADR27 limit of 6 grams for both old and replaced canister tests.

Vehicle 3 remained above its ADR limit despite the replacement canister (decrease of 0.5 grams). The vehicle that had the greatest reduction was Vehicle 5. This vehicle reduced it's SHED result by 13 grams. It is noteworthy that this vehicle had the lowest purge rate and the highest break through value on the old canister.

ADR 37/00 Vehicle Results

The total gain from replacing the canisters was 9 grams. All four of the vehicles had reduced evaporative emissions with replaced canisters. Three of the vehicles (vehicle 7, vehicle 8 and vehicle 9) already met their design limit of 2 grams before the replacement of their canister. Vehicle 6 gave an improvement of 6 grams (test dates 16/5/96 - 17/5//96). The canister was replaced on Vehicle 6 during the NISE study (test dates pre & post tune of 28/6/94, 30/6/94 respectively). The results were similar for both sets of tests.

The reduction in replacing the canister was greater for the NISE study (13 grams). Figure 6-1 below, summarises both the NISE test results and the canister replacement results for Vehicle 6. This vehicle also has the lowest purge rate, lending support to the view that the purge rate may have a determining influence on the uptake of heavy end hydrocarbons and therefore diminished carbon adsorptive capacity.

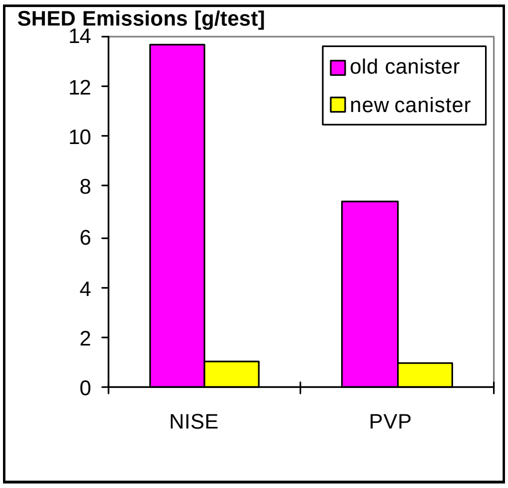


Figure 6-1 Vehicle 6 - Comparison of NISE and PVP canister replacement

6.5.2 *Canister isotherm testing*

From the solvent testing of the new carbon canisters it was determined that the fresh carbon could adsorb approximately 35% by weight of hydrocarbon. Material was adsorbed on the original (old) canisters ranged from 5% to 26%. This was shown to reduce the working capacity of the canister from 12% to 70%. The unpurgeable material was shown to be mainly C9 to C10 hydrocarbons, 30%-40% of which were aromatic in nature. This unpurgeable material was shown not to be completely desorbed and therefore it will build up slowly over the life of the canister. The purge rate may have an effect on the speed at which this build up occurs.

6.5.3 *Canister degradation*

The activated carbon can be affected by many factors, including: water, oil, attrition, dust, liquid petrol or the build up of heavy ends in the carbon. Deactivation can be instantaneous, for example by the flooding of the canister through overfilling of the petrol tank, or long term, through the slow build up of the heavy end hydrocarbons. It is unlikely that the purge regime with our current vehicles will remove the hydrocarbons. There may be some scope for considering design changes to the vapour control system on present motor vehicles, although this aspect was not investigated in this project.

The CSIRO testing showed that attrition was not a main factor in the working capacity degradation of the canisters tested.

This has a bearing on the results. It is possible, for example, that the owner of Vehicle 6 has a habit of over filling the petrol tank thus flooding the canister, rather than the poor purge flow rate.

6.5.4 *Canister Break through*

Every original canister broke through ie a “sniff” using an extensible sampling hose connected to a hydrocarbon analyser around the canister outlet detected very high levels of hydrocarbons. This indicates that the canister was close to or at saturation. The one exception was vehicle 4 where the canister was not being loaded properly because of filler neck damage. None of the new canisters broke through. The old canisters are presumed to have broke through because of their apparent reduced adsorptive capacity.

Artificial Purge

To bring the old canisters to a similar starting point, the old canisters were purged to get them to a constant weight. This was not possible using the time constraints and purging method. All canisters were purged for 2 hours with dry air at 100kPa (this is equivalent to between 80 and 400 bed volumes, the EPEFE report (1996) suggests 200). The canisters weight and hydrocarbon emissions were measured every 15 minutes throughout the purging period.

All canisters reduced in weight considerably over this time. The rate of decrease was rapid for the first 15 to 45 minutes after which the weight drop rate slowed. This was shown on the graph, as an elbow in the weight decrease. All of the original canisters showed this except the initial two canisters where the procedure had not been introduced, and the vehicle 1 canister that was 16 years old.

All of the canisters showed improved adsorption capacity once they had been artificially purged. They also showed an increase in the rate of desorption. It would seem that the canisters working capacity was improved simply through this cycle.

The differences in fuel types (ie commercially available and NISE baseline fuels) are noted and for this reason caution should be exercised in extrapolating this finding universally.

6.5.5 Different vehicle engine, petrol tank and system design

Some canisters have purge control valves. These valves control the amount of purging by gauging whether the conditions are suitable.

Some vehicles have fuel caps with pressure relief valves. Care must be taken that these valves are not emitting evaporative emissions into the atmosphere when they could be channelled through to the canister.

The way a vehicle is driven can have an affect on the performance of the evaporative emissions system. For example a vehicle that is only used for short distances may never get the opportunity to purge the canister. This will, in most cases, eventually cause break through, as the carbon can only adsorb a certain volume of hydrocarbons before venting the rest into the atmosphere. Exposure to very dusty, or conversely, very wet and muddy conditions may also input on the canister's effective capacity.

6.5.6 Manufacturer maintenance procedures

The canister component results indicate that regular replacement and maintenance of canisters should be encouraged. Vehicle manufacturers currently have service and maintenance requirements for canisters in their service manuals, but these procedures vary greatly.

Table 6-2 below summarises the procedures that were found in vehicle manufacturer service handbooks.

Table 6-2 Manufacturer evaporative emissions service procedures

	Ford	Mitsubishi	Toyota	Nissan	Holden
SHAKE TEST	x	Ō	x	Ō	Ō
VISUAL INSPECTION	x	x	Ō	x	x
CONTAMINATION (FUEL, WATER, OIL)	Ō	x	x	x	x
FILTER CHECK	x	Ō	Ō	Ō	Ō
FREE FLOW	x	Ō	x	Ō	Ō
LEAKAGE	x	x	Ō	Ō	Ō

Ō	Procedure present
x	Procedure not specified

7. SUMMARY OF RESULTS AND OBSERVATIONS

Fuel Volatility

Reducing the volatility of petrol led to a reduction in the evaporative emissions of the four vehicles tested.

The emissions inventory modelling for the volatility component showed a reduction in total fleet emission (exhaust and evaporative) was 12% and 17 % from a RVP of 73.5 kPa to 68.5 and 63.5 kPa respectively for a summer day. The equivalent reduction for a high oxidant day was 8% and 15 %.

Photochemical smog modelling results indicated that for the modelled conditions, a RVP reduction or canister replacement strategy will result in a small reduction in peak concentrations of photochemical smog of 2-6%. It is difficult to translate this result to other airsheds or to the development of photochemical smog under other classes of meteorological conditions. Further modelling work could be undertaken to investigate the predicted photochemical smog reductions in other airsheds, particularly as photochemical smog models are developed for these regions.

The AIP reported that on average, the petroleum industry costs (capital and operating) associated with reducing petrol volatility are likely to be substantial on a one off capital investment basis as well as on-going operating expenses. Proposals to reduce the volatility of petrol would need to take account of these costs and the timeframes needed by industry to commission plant where necessary.

Canister Replacement

Replacing canisters led to a reduction in evaporative emissions of seven test vehicles, whose evaporative emission control systems were functionally intact. The canister testing showed a total reduction of 46% for leaded vehicles and 83% for unleaded vehicles. The vehicles with the lowest purge flows had the greatest reductions in evaporative emissions when their canisters were replaced.

The emissions inventory modelling showed that the replacement of 50% of the carbon canisters on the Brisbane vehicle fleet was estimated to produce a reduction in evaporative emissions of 24 % for both the summer and high oxidant day with a fuel RVP of 73.5 kPa. The reduction in total vehicle emission (exhaust and evaporative) of 11% and 13 % for a summer and high oxidant day respectively. This should be seen an a best case scenario.

Two of the vehicles tested under the canister component showed unexpectedly high evaporative emissions. These results were indicative of faults with the evaporative emission control system.

The FCAI reported that the costs to be associated with a canister replacement proposal would be, on average, high depending on the frequency of the replacement program. Before implementation, the duration of the emissions benefits need to be investigated. Other options which could be considered are service and maintenance schemes and possible redesign of the evaporative emissions control system to avoid liquid fuel contamination of canisters as well as improved purge rates. Regular artificial purging and servicing of the evaporative emissions control system is likely to be an effective means of rejuvenating the adsorptive capacity of carbon canisters on motor vehicles.

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