MOTOR VEHICLE POLLUTION IN AUSTRALIA

Supplementary Report No. 2

Petrol Volatility Project

prepared by the

Environment Protection Authority of Victoria

for

Environment Australia

&

Federal Office of Road Safety

November 1997

GPO Box 594
Canberra ACT 2601
Australia

Tel: +61 2 6274 7111
Fax: +61 2 6274 7714

ACKNOWLEDGMENTS

Many organisations and individuals generously provided support and assistance with this project. The following organisations and individuals are gratefully acknowledged -

- Environment Australia
- Federal Office of Road Safety
- Australian Institute of Petroleum Ltd
- Federal Chamber of Automotive Industries
- Australian Automobile Association
- Commonwealth Scientific & Industrial Research Organisation (Division of Coal and Energy Technology)
- Mobil Oil Australia Ltd
- Centre for Air Quality Studies, EPA (Vic)
- General Motors-Holden's Automotive Ltd
- Royal Automobile Club of Victoria
- NRMA
- DASFleet
- NipponDenso
- Ford Motor Company of Australia Ltd
- Rollins Hudig Hall
- Members of the public for loaning their motor vehicles.

Particular mention is made of the Research and Technical Services of Mobil Oil Australia Ltd for the significant resources that were provided in formulating the modified test fuels in a timely manner.

The Australian Institute of Petroleum Ltd and the Federal Chamber of Automotive Industries also made significant contributions to this project in providing the costings for the fuel changes, and canister replacements respectively.

To all of you, our sincere thanks.

S. McDonald, N. Beeston, R. Allen, D. Whittle,
S. Dwyer & D. Hes

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.

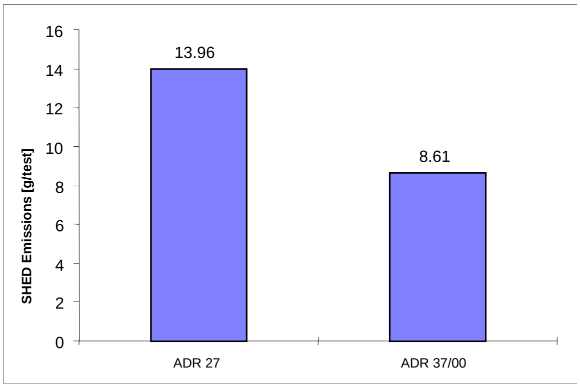

Figure 1 Total SHED Emissions Saved by the Replacement of Canisters

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