EVAPORATIVE EMISSIONS: DEVELOPING AUSTRALIAN EMISSION ALGORITHMS

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Abstract

Evaporative emissions from motor vehicles contribute significantly to hydrocarbon emissions in urban areas. This contribution is typically in the order of 10-25% of total HC emissions from road transport, but contributions up to about 60% have been reported. Given the importance of hydrocarbon emissions for modelling of photochemical smog and secondary particles, as well as quantification of the levels of exposure to specific hydrocarbons (benzene, toluene, etc.), accurate estimation of evaporative emissions is vital. This paper discusses the development of emission algorithms from Australian and European test data, which have been incorporated in the COPERT Australia software program. Differences between Australian and European technologies (canister size, fuel tank size, etc.) are discussed. The algorithms are then used to estimate total evaporative emission loads for Queensland and these estimates are compared to predictions for other types of emissions (hot running, cold start).

Keywords: evaporative emission, motor vehicles, diurnal losses, activated carbon canister

1. Introduction

The term ‘evaporative emissions’ refers to the sum of all fuel-related non-methane volatile organic compounds (NMVOC) emissions not derived from fuel combustion. Breathing losses through the tank vent and fuel permeation are in general the most important sources of evaporative emissions in a vehicle. Breathing losses are due to evaporation of petrol in the fuel tank during driving and parking as a result of normal diurnal temperature variation. In current vehicles vapour emissions are controlled by means of an activated carbon canister connected to the fuel tank. Various studies (CRC 2004, Reuter et al 1994) indicate that fuel permeation through the plastic and rubber components of the fuel and vapour control system contribute significantly to the total evaporative emissions.

There are three main mechanisms causing evaporative emissions from gasoline powered vehicles.

- Diurnal losses are associated with the daily (diurnal) variation in ambient temperature and result from the vapour expansion inside the gasoline tank that occurs as the ambient temperature rises during the daylight hours.
- Hot soak emissions occur when a hot engine is turned off and heat from the engine and exhaust system increases the temperature in the fuel system.
- Running losses are the result of vapour generated in petrol tanks during vehicle operation.

Evaporative emissions can have a significant contribution to total NMVOC emissions from road transport, especially at high ambient temperatures and when high volatility fuels are used (e.g. petrol – ethanol blends). Therefore, it is essential to use accurate evaporative emission factors for Australian conditions. Empirical Australian vehicle emissions data have therefore been analysed and used in this research to develop appropriate evaporative emission factors. Coupled with a well-established method already used in Europe (EEA, 2009), these emission factors have been incorporated in the COPERT Australia software (Emisia, 2013).

2. Evaporative emissions modelling in COPERT Australia

2.1. Methodology outline

The detailed Tier 3 methodology developed for COPERT 4 (Ntziachristos *et al.*, 2009) is applied in COPERT Australia. A wide range of input parameters are required to run the model. These can be grouped into the following categories:

- Fuel related parameters: (i) Vapour pressure; (ii) Ethanol content
- Vehicle related parameters: (i) Fuel tank size and structure; (ii) Mass and quality of activated carbon; (iii) Purging strategy
- Vehicle activity related parameters: (i) Parking duration; (ii) Distance travelled; (iii) Ambient temperature.

Fuel vapour is generated in the fuel tank as a result of normal ambient temperature variation when a vehicle is parked. Vapour generation depends on the ambient temperature at the start and end of a parking event, and the available vapour space, determined by fuel tank size and fill level. For uncontrolled vehicles (i.e. vehicles without a carbon canister installed), emissions are determined by the amount of fuel vapour generated in the fuel tank.

Since a parking event may occur anytime during the day, a daily parking pattern is used. A parking activity table is thus created, providing a distribution of the parking events into different parking durations and into the time of the day that the parking event takes place.

For canister-equipped vehicles, the evaporative emissions depend on the load of the activated carbon canister with fuel vapour (Mellios et al 2007). In order to estimate the canister status going into a parking event, the distance driven prior to each parking event is taken into account in the calculations. To this aim, a trip distribution is introduced in the model.

Canister breakthrough emissions where the working capacity of the carbon canister is exceeded are then calculated for each parking event taking into account the canister status, vapour load and temperature, for a given canister size and carbon quality.

For older vehicles without vapour control, tank emissions are calculated from the vapour generation in the fuel tank.

Emissions due to fuel permeation are also calculated assuming different permeation rates for a given tank structure (fluorinated mono-layer or multi-layer tanks) and fuel type (ethanol or non-ethanol containing petrol).

The total evaporative emissions for each evaporation process (diurnal emissions, hot-soak emissions and running losses) are determined by the sum of breakthrough or tank emissions and emissions due to fuel permeation.

2.2. Development of emission factors

A large amount of vehicle emissions test data have been made available from various Australian test programs that were conducted over the last years. Test results from the following studies have been examined: National In-Service Emission Studies (NISE1 and NISE2), Comparative Vehicle Emissions Study, Ethanol Health Study.

These studies combine 508 SHED (Sealed Housing for Evaporative Determination) tests for Australian light-duty vehicles for a wide range of model years, make/models and emission control technologies.

It is noted that vehicles with faulty emission control systems (e.g. faulty fuel caps) were not included in the calibration. The main reason is the difficulty in determining an accurate proportion of these high emitters in the on-road fleet. A method to adequately include these vehicles in the emission factors will be explored further.

The basic equations included in COPERT 4 describing vapour generation, canister loading and purging, and breakthrough emissions were used to simulate the above SHED tests for the various vehicle categories: small, medium and large passenger cars (PC-S, PC-M, PC-L), compact and large SUVs (SUV-C, SUV-L) and light-commercial vehicles (LCV).

A number of technical characteristics of the test vehicles and fuels, required for the simulations, were already included in the experimental dataset (Reid Vapour Pressure or RVP of the test fuel, vehicle mileage, and fuel tank volume).

However, no information was available on canister size and durability, which is essential for the simulations. Therefore, assumptions on the quantity of activated carbon contained in the canister, as well as carbon quality (relevant for estimating carbon degradation), were made using the European experience (Haq et al. 2013).

For latest technology vehicles (Australian Design Rule (ADR) 79-00 and ADR79-01) it was assumed that PC-S are equipped with a one-litre canister, whereas all other classes (PC-M, PC-L, SUV-C, SUV-L, LCV) have a two-litre canister installed.

In general, there are two classes of durability of activated carbons: Low Degradation and High Degradation Carbons. Similarly to European cars, it was assumed that the degradation of the activated carbon is higher for small cars and lower for medium and large cars.

In order to quantify this emissions deterioration effect, the latter was simulated using the Australian experimental dataset and assuming a variable decrease in the efficiency of the activated carbon. Based on these simulations it was found that the efficiency of the activated carbon decreases by 1% every 40000 km for small cars (i.e. about 5% decrease over vehicle lifetime), and by 1% every 60000 km for medium and large cars (i.e. about 3.5% decrease over vehicle lifetime).

Table 1 provides a summary of the main technical specifications used for the simulation of the different vehicle classes and technologies.

Table 1. Technical specifications for the different vehicle classes and technologies.

	Fuel tank volume	Canister size	Degradation
ADR79-01 and ADR79-00			
PC-S	50	1.0	40 000
PC-M	65	2.0	60 000
PC-L	70	2.0	60 000
LCV	75	2.0	60 000
SUV-C	65	2.0	60 000
SUV-L	75	2.0	60 000
ADR37-01			
PC-S	50	1.0	40 000
PC-M	65	1.25	40 000
PC-L	70	1.25	40 000
LCV	75	1.25	40 000
SUV-C	65	1.25	40 000
SUV-L	75	1.25	40 000
ADR37-00 and ADR36			
PC-S	50	0.43	25 000
PC-M	65	0.43	25 000
PC-L	70	0.54	25 000
LCV	75	0.77	25 000
SUV-L	75	0.77	25 000
ADR27			
PC-S	50	0.38	20 000
PC-M	65	0.43	20 000
PC-L	70	0.50	20 000

The results of this simulation exercise for ADR79-00 and ADR79-01 are shown in the bar charts of Figure 1. Modelled diurnal emissions (in grams of NMVOC per day) are compared against SHED test results for the different vehicle categories for ADR79-01 (top graph) and ADR79-00 (bottom graph). Medium (PC-M, SUV-C) and large (PC-L, LCV, SUV-L) cars are also shown together because of their similar technical specifications (canister size, fuel tank volume, carbon quality).

Although the sample is relatively small (2-4 vehicles tested for each category), a few interesting observations can be made:

- PC-S have higher emissions than PC-M and PC-L (in some cases). This is most probably due to the combined effect of lower carbon quality and lower purge rates.
- Emissions of ADR79-00 cars are slightly higher compared to ADR79-01, although they have similar technical specifications (canister size, fuel tank volume, carbon quality). This is due to the fact that they have higher mileage accumulated and hence a reduced carbon efficiency.
- Modelled emissions for ADR79-00 vehicles are overestimated, whereas there is a somewhat better agreement between SHED and model results for ADR79-01 vehicles.

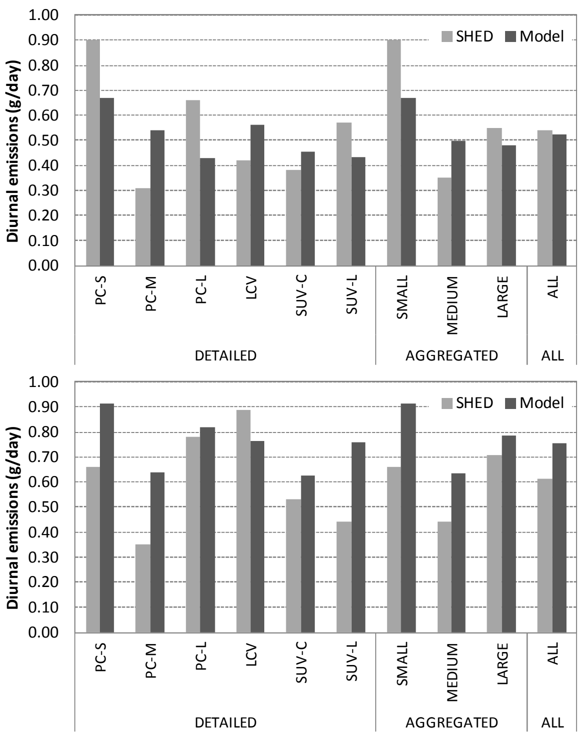

Figure 1. Modelled vs tested diurnal emissions for ADR79-01 (top) and ADR79-00 (bottom) vehicles.

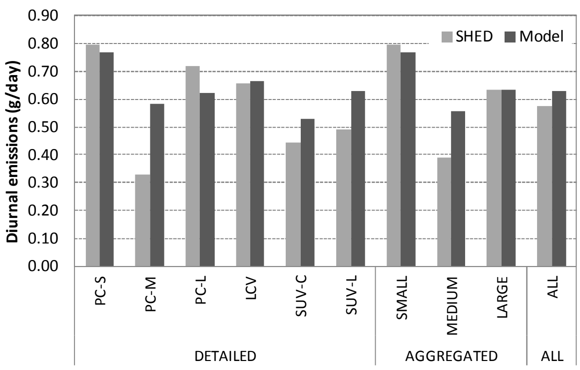

Figure 2. Modelled vs tested diurnal emissions for ADR79-01 and ADR79-00 vehicles combined.

In order to increase the sample size, and taking into account that ADR79-00 and ADR79-01 vehicles should have similar emissions (differences are due to mileage as explained previously), the two vehicle technologies can be grouped together. With the exception of PC-M, there is now a much better agreement between experimental and modelled emission data for all vehicle categories as shown in Figure 2.

The same approach was followed for older technologies, assuming lower values for canister size and higher values for carbon degradation.

Results are presented in Figure 3 for ADR37-01 and in Figure 4 for ADR37-00, ADR36 and ADR27.

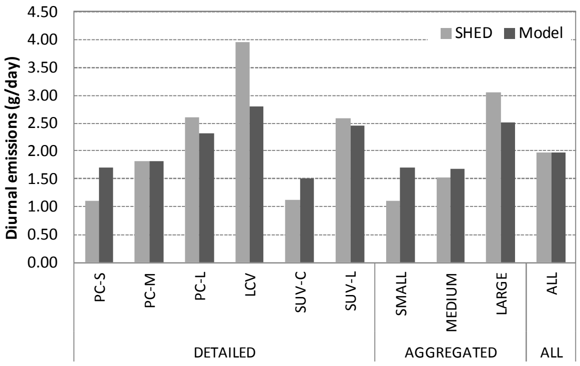

Figure 3. Modelled vs tested diurnal emissions for ADR37-01 vehicles.

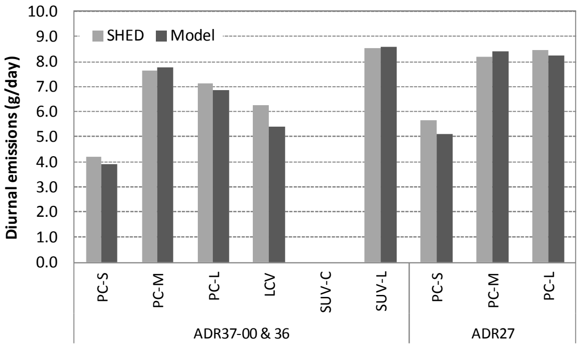

Figure 4. Modelled vs tested diurnal emissions for ADR37-00, ADR36 and ADR27 vehicles.

Contrarily to what was observed previously for ADR79-01 and ADR79-00, small ADR37-01, ADR37-00, ADR36 and ADR27 vehicles have lower emissions compared to medium and large ones. This is an indication that there is no differentiation in the carbon quality across the various vehicle categories.

2.3. COPERT 4 vs COPERT Australia

As explained above, the basic methodology for estimating evaporative emissions in COPERT 4 has been adopted in COPERT Australia after adjusting the emission factors with Australian data. The main differences between COPERT 4 and COPERT Australia relate to the vehicle technical specifications, notably canister size and durability.

2.3.1. Canister size

Road vehicles in Australia are generally bigger than in Europe, with bigger engines and fuel tanks. Hence, they are equipped with larger canisters to accommodate for the increased fuel vapour generation.

The assumed canister size ranges between 1.0 (for small cars) and 2.0 (for large cars and SUVs) litres, whereas typical values in Europe are in the range of 0.8 to 1.5 litres respectively.

One litre of canister typically contains 300 grams of activated carbon, which can adsorb about 60 grams of fuel vapour.

2.3.2. Degradation

The activated carbon degradation with mileage is lower in COPERT Australia compared to COPERT 4.

For the same mileage travelled, canister efficiency loss for small cars is more than double for the European vehicle fleet than for the Australian fleet. For medium and large cars this loss is about 50% higher for the European fleet.

Ethanol may have a significant effect on carbon degradation. Although there is very limited Australian data available to verify this, data from the in-service conformity testing programs conducted in Europe (in Germany and Sweden) have shown a decrease in efficiency when 5-10% ethanol is blended in petrol.

2.3.3. Emission factors

As a result of the above differences in canister size and degradation, the average diurnal emission factors in Australia are about half compared to Europe. This is despite the fact that ambient temperatures in Australia are generally higher than in Europe.

3. Application – A case study

The COPERT Australia software program was used to estimate total evaporative emission loads for Queensland.

3.1. Fleet input data

Fleet data and utilization data are an essential input to COPERT Australia. Since evaporative emissions are only relevant for petrol vehicles, information is required for 132 vehicle classes (out of the 223 in total) regarding the number of vehicles in the fleet for a particular base year, their annual mileage and accumulated mileage. The challenge is that available fleet data are often too aggregated to be useful for vehicle emissions modeling and that these data reflect different vehicle class definitions. The first step is to create a vehicle population input table that reflects the level of detail required for

COPERT Australia. Queensland vehicle registration data (TMR, 2013) were used to create this table. The TMR database provides information on the number of registered vehicles in Queensland by post code and other variables. All registered vehicles that are typically non-road or non-motorised vehicles were removed from the dataset (e.g. mobile machinery, boat trailers). Each vehicle was then attributed to the appropriate COPERT Australia vehicle class using information on vehicle make and model, year of manufacture, registration category, fuel type, and number of cylinders. The second step is to estimate total travel for Queensland. Total travel is expressed as vehicle kilometers travelled (VKT). VKT cannot be measured directly but can be estimated using different methods including analysis of odometer reading databases, combination of traffic volume and road length data (either from road-based traffic counts or transport models) and household travel surveys. A number of data sources (ABS, 2011; BITRE, 2011) were examined, compared and used to create an estimate of total annual VKT for 2010 for Queensland by main vehicle type. Total VKT estimates were created for petrol passenger vehicles, light-commercial vehicles, and motor cycles (petrol).

Annual mileage is a function of vehicle type and vehicle age. Vehicle utilization curves were sourced from BTCE (1996) and combined with the Queensland vehicle stock table that was created in the first step. The utilization curves were then calibrated to reproduce the total VKT estimates for each vehicle type that were computed in the second step. This ensures that total VKT for the Queensland fleet is equivalent to reported values, and at the same time achieves the required breakdown of annual mileage by main vehicle type, fuel type and ADR category. The calibrated age-mileage relationships are also used to compute accumulated mileage for each COPERT Australia vehicle class. As a last step the use of ethanol blends (E10) in the petrol light duty fleet was estimated. This was done by considering the total use of E10 in Queensland (DRET, 2010), which is about 22% (mass) of total petrol/E10 use in 2010, as well as consideration of E10 suitability for LDVs by model year. With respect to the last point, Pre-1986 vehicles are not ethanol compatible and practically all post-2003 vehicles are ethanol compatible, with a rising portion of 1986-1998 MY vehicles being ethanol compatible as a function of model year (DEWHA, 2008).

3.2. Fuel input data

Fuel consumption or energy data are available from a number of sources (ABS, 2011; BITRE; 2011; DRET, 2010; BREE, 2012). The data have different levels of detail. For instance, the 'Survey of Motor vehicle Use' or SMVU (ABS, 2011) combines petrol and E10 together in a category called "petrol" and does not distinguish between ULP and PULP, whereas DRET (2010) does distinguish between ULP, PULP and E10. The fuel data were first converted to mass units (tonne) using fuel density and lower heating values for each type of fuel. Then financial year data were converted to calendar year data by taking the average of the overlapping financial years (e.g. 2010 is the average of 2009-2010 and 2010-2011 financial years).

The petrol sales and consumption data from DRET and BREE will contain a small fraction that is not used by road transport. BITRE (2011) estimates that this fraction has been relatively constant over time (about 5%). It appears that the SMVU data provides the most accurate total petrol use data for road transport, but APS data have been used to split the SMVU data into ULP, PULP and E10 use for Queensland.

3.3. Emissions results

The above vehicle fleet and fuel input data have been inserted in the COPERT Australia software program and a full run for Queensland has been performed.

COPERT Australia may calculate total NMVOC emissions per vehicle category and vehicle technology, split between different driving modes (urban, rural, highway), as well as between hot, cold and evaporative emissions. Figure 5 shows the NMVOC emissions calculated for the different petrol vehicle classes, as well as the split into hot (Smit and Ntziachristos, 2012), cold (Smit and Ntziachristos, 2013) and evaporation (this paper).

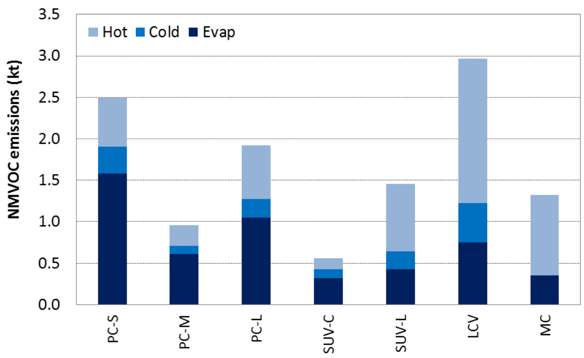

Figure 5. Breakdown of total NMVOC emissions by type of emission (hot, cold, evap).

The percentage contribution of evaporative emissions to total NMVOC emissions increases with decreasing vehicle size. It ranges from 25% for LCV and 30% for SUV-L to 63% for PC-S. For the latter, this is due to the combined effect of smaller canister size and lower carbon quality. Uncontrolled emissions (i.e. from cars without carbon canister installed) also contribute significantly to the total emissions, despite the relatively small share of the uncontrolled vehicles in the Australian fleet.

4. Conclusions

- Evaporative emissions algorithms have been developed for the Australian vehicle fleet, using a wide range of experimental data.
- The developed algorithms can predict tested emissions reasonably well for most vehicle categories and technologies.
- Small vehicles have higher emission levels compared to medium and large vehicles mainly due to the lower carbon quality.
- The basic assumptions on the various input parameters, mainly canister size, and carbon quality / degradation, need to be confirmed.
- The effect of ethanol on evaporative emissions has to be further investigated for the Australian fleet.
- A dedicated emission methodology and software tool for the Australian road vehicle stock has been prepared and applied to the Queensland region in this paper.
- Older vehicles without evaporation control contribute to total evaporative emissions disproportionally to their stock size, because of their higher emission levels.
- High emitter impacts are subject to further study.

Acknowledgments

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