SNAP CODE: **070600**

SOURCE ACTIVITY TITLE: **GASOLINE EVAPORATION FROM VEHICLES**

NOSE CODE: **201.06**

NFR CODE: **1 A 3 b v**

1 ACTIVITIES INCLUDED

Evaporative emissions occur in significant quantities for gasoline vehicles in the form of NMVOC emissions. For some vehicle classes and some pollutants, the different types of emissions are lumped together into one emission factor, for some others, individual emission factors are proposed. It should be noted that also refuelling losses exist. These are not included in this chapter as they are emitted at petrol stations.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Evaporative losses contribute substantially to total road transport related VOC emissions. On the basis of the results of CORINAIR 90 exercise, evaporative losses account for about 25% of total VOC emissions from road transport in the EU, as Table 2.1 shows.

Table 2.1: 1990 Total Evaporative Emissions as Percentage of the National and EU Total VOC of Road Transport

B	34.2
DK	34.9
D	22.1
F	30.1
GR	28.2
IRL	44.8
I	23.9
L	41.9
NL	n.a.
P	33.0
E	27.1
UK	14.5
EU 12	23.7

n.a.: not available

3 GENERAL

3.1 Description

There are three primary sources of evaporative emissions from vehicles[(1)] :

i) diurnal (daily) emissions;
ii) hot soak emissions; and
iii) running losses.

These are estimated separately. Again they are affected by factors that vary from country to country.

3.1.1 Diurnal Emissions

The evaporative emissions associated with the daily (diurnal) variation in ambient temperature result from the vapour expansion inside the gasoline tank that occurs as the ambient temperature rises during the daylight hours. Without an emission control system, some of the increasing volume of fuel vapour is vented to the atmosphere. At night, when the temperature drops, vapour contracts and fresh air is drawn into the gasoline tank through the vent. This lowers the concentration of hydrocarbons in the vapour space above the liquid gasoline, which subsequently leads to additional evaporation.

3.1.2 Hot Soak Emissions

Hot soak evaporative emissions are the emissions caused when a hot engine is turned off. Heat from the engine and exhaust system increases the temperature of the fuel in the system that is no longer flowing. Carburettor float bowls are particularly significant source of hot soak emissions.

3.1.3 Running losses

Running losses are the result of vapour generated in gasoline tanks during vehicle operation. Running losses are most significant during periods of high ambient temperatures. The combined effect of high ambient temperature and exhaust system heat can generate a significant amount of vapour in the gasoline tank.

All three types of evaporative emissions are significantly affected by the volatility of the gasoline being used, the absolute ambient temperature and temperature changes, and vehicle design characteristics. For hot soak emissions and running losses the driving pattern is also of importance.

[(1)] In US literature there is a fourth source mentioned: "Resting Loss Emissions" which result from vapour permeating parts of the evaporative control system. However, they are not taken into account explicitly in this paper.

3.2 Emissions

Evaporative VOC emissions from gasoline fuelled vehicles add to total NMVOC emissions. For evaporating emissions tank breathing is reported as $CH_{2,33}$ and hot soak as $CH_{2,20}$. These are the units used to report test protocols.

3.3 Controls

Until 1993 evaporative losses of gasoline passenger cars were not controlled in Europe, with the exception of the EFTA countries which have adopted the US EPA SHED test procedure. Since 1993 the EC adopted equivalent emission standards as well (Directive 91/441/EEC). In order to comply with these requirements the application of an on board carbon canister is necessary, which adsorbs gasoline vapours and desorbs them to the engine under appropriate conditions. The overall efficiency of these canisters is of the order of 90%. Currently a step further is under consideration (namely introduction of the "large canister").

4 SIMPLER METHODOLOGY

No simple methodology is proposed here, because in principle all countries are in the position to apply the detailed methodology.

5 DETAILED METHODOLOGY

The main equation for estimating the evaporative emissions is (Gorißen 1988):

$$E_{eva,voc,j} = 365 \cdot a_j (e^d + S^c + S^{fi}) + R \qquad (1)$$

where:

$E_{eva,voc,j}$ = VOC emissions due to evaporative losses caused by vehicle category j

a_j = number of gasoline vehicles of category j

e^d = mean emission factor for diurnal losses of gasoline powered vehicles equipped with metal tanks, depending on average monthly ambient temperature, temperature variation, and fuel volatility (RVP)

S^c = average hot and warm soak emission factor of gasoline powered vehicles equipped with carburettor

S^{fi} = average hot and warm soak emission factor of gasoline powered vehicles equipped with fuel injection

R = hot and warm running losses

and

$$S^c = (l\text{-}q)(p \cdot x \cdot e^{s,hot} + w \cdot x \cdot e^{s,warm}) \qquad (2)$$

$$S^{fi} = q \cdot e^{fi} \cdot x \qquad (3)$$

$$R = m_j (p \cdot e^{r,\ hot} + w \cdot e^{r,\ warm}) \qquad (4)$$

where:

q	=	fraction of gasoline powered vehicles equipped with fuel injection
p	=	fraction of trips finished with hot engine (dependent on the average monthly ambient temperature)
w	=	fraction of trips finished with cold or warm engine[(1)] (shorter trips) or with catalyst below its light-off temperature
x	=	mean number of trips of a vehicle per day, average over the year $x = v_j / (365 \cdot l_{trip})$ (5)
$e^{s,hot}$	=	mean emission factor for hot soak emissions (which is dependent on fuel volatility RVP)
$e^{s,warm}$	=	mean emission factor for cold and warm soak emissions (which is dependent on fuel volatility RVP and average monthly ambient temperature)
e^{fi}	=	mean emission factor for hot and warm soak emissions of gasoline powered vehicles equipped with fuel injection
$e^{r,hot}$	=	average emission factor for hot running losses of gasoline powered vehicles (which is dependent on fuel volatility RVP and average monthly ambient temperature)
$e^{r,warm}$	=	average emission factor for warm running losses of gasoline powered vehicles (which is dependent on fuel volatility RVP and average monthly ambient temperature)
m_j	=	total annual mileage of gasoline powered vehicles of category j

The fraction of trips finished with cold and warm engine, w, is connected with the parameter β used in the calculation of cold start emissions: both depend, inter alia, on ambient temperature. In the absence of better data, the assumed relation between w and β is:

$w \sim \beta$

Parameter β depends on the average trip length l_{trip}. This indicates that, for the calculation of the cold start emissions and soak emissions, the average trip length is of great importance.

With reference to the application of the baseline calculation scheme outlined in chapter B710 Table 5.1, Table 5.1 summarises the methods proposed for application for the calculation of evaporation losses.

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(1) Engines are defined as "cold" or "warm" if the water temperature is below 70°C

Table 5.1: Summary of Calculation Methods applied for Calculation of Evaporation Losses (cf. chapter B710, Table 5.1)

Evaporation	NMVOC
Pass. Cars Conventional	A
Pass. Cars Closed Loop	A
Light Duty Vehicles	C
Two Wheelers <50 cm^3	D
Two Wheelers >50 cm^3	D

6 RELEVANT ACTIVITY STATISTICS

Apart from the emission factors, the proposed methodology requires, a number of statistical data which are most likely not available in many countries, e.g. the parameters p, i, w and x. Table 6.1 shows an example from the data base of CORINAIR85 exercise. These data can be found only in detailed national statistics, or can be produced via surveys.

Table 6.1: Examples of Statistical Input Data Relevant for Estimating Evaporative Emissions as used by EC Member States in COPERT 85

Country	Vehicle Category	Vehicles equipped with fuel injection [%]
	< 1.4 l	0.0
B	1.4 - 2.0 l	3.1
	> 2.0 l	1.8
	< 1.4 l	8.4
D	1.4 - 2.0 l	8.4
	> 2.0 l	8.4
	< 1.4 l	0.0
DK	1.4 - 2.0 l	0.0
	> 2.0 l	0.0
	< 1.4 l	4.9
E	1.4 - 2.0 l	4.9
	> 2.0 l	4.9
	< 1.4 l	0.0
F	1.4 - 2.0 l	4.2
	> 2.0 l	15.5
	< 1.4 l	1.0
GR	1.4 - 2.0 l	1.0
	> 2.0 l	1.0
	< 1.4 l	5.0
I	1.4 - 2.0 l	5.0
	> 2.0 l	5.0
	< 1.4 l	0.0
IRL	1.4 - 2.0 l	0.0
	> 2.0 l	0.0
	< 1.4 l	5.0
L	1.4 - 2.0 l	10.0
	> 2.0 l	15.0
	< 1.4 l	0.0
NL	1.4 - 2.0 l	0.0
	> 2.0 l	10.0
	< 1.4 l	0.0
P	1.4 - 2.0 l	10.0
	> 2.0 l	30.0
	< 1.4 l	0.0
UK	1.4 - 2.0 l	0.0
	> 2.0 l	0.0

7 POINT SOURCE CRITERIA

There are no relevant point sources which fall under the source activities dealt with in this chapter.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Due to the lack of data, evaporative emissions can be estimated only for gasoline passenger cars, gasoline light duty vehicles and two wheelers. However, the methodology can only be fully applied for gasoline passenger cars. For the other two vehicle categories simplifications have to be made. Since evaporative emissions are very sensitive to temperature, the estimates are made on a monthly basis.

8.1 Gasoline Passenger Cars

The evaporative losses depend on the technology used, the fuel properties and the average ambient temperatures. The basic emission factors, which are necessary to apply the methodology, are listed in Table 8.1 for uncontrolled and controlled vehicles (based mainly on Concawe 1987, 1990, Eggleston 1991, Heine 1987, US EPA 1990). However, it should be mentioned that the working group considers the data base as still far too small, so that the reliability of the estimates obtained when using the emission factors is not very satisfactory.

Table 8.1: Summary of Emission Factors for Estimating Evaporative Emissions of Gasoline Powered Vehicles (all RVP in kPa, all temperatures in ^{o}C)

Emission factor (units)	**Uncontrolled vehicle**	**Small carbon canister controlled vehicle**
Diurnal (g/day)	$9.1 \cdot \exp(0.0158 (RVP-61.2) + 0.0574 (t_{a,min} - 22.5) + 0.0614 \cdot (t_{a,rise} - 11.7))$	$0.2 \cdot$ uncontrolled
warm soak (g/procedure)	$\exp(-1.644 + 0.01993\ RVP + 0.07521\ t_a)$	$0.2 \cdot \exp(-2.41 + 0.02302\ RVP + 0.09408\ t_a)$
hot soak (g/procedure)	$3.0042 \cdot \exp(0.02\ RVP)$	$0.3 \cdot \exp(-2.41 + 0.02302\ RVP + 0.09408\ t_a)$
warm and hot soak For fuel injected vehicles (g/procedure)	0.7	none
warm running losses (g/km)	$0.1 \cdot \exp(-5.967 + 0.04259\ RVP + 0.1773\ t_a)$	$0.1 \cdot$ uncontrolled
hot running losses (g/km)	$0.136 \cdot \exp(-5.967 + 0.04259\ RVP + 0.1773\ t_a)$	$0.1 \cdot$ uncontrolled

The application of the proposed methodology requires detailed knowledge of driving behaviour and vehicle park composition.

8.2 Light Duty Vehicles

For estimating evaporative emissions of this category, all vehicles are treated like uncontrolled gasoline passenger cars with regard to emission factors and driving pattern. As in the case of cold start emissions, this is a drastic simplification, because it implies the assumption that light duty vehicles are used in the same way as passenger cars.

8.3 Motorcycles

For estimating evaporative emissions of two wheelers, the latter are treated like uncontrolled gasoline passenger cars with regard to the driving pattern. Due to the smaller fuel tanks of two wheelers, it is assumed that the emissions are 0.2 times those of passenger cars for motor cycles <50 cc and 0.4 times those of passenger cars for motor cycles >50 cc. Again this approach has to be considered as a drastic simplification, which has been chosen only because the required data are not available.

9 SPECIES PROFILES

See the discussion in section 9 of Chapter B710 on road transport.

10 UNCERTAINTY ESTIMATES

Using the indicators introduced in Chapter B710 Table 8.24, Table 10.1 provides qualitative estimates of the precision which can be allocated to the calculation of evaporative losses.

Table 10.1: Summary of Precision Indicators of the Evaporative Emission Estimates (cf. Chapter B710 Table 8.24)

Evaporation	NMVOC
Pass. Cars Conventional	C
Pass. Cars Closed Loop	C
Light Duty Vehicles	D
Two Wheelers <50 cm^3	D
Two Wheelers >50 cm^3 2 str.	D
Two Wheelers >50 cm^3 4 str.	D

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

In general, the estimation of evaporative emissions from gasoline vehicles involves still a large number of uncertainties which can not be solved without carrying out further measurements. Therefore the methodology cannot overcome many of the problems, but can try only to improve on some specific aspects. It should be strongly underlined that the authors see a need to improve the proposed methodology further, in particular in order to take into account better the temperature and RVP dependencies of evaporative emissions for the different vehicle categories. In addition the following points require further attention:

i) evaporative emission factors for all vehicle categories, and

ii) quantitative determination of parameters relevant to evaporative emissions, e.g. fuel properties (Reid vapour pressure);

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Evidently the principles of the approaches outlined for exhaust emission spatial allocation apply equally to evaporative losses. In particular as regards the top down approach, the following hints may be useful:

- **Diurnal losses**: As diurnal losses occur at any time, their spatial allocation to urban/rural/highway conditions depends on the time spent by the vehicles on the different road classes. Therefore for those vehicles that are used by city inhabitants one can assume that 11/12 of their diurnal emissions occur in urban areas, the rest being split between rural and highway driving proportionally to the ratio of (rural mileage · highway speed) / (highway mileage · rural speed)

- **Soak losses**: The majority of these emissions occur in the area of residence of the car owner, as they are associated with short trips.

- **Running losses**: Running losses are proportional to the mileage driven by the vehicles. Therefore their allocation to urban areas - rural areas - highways has to follow the mileage split assumed for the calculation of the exhaust emissions.

13 TEMPORAL DISAGGREGATION CRITERIA

- **Diurnal losses and Soak losses**: The calculation scheme proposed can be applied for finer temporal resolution (e.g. during a diurnal cycle)
- **Running losses**: The temporal variation of these emissions depends (as outlined in Chapter B710 on road transport) on the availability of traffic data (e.g. traffic counts).

14 ADDITIONAL COMMENTS

The evaporation losses calculation scheme presented above, is fully integrated into COPERT II (**Co**mputer **P**rogramme to Calculate **E**missions from **R**oad **T**raffic), which substantially facilitates the practical application of the methodology (see Ntziachristos et al. 1997).

15 SUPPLEMENTARY DOCUMENTS

Eggleston S., D. Gaudioso, N. Gorißen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.-H. Zierock (1993): CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors. Final Report, Document of the European Commission ISBN 92-826-5571-X

Andrias A., Z. Samaras, D. Zafiris and K.-H. Zierock (1993): CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic. Volume 2: COPERT - Computer Programme to Calculate Emissions from Road Traffic - User's Manual. Final Report, Document of the European Commission ISBN 92-826-5572-X

Ntziachristos L., Samaras Z., (1997), COPERT II - Computer Programme to Calculate Emissions from Road Transport, User’s Manual - European Environmental Agency

16 VERIFICATION PROCEDURES

See the discussion in Chapter 16 of Chapter B710 on road transport.

17 REFERENCES

CONCAWE (1987): An investigation onto evaporative hydrocarbon emissions from European vehicles. Report N° 87/60

CONCAWE (1990): The effects of temperature and fuel volatility on vehicle evaporative emissions. Report N° 90/51

Eggleston S. (1991): Data on evaporative emissions of gasoline passenger cars submitted to the CORINAIR Working Group on Emission Factors for Calculating 1990 Emissions from Road Traffic. Brussels 7 and 8/10/1991

Gorißen N. (1988): Evaporative Emissions of Gasoline Powered Vehicles. Paper contributed to the CORINAIR working group on Emission from Road Traffic, unpublished. Umweltbundesamt, Berlin

Heine P. and Baretti A. (1987): Emissionsfaktoren für die Verdampfungsemissionen von Kraftfahrzeugen mit Ottomotoren. Im Auftrag des Umweltbundesamtes Berlin, November 1988

Mobley J.D. and M. Saeger (1994): Concepts for Emissions Inventory Verification, US EPA Draft Final Report.

U.S. Environmental Protection Agency (1990): Volatile Organic Compounds from On-Road Vehicles - Sources and Control Options. Draft Report

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U.S. Environmental Protection Agency; *Supplement A to Compilation of Air Pollutant Emission Factors (AP-42) - Volume II: Mobile Sources*, Test and Evaluation Branch, Office of Air and Radiation, January 1991.

U.S. Environmental Protection Agency; *User's Guide to MOBILE5*, Test and Evaluation Branch, Office of Air and Radiation, Draft 4a, December 3, 1992.

Organisation for Economic Co-operation and Development (OECD); *Estimation of Greenhouse Gas Emissions and Sinks*, Final Report, prepared for the Intergovernmental Panel on Climate Change, revised August 1991.

List of Abbreviations

CH_4:	Methane
NMVOC:	Non-Methane Volatile Organic Compounds
RVP:	Reid Vapour Pressure (standardised vapour pressure measurement, conducted at 38 ^{o}C, with a vapour: liquid ratio 4:1)
VOC:	Volatile Organic Compounds

List of Symbols

a_j	=	number of gasoline vehicles of category j, operated in 1990
e^{d}	=	mean emission factor for diurnal losses of gasoline powered vehicles equipped with metal tanks, depending on average monthly weighted temperature, temperature variation and fuel volatility (RVP)
$e^{s,hot}$	=	mean emission factor for hot soak emissions
$e^{s,warm}$	=	mean emission factor for cold and warm soak emissions
e^{fi}	=	mean emission factor for hot and warm soak emissions of gasoline powered vehicles equipped with fuel injection
$e^{r,hot}$	=	average emission factor for hot running losses of gasoline powered vehicles
$e^{r,warm}$	=	average emission factor for warm running losses of gasoline powered vehicles
l_{trip}	=	average trip length
p	=	fraction of trips, finished with hot engine (depending on the average monthly ambient temperature)
q	=	fraction of gasoline powered vehicles equipped with fuel injection
t_a	=	monthly mean ambient temperature in [^{o}C]
$t_{a,min}$	=	monthly mean minimum ambient temperature in [^{o}C]
$t_{a,rise}$	=	monthly mean of the daily ambient temperature rise in [^{o}C]

w	=	fraction of trips, finished with cold or warm engine
x	=	mean number of trips of a vehicle per day, average over the year
y	=	total number of trips of a vehicle per day
β_j	=	fraction of mileage driven with cold engines
$E_{eva,VOC,j}$	=	VOC emissions due to evaporative losses, caused by vehicles of category j under urban driving conditions
R	=	hot and warm running losses
S^c	=	average hot and warm soak emission factor of gasoline powered vehicles equipped with carburettor
S^{fi}	=	average hot and warm soak emission factor of gasoline powered vehicles equipped with fuel injection

19 RELEASE VERSION, DATE AND SOURCE

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