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1.0 Introduction

Methane is an important constituent of exhaust emission gases. However, unlike other hydrocarbon species, Methane does not contribute significantly to ozone formation due to its chemical properties. Thus, MOBILE6 is required to separate it from other more reactive hydrocarbons when estimating vehicle emissions. A data analysis was done to determine the methane emissions from exhaust so that they could be properly accounted for in MOBILE6. This document briefly describes methodologies for calculating this methane "offset" based on the separation of start and running emissions proposed for MOBILE6, and presents the results.

The calculation procedure follows the scheme of modeling the in-use deterioration of emissions as a function of accumulated mileage. For model year 1981-1993 light-duty cars and trucks, stratified into carbureted versus fuel-injected, the method parallels that used for total hydrocarbons, carbon monoxide and oxides of nitrogen. This analysis utilizes actual methane data from emissions tests conducted on vehicles from those model years. For pre-1981 model year light-duty vehicles and most heavy-duty vehicles, data of the type used in the newer vehicles is not available. Therefore, procedures are described for estimating methane as a function of mileage using existing data in combination with methods that are applied in MOBILE5b.

2.0 Data

The data underlying the analysis of 1981-93 light-duty vehicles are drawn from a subset of the Federal Test Procedure (FTP) tests described in the reports cited above. These tests were conducted by EPA, the American Automobile Manufacturers Association (AAMA), and the American Petroleum Institute (API). Most, but not all, of these tests produced measurements of methane. In particular, the database sample sizes for which methane is recorded are compared in the table below, subdivided by vehicle type and the model year/technology groups used to determine basic emission rates of total HC, CO and NOx.

Another key data set is that based on a sample of FTP tests to which were appended a 505-second cycle without an engine start. This cycle is identical to that of Bags 1 and 3, but contains no emissions associated with the cold start of Bag 1 or warm start of Bag 3. It is referred to as the Hot Running 505 (HR505). Pure cold and warm start emissions are estimated by deducting HR505 emissions from the 505 bags that include a start.3 The data from this test program were used to estimate the relation between the HR505 and Bags 1 to 3 of an FTP. From this function, the portions of FTP emissions attributed to start and running are computed. This calculation then was applied to the larger FTP data set described above for which Bags 1 to 3, but not the HR505, are measured.

Table 1 **Car and Truck Sample Sizes Used in the Methane Analysis**			
Car Group	**Sample Size**	**Truck Group**	**Sample Size**
1981-82 Carb	580	1981-83 Carb	72
1981-82 FI	88	1981-87 FI	92
1983-85 Carb	203	1984-93 Carb	125
1983-87 FI	688	1988-93 PFI	199
1986-93 Carb	93	1988-93 TBI	458
1988-93 PFI	1361		
1988-93 TBI	437		

3.0 1981-93 Gasoline Cars and Light Trucks

To understand the current analysis, it is helpful to review how emissions deterioration is modeled in MOBILE6. The basic method involves separating start and running emissions.

3.1 Running Emissions

For the running component, simple linear functions of emissions versus mileage are fitted by the method of least squares regression. To improve the fit at low mileage, the mean of emissions is used. This produced piecewise continuous functions in which emission rates (in grams per mile) are constant at low mileage and increase when mileage accumulation exceeds approximately 20,000 miles. The higher mileage portion of the function has constant slope in most cases, but under certain conditions the slope may change, adding a second "corner" point to the graph of emissions as a function of mileage. There was also a concern that the FTP data suffer from sample bias due to the self-selecting nature of the data collection. In order to account for such bias, adjustments were made to these running emission lines using data from a large sample of inspection and maintenance tests conducted in Dayton, Ohio. (See document M6.EXH.003 for details.) However, methane was not recorded in these tests, so it was not possible to compute this adjustment for the analysis described in this report. Instead, we propose using a proportional adjustment for sample bias corresponding to that used for total HC.

Tables 2a and 2b report the running LA4 emissions deterioration coefficients derived for methane for cars and light trucks, respectively. These coefficients include the effect of correcting the underlying FTP data for recruitment bias (Dayton correction factor). The first slope in effect for the mileage up to the Corner1 (this is typically about 20,000 miles) is always zero. This reflects the use of the low mileage mean (ZML Emissions), and the lack of deterioration on very low mileage vehicles.. The first Corner occurs at the mileage where the emission rate begins to slope positively. Between Corner1 and Corner2, 'Slope1' in Tables 2a and 2b are used to calculate methane deterioration. The 'Slope2' in Tables 2a and 2b are used for mileages greater than Corner2. The methane emission factors are in units of grams per mile, the slopes are in units of g/mi per 10,000 miles, and the corners are in units of 10,000 miles.

Table 2a
Methane Running Emissions Deterioration Model Coefficients for Cars

MY Group	ZML (g/mi)	Slope1 (g/mi) per 10K miles	Corner1 10k miles	Slope2 (g/mi) per 10K miles	Corner2 10k miles
1981-82 Carb	0.0845	0.019	2.211	0.009	10.000
1981-82 FI	0.0271	0.020	1.392	0.020	26.540
1983-85 Carb	0.0721	0.002	2.000	0.000	10.000
1986-93 Carb	0.0405	0.019	1.519	0.009	7.191
1983-87 FI	0.0365	0.000	2.121	0.006	8.129
1988-93 TBI	0.0240	0.004	3.218	0.004	10.000
1988-93 PFI	0.0167	0.004	1.547	0.005	6.789

Table 2b
Methane Running Emissions Deterioration Model Coefficients for Light Trucks

MY Group	ZML (g/mi)	Slope1 (g/mi) per 10K miles	Corner1 10k miles	Slope2 (g/mi) per 10K miles	Corner2 10k miles
1981-83 Carb	0.1033	0.003	1.235	0.003	8.035
1981-87 FI	0.0594	0.000	4.867	0.004	10.000
1984-93 Carb	0.1118	0.00	9.072	0.003	10.000
1988-93 TBI	0.0253	0.004	1.625	0.005	5.446
1988-93 PFI	0.0291	0.004	1.918	0.009	10.000

3.2 Start Emissions

The Methane Start emissions are modeled with a simple linear regression through the cold start emission estimates instead of the piecewise linear regression used to model the running emissions. These were derived from straight least squares linear regressions of the data after it had been disaggregated into the model year and technology grouping shown in Table 3. Hot start emissions are calculated as a function of cold start estimates. The regression coefficients for cars and light trucks are shown in Table 3.

Table 3
Methane Start Emissions Deterioration Model Coefficients
Cars and Light Trucks

Cars			**Light Trucks**		
MY Group	ZML (g/mi)	Deterioration (g/mi per 10K miles)	**MY Group**	ZML (g/mi)	Deterioration (g/mi per 10K miles)
1981-82 Carb	0.2003	0.021	1981-83 Carb	0.4062	0.010
1981-82 FI	0.1005	0.014	1981-87 FI	0.0927	0.003
1983-85 Carb	0.1373	0.018	1984-93 Carb	0.2707	0.009
1986-93 Carb	0.1023	0.004	1988-93 TBI	0.1402	0.000
1983-87 FI	0.0963	0.001	1988-93 PFI	0.0505	0.000
1988-93 TBI	0.0711	0.000			
1988-93 PFI	0.0936	0.002			

3.3 FTP Emissions

Final FTP deterioration functions can be obtained by combining the start and running estimates according to their relative importance in that test. The weights used coincide with those used for HC, CO and NOx. They form the equation:

$$FTP=(7.5*Run + .43*CS + .57*HS)/7.5 \quad \text{Eqn 1}$$

where: Run is emissions in grams per mile from the running LA4 portion; CS is emissions in grams from cold start; and HS is hot start, computed as simply 0.16*CS. The factor 7.5 is the driving mileage corresponding to Bags 1 and 2 (the LA4 cycle) in the FTP. The HS factor of 0.16 was determined from statistical analysis of FTP bag emission data (See M6.STE.003).

4.0 Other Model Year Gasoline Cars and Trucks

4.1 Pre-1981 Model Years

For pre-1981 model year light duty vehicles, MOBILE5 estimated the methane emissions separately for each of the three FTP bags. MOBILE6 calculates the overall methane for pre-1981 model year light duty vehicles identically to those in MOBILE5. MOBILE6 uses these methane emission bag results to calculate the methane emission rate for running and engine start emissions separately.

The rate of methane emissions for the running emission estimate is calculated as the VMT weighted average of FTP Bag 2 (52.1% stabilized operation) and FTP Bag 3 (47.9% hot engine start). The effect of the hot engine start in FTP Bag 3 on the methane emission rate is assumed to be negligible. The combined driving cycle in these two bags matches the LA4 driving cycle of the basic exhaust emission factor for MOBILE6.

The rate of methane emissions for the engine start emission estimate is calculated from the methane rate in FTP Bag 1 (cold engine start) less the methane rate in FTP Bag 1 (hot engine start). The driving cycle of both FTP Bag 1 and FTP Bag 3 are identical. The difference in the emission rates in grams per mile is multiplied by the number of miles in FTP Bag 1 or FTP Bag 3 (both are 3.49 miles) to give the methane in grams. It is assumed that this represents the methane grams in a engine cold start. This assumes that the effect of the hot engine start on the rate of methane in bag 3 is negligible.

4.2 Model Years 1994 and Later

For model year 1994 and later vehicles subject to Tier I standards, the basic hydrocarbon emission factors in MOBILE6 are in terms of non-methane hydrocarbon (NMHC) emissions. In the case of LEVs and Tier2 vehicles, the HC emission factors are in terms of non-methane organic gas (NMOG). For consistency, the model also needs to calculate and report hydrocarbon emissions in terms of Total hydrocarbon (THC), volatile organic gases VOC), and total organic gases (TOG) for these model years. Thus, the calculation of a methane offset is required.

Unfortunately, no adequate methane data exist for estimating methane deterioration functions for these technologies. Therefore, EPA proposes to develop multiplicative methane offsets from the Tier0 vehicle data. This means using a ratio of the HC certification standards to step down the methane fraction of Tier0 vehicles to the Tier1 and later technology vehicles.

$$\text{Tier1 Methane} = \text{Tier0 Methane (Tier1 Cert Std / Tier0 Cert Std)} \qquad \text{Eqn 2}$$

5.0 Methane Offset for Other Vehicle Types

The vehicles covered in this section are non-light duty gasoline vehicles or MOBILE6 vehicle types 6 through 28. Initially, it was decided to just use the methane offsets from MOBILE5 in MOBILE6, and not do any updates for these vehicles. The rationale for this decision was a complete lack of new data. However, it was discovered that the MOBILE5 methane offsets were inconsistent and generally too large relative to the new lower hydrocarbon certification standards and projected HC emission factors. Also, the MOBILE5 methane offsets were generally in terms of the full FTP cycle, and contained no individual FTP Bag Fractions. The use of the absolute gram per mile FTP cycle based methane offset was a problem since it was desired in MOBILE6 to split the FTP cycle emissions into running and start emission components.

The solution that was chosen was to change the MOBILE6 methane offsets so that they are proportionally the same to the MOBILE6 base hydrocarbon emission factors as the MOBILE5 methane offsets were. This is accomplished by computing the ratio of the MOBILE5 methane offset to the MOBILE5 base emission factor, and applying this ratio to the MOBILE6 base emission factors to produce an updated methane offset. The data on which the MOBILE5 ratios were based was obtained from EPA document AP-42. The calculation of each methane fraction value is discussed below.

5.1 Heavy-Duty Gas Vehicles (HDGV)

Analysis of the MOBILE5 methane offset and base emission factors from AP-42 showed for HDGVs the base emission factor and the methane offset are fairly constant across 1988+ model years in MOBILE5. For example, the base emission rate is approximately 0.820 g/mi and the methane offset is approximately 0.095 g/mi. Thus, the ratio is 0.095/0.820 = **0.116 for HDGV** for 1988 and newer vehicles in MOBILE6**.** The pre-1988 model year methane offsets were not changed for the HDGV class.

5.2 Heavy-Duty Diesel Vehicles (HDDV)

A similar analysis of the MOBILE5 methane offsets was done for the HDDVs. Like the HDGVs, the ratios are generally consistent for the 1988 and later model years in MOBILE5. Here, the base emission factors and methane offset are 2.18 g/mi and 0.100 g/mi respectively. The ratio is 0.100 / 2.18 = **0.046 for HDDV** for1988 and newer vehicles in MOBILE6. The pre-1988 model year methane offsets were not changed for the HDDV class.

5.3 Light-Duty Diesel Vehicles (LDDV and LDDT)

Similarly, the LDDVs (IV=14,15 and 28) show fairly constant base emission factors and methane offsets in MOBILE5. In MOBILE5, the methane offsets were in terms of absolute grams per mile units. On a percentage basis, these methane offsets range from about 0.5 percent to 3.0 percent of the base HC emissions. These factors have not been updated in many years so generally the same offset was used for a number of model years. Since the overall hydrocarbon emission level has decreased, the lower relative methane offsets (0.5%) are for the older model years and the higher values are for the newer model years (3.0%).

Unfortunately, because of the structure of the MOBILE6 code, a methane offset in absolute grams per mile units could not easily work. Thus, a relative or percentage unit was needed. Lacking any new data, a **1.0 percent** methane offset was chosen for use in MOBILE6 for vehicle types 14, 15 and 28 for the 1988 and later model years.

5.4 Motorcycles

Like the light-duty gasoline vehicles, the motorcycle's calculation and report are in terms of both running and start emissions. Unfortunately, the MOBILE5 methane offsets are in terms of FTP emissions. Also, the ratio of methane to base emissions is neither constant (like for HDDV and HDGV) or small like (LDDV). For instance, the methane offsets range from about 7 percent to about 20 percent based on age / mileage. This is a fairly large range so picking a number within this range would seem arbitrary.

Rather than assuming a fixed percentage between 7 and 20 percent, multiplicative factors to the base FTP methane emission factors to produce separate start and running methane emission factors were developed. The running factor that is applied to the FTP offsets (in grams per mile) is 0.792. This creates a running emission methane offset in grams per mile. The start emission methane offset is calculated by multiplying the FTP emissions in grams per mile by 0.283 * 7.5 = 2.1225 to produce a methane start offset in grams (the 7.5 miles is the FTP mileage). The offsets of 0.792 and 2.1225 are the same offsets used to split the MOBILE5 based FTP base motorcycle emission factors into separate start and running emission factors. Thus, the methane offset is consistent with the basic motorcycle emission factors. Also, splitting by start and running methane in this fashion will allow motorcycle methane emissions to continue to vary by age / mileage like they did in MOBILE5.