PM Speciation Profiles for Gasoline-Powered Vehicle Exhaust

Wenli Yang, PhD
Planning and Technical Support Division
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1 Background

There are currently two official ARB gasoline vehicle exhaust PM speciation profiles, PM399 and PM400. PM399 is for PM emitted by gasoline-powered vehicles without a catalytic converter, and PM400 is for PM emitted by gasoline-powered vehicles equipped with a catalytic converter [1]. These two profiles were created based on source tests conducted by KVB INC in 1978 under ARB research contract 5-1323 [2]. Problems exist with the current profiles in that they indicate that PM exhaust from gasoline vehicles consists of 45% sulfate and no organic carbon (OC). However, all source tests on gasoline vehicles have shown that OC and elemental carbon (EC) are the most abundant species, and the content of sulfate is much less compared to OC and EC. Because of these discrepancies, the existing ARB gasoline vehicle PM profiles need to be updated using currently available vehicle source testing results.

Gasoline-powered vehicle PM is an important contributor to the total PM emissions. For calendar year 2010, the statewide annual average $PM_{2.5}$ emitted from gasoline vehicles was 16.3 tons/day, which was 1.8% of the total statewide $PM_{2.5}$ emissions [3]. In addition to on-road gasoline vehicles, there are other categories for which these two profiles are used, such as gasoline-fueled off-road equipment, recreational boats, and motor homes. The update of the PM profiles for gasoline vehicles will also improve the emission inventory for those categories. The overall $PM_{2.5}$ emissions from all gasoline-fueled related categories are 28.6 tons/day, which is 3.2% of the total statewide $PM_{2.5}$ emissions inventory [3]. In this work, the following three PM profiles are developed for California air quality modeling and emission inventory use:

- PM4001—Gasoline Vehicle Equipped with Catalytic Converter
- PM4002—Gasoline Vehicle without Catalytic Converter
- PM4003—Smoking Gasoline Vehicle (High Emitter)

2 Profile Updates

In this section the methodology and data used for profile updates is discussed. Since a complete ARB PM profile includes two parts, the weight fraction of chemical species and the particle size fraction, separate discussions of each of these two parts are provided. Section 2.1 covers the update to the chemical species fractions while Section 2.2 covers the update to the particulate matter size fractions.

2.1 Chemical Species Profile Updates

In order to create representative profiles that map to ‘catalyzed’, ‘non-catalyzed’ and ‘smoking vehicle’ emissions, this update required combining detailed study-specific source test data into

three corresponding profiles (catalyzed, non-catalyzed and smoking gasoline vehicle profiles). To distinguish between study-specific data and composited data in this document, the study-specific data and composited data are labeled differently (i.e. with different prefixes). Detailed profile data from source testing studies are numbered starting with the letter 'G' (for gasoline). The 'G' profiles include relatively detailed vehicle and test condition information and are used for making composite ARB speciation profiles. The composite profiles are PM4001, PM4002, and PM4003. PM4001 and PM4002 will be mapped to catalyzed and non-catalyzed emission categories in the ARB emission inventory. PM4003 will not be mapped to the emissions inventory for reasons described later.

The following study-specific data sources were used to create the 'G' profiles that are summarized in Table 1.

a. Kansas City PM characterization study [4]

   This study measured PM from approximately 480 randomly selected light duty gasoline vehicles in the Kansas City Metropolitan Area in 2004 and 2005. Full chemical speciation was determined from over 100 vehicles tested over the LA92 Unified Driving Cycle (UC). All the vehicles were certified to Federal Standards. Local summer and winter fuels were used in the tests. Sixteen profiles, G30010-G30025 (Table 1), were created for different model year groups. All the profiles are for catalyzed gasoline vehicles.

b. CRC E-24-2: Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles [5]

   This study was conducted in Southern California from September 1996 to August 1997. Chemical analyses were performed on 40 gasoline vehicles. All vehicles were tested over the Federal Test Procedure (FTP) Cycle. California Phase 2 Reformulated Gasoline (CaRFG2) was used for the test vehicles. Four profiles, G30026-G30029 (Table 1), were created for different model year groups. Profiles G30026-G30028 are for catalyzed vehicles and G30029 is for non-catalyzed vehicles.

c. Gasoline/Diesel PM Split Study: Source and Ambient Sampling, Chemical Analysis, and Apportionment Phase [6]

   Tailpipe emissions of particulate matter from 53 gasoline vehicles were characterized during the cold-start and warm-start UC cycles on chassis dynamometers as part of the Gasoline/Diesel PM Split Study conducted in Riverside, California in 2001. CaRFG2 was used for the test vehicles. Eleven profiles (Table 1) resulted from this study: G30036-G30054. These are for catalyzed vehicles over different model year groups and mileage ranges. G30055 is the profile for smoking vehicles (i.e., high emitter).

Table 1. Study-specific, intermediate 'G' profiles created from source tests

Study	Profile No.	Catalyzed or non-catalyzed	Model Year	Fuel	Test Cycle	No. of test vehicles	Note (Vehicle type or Catalyst type or Start type)
Kansas City PM Study	G30010	Catalyzed	pre-81	summer	UC	2	Truck
	G30011	Catalyzed	81-90	summer	UC	4	Truck
	G30012	Catalyzed	91-95	summer	UC	6	Truck
	G30013	Catalyzed	96+	summer	UC	8	Truck
	G30014	Catalyzed	pre-81	summer	UC	5	Car
	G30015	Catalyzed	81-90	summer	UC	4	Car
	G30016	Catalyzed	91-95	summer	UC	7	Car
	G30017	Catalyzed	96+	summer	UC	15	Car
	G30018	Catalyzed	pre-81	winter	UC	3	Truck
	G30019	Catalyzed	81-90	winter	UC	4	Truck
	G30020	Catalyzed	91-95	winter	UC	8	Truck
	G30021	Catalyzed	96+	winter	UC	11	Truck
	G30022	Catalyzed	pre-81	winter	UC	5	Car
	G30023	Catalyzed	81-90	winter	UC	6	Car
	G30024	Catalyzed	91-95	winter	UC	9	Car
	G30025	Catalyzed	96+	winter	UC	9	Car
CRC E-24-2	G30026	Catalyzed	91-97	CaRFG2	FTP	9	TWC
	G30027	Catalyzed	86-90	CaRFG2	FTP	11	TWC
	G30028	Catalyzed	81-85	CaRFG2	FTP	9	TWC+OC
	G30029	Non-catalyzed	pre-81	CaRFG2	FTP	11	Truck+Car
Gasoline /Diesel PM Split Study	G30036	Catalyzed	96+	CaRFG2	UC	4	<50K mile, cold start
	G30037	Catalyzed	96+	CaRFG2	UC	4	<50K mile, warm start
	G30038	Catalyzed	93-95	CaRFG2	UC	4	<75K mile, cold start
	G30039	Catalyzed	93-95	CaRFG2	UC	4	<75K mile, warm start
	G30040	Catalyzed	96+	CaRFG2	UC	4	>100K mile, cold start
	G30041	Catalyzed	96+	CaRFG2	UC	4	>100K mile, warm start
	G30042	Catalyzed	90-92	CaRFG2	UC	4	<100K mile, cold start
	G30043	Catalyzed	90-92	CaRFG2	UC	4	<100K mile, warm start
	G30044	Catalyzed	93-95	CaRFG2	UC	8	>125K mile, cold start
	G30045	Catalyzed	93-95	CaRFG2	UC	8	>125K mile, warm start
	G30046	Catalyzed	90-92	CaRFG2	UC	9	>125K mile, cold start
	G30047	Catalyzed	90-92	CaRFG2	UC	9	>125K mile, warm start
	G30048	Catalyzed	86-89	CaRFG2	UC	6	>125K mile, cold start
	G30049	Catalyzed	86-89	CaRFG2	UC	6	>125K mile, warm start
	G30050	Catalyzed	81-85	CaRFG2	UC	6	>125K mile, cold start
	G30051	Catalyzed	81-85	CaRFG2	UC	6	>125K mile, warm start
	G30052	Catalyzed	pre-81	CaRFG2	UC	6	>125K mile, cold start
	G30053	Catalyzed	pre-81	CaRFG2	UC	6	>125K mile, warm start
	G30054	Smoker	69-90	CaRFG2	UC	6	Smoker, cold start
	G30055	Smoker	69-90	CaRFG2	UC	6	Smoker, warm start

Three composite PM profiles are developed using the 'G' profiles listed in Table 1:

- PM4001—Gasoline Vehicle Equipped with Catalytic Converter
- PM4002—Gasoline Vehicle without Catalytic Converter
- PM4003—Smoking Gasoline Vehicle (High Emitter)

The complete chemical species for the three composite profiles PM4001, PM4002 and PM4003 are provided in Table 2. These composite profiles will be added to the ARB speciation profile database. However, PM4003 for smoking vehicles will not be assigned to any category in the inventory (see discussion below). The discussion below provides additional details for each of the composite profiles as well as plots of the relative amount of the five species that are used in photochemical modeling (OM, EC, sulfate, nitrate, and all other species).

- ***PM4001: Gasoline Vehicle Equipped with Catalytic Converter***

  All the 'G' profiles obtained from catalyzed vehicle tests (Table 1) are used to generate the composite ARB profile PM4001—Gasoline Vehicle Equipped with Catalytic Converter. The 'G' profiles include: G30010-G30028 and G30036-G30053. The profiles cover a wide model year range and they can be grouped into four groups: pre-81, 81-90, 91-95 and 96+. No apparent trend can be found in speciation profiles with changing model year (Figure 1). Similarly, there are no significant impacts of fuel type (winter vs. summer fuel; CaRFG2 vs. Kansas fuel), start type (cold start vs. hot start) and vehicle type (car vs. pickup) shown in speciation by comparing these profiles in corresponding groups. Therefore the arithmetic mean of all the above 'G' profiles is calculated as the composite ARB speciation profile for the gasoline vehicles equipped with a catalytic converter, in which OM is 56.0%, EC is 25.2%, and sulfate is 4.7% (Table 2 and Figure 2).

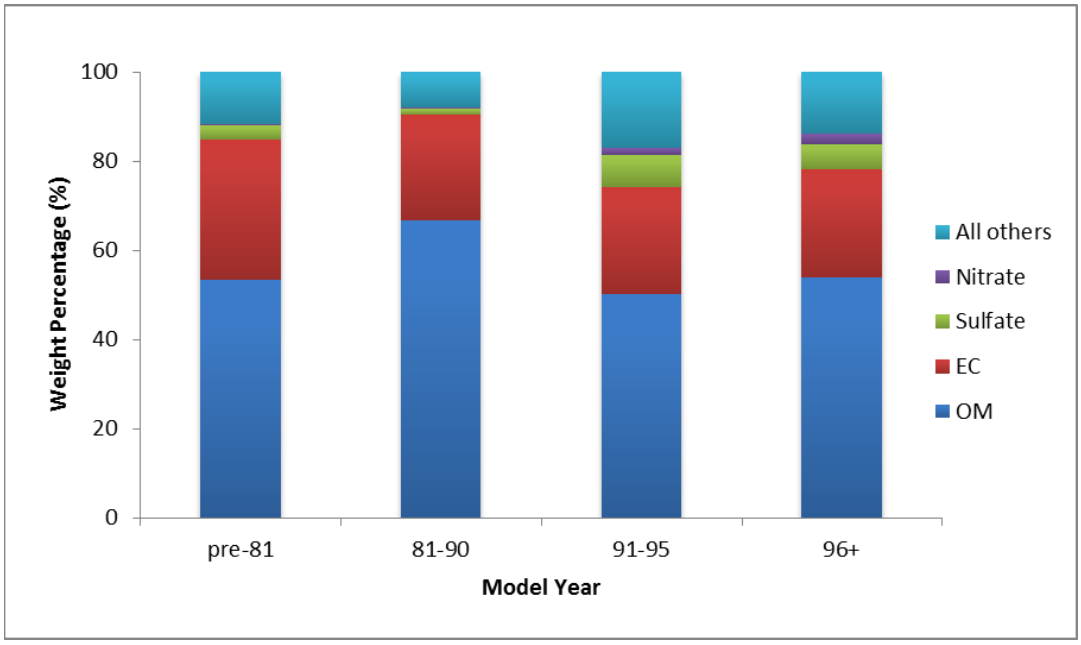

Figure 1. Impact of Model Year on Modeling-required PM Species for PM4001 (Table 2 provides a detailed list of composited species for PM4001)

- ***Gasoline Vehicle without Catalytic Converter (PM4002)***

  Because all gasoline vehicles have been catalyzed since about 1980, the tests for non-catalyzed vehicles are very limited. The only available 'non-catalyzed' profile listed in Table 1 is Profile G30029, and it is used to replace the existing ARB non-catalyzed vehicle PM profile. Since it is the only detailed profile, Profile G30029 is renumbered as ARB PM4002. This profile indicates that 76.2% of the PM2.5 emitted from non-catalyzed vehicles is OM and 14.1% is EC (Table 2 and Figure 2). Compared to the profile for catalyzed vehicles (i.e. PM4001), the PM exhausts from non-catalyzed vehicles consist of 20% more OM and 10% less EC.

- ***Smoking Gasoline Vehicle (PM4003)***

  Although ARB's current emissions inventory does not have a specific emissions category defined to represent smoking vehicles, a profile for high emitters (PM4003) has been created along with the profiles for catalyzed and non-catalyzed vehicles. Because the small fraction of high emitters in the fleet can account for a disproportionate fraction of cumulative emissions [7], this profile may be useful in the future or for research purposes. However, it will not be assigned to any category in the current ARB emission inventory. As illustrated in Table 1, there are two study-specific profiles available for smoking vehicles: G30054 and G30055. They are based on tests of 12 smoking vehicles conducted in the Gasoline/Diesel PM Split Study [6]. The average of these two profiles is calculated as PM4003. The OM is as high as 84.0% of the total PM2.5 mass (Table 2 and Figure 2).

As illustrated in Figure 2, the profile for catalyzed gasoline vehicles (PM4001) consists of more EC, sulfate and nitrate than the profiles for non-catalyzed (PM4002) and smoking (PM4003) vehicles, and there is less OM in the catalyzed profile than in the other two profiles.

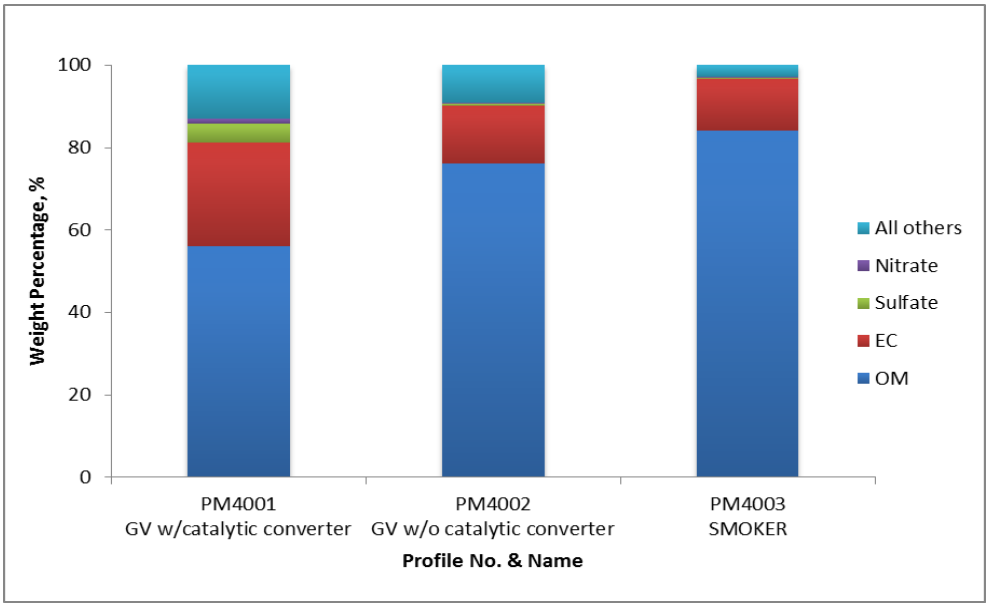

Figure 2. Impact of Model Year on modeling-required PM Species (Table 2 provides a detailed list of composited species)

Table 2. ARB gasoline vehicle (GV) $PM_{2.5}$ speciation profiles

Species		Profile (weight Percentage, %)		
Name	SAROAD*	PM4001 GV with Catalytic Converter	PM4002 GV without Catalytic Converter	PM4003 Smoking GV
OM	11102	56.0003 *(±11.8147)***	76.1821	84.0137 *(±1.0871)*
EC	12116	25.1753 *(±9.8101)*	14.0601	12.6835 *(±1.1693)*
sulfate	12403	4.6731 *(±4.398)*	0.4175	0.2718 *(±0.0208)*
nitrate	12306	1.0823 *(±1.6468)*	0.1278	0.1374 *(±0.0433)*
aluminum	12101	0.1701 *(±0.1921)*	0.1007	0.0311 *(±0.0156)*
ammonium	12301	1.3626 *(±2.1944)*	0.3301	0.0957 *(±0.0057)*
antimony	12102	0.0192 *(±0.0341)*	0.0028	0.0036 *(±0.0011)*
arsenic	12103	0.0012 *(±0.0022)*		
barium	12107	0.0971 *(±0.1198)*	0.0139	0.0880 *(±0.0974)*
bromine	12109	0.0228 *(±0.0309)*	0.0042	0.00050 *(±0)*
cadmium	12110	0.0043 *(±0.0062)*		0.0059 *(±0.0066)*
calcium	12111	0.7196 *(±0.4822)*	0.3692	0.3207 *(±0.0559)*
chloride ion	12203	0.2095 *(±0.2906)*	0.3766	0.1975 *(±0.1341)*
chlorine	12115	0.0719 *(±0.3038)*		
chromium	12112	0.0399 *(±0.0475)*	0.0397	0.0014 *(±0.0011)*
cobalt	12113	0.0021 *(±0.0031)*		0.0006 *(±0.0008)*
copper	12114	0.0689 *(±0.0726)*	0.0366	0.0439 *(±0.0141)*
gallium	12124	0.0042 *(±0.006)*		0.0016 *(±0.0017)*
gold	12143	0.005 *(±0.0087)*		0.0022 *(±0.0028)*
indium	12131	0.0043 *(±0.0056)*		0.0019 *(±0.0027)*
insoluble chlorine	12202	0.0358 *(±0.0913)*	0.1310	0.0068 *(±0.0032)*
insoluble potassium	12182	0.0063 *(±0.015)*		0.0083 (±0.0041)
iron	12126	0.6937 *(±0.6093)*	2.0593	0.0818 (±0.0025)
lanthanum	12146	0.0545 *(±0.0967)*	0.0076	0.0070 (±0.0099)
lead	12128	0.0434	0.1062	0.0185

Species		Profile (weight Percentage, %)		
Name	SAROAD*	PM4001 GV with Catalytic Converter	PM4002 GV without Catalytic Converter	PM4003 Smoking GV
		(±0.0359)		*(±0.0065)*
magnesium	12140	0.157 *(±0.1436)*	0.1805	0.1445 *(±0.0449)*
manganese	12132	0.0110 *(±0.0145)*	0.0167	0.0007 *(±0.0002)*
mercury	12142	0.0018 *(±0.0024)*		0.0009 *(±0.0013)*
molybdenum	12134	0.0085 *(±0.0085)*		0.0012 *(±0.001)*
nickel	12136	0.0118 *(±0.0158)*	0.1059	0.0014 *(±0.0002)*
nonsulfate sulfur	12404	0.2839 *(±0.2281)*	0.1350	0.1468 *(±0.0158)*
palladium	12151	0.0092 *(±0.0096)*		0.008 *(±0.0006)*
phosphorous	12152	0.2576 *(±0.2115)*	0.3298	0.1919 *(±0.0261)*
potassium	12180	0.0321 *(±0.0635)*	0.0061	
potassium ion	65312	0.0346 *(±0.047)*		0.0029 *(±0.0013)*
rubidium	12176	0.0014 *(±0.0024)*		0.0001 *(±0.0001)*
selenium	12154	0.0005 *(±0.0012)*		
silicon	12165	3.0828 *(±2.7817)*	1.4391	0.4816 *(±0.1544)*
silver	12166	0.009 *(±0.0103)*		0.0037 *(±0.0034)*
sodium	12184	0.6523 *(±1.2652)*	0.0071	0.0113 *(±0.016)*
strontium	12168	0.0021 *(±0.0026)*		0.0006 *(±0.0001)*
thallium	12173	0.0017 *(±0.0035)*		
tin	12160	0.0089 *(±0.0098)*	0.0030	0.0048 *(±0.0045)*
titanium	12161	0.0215 *(±0.0428)*		0.0007 *(±0.0009)*
uranium	12179	0.0037 *(±0.0042)*		0.0006 *(±0.0002)*
vanadium	12164	0.009 *(±0.0241)*		0.0001 *(±0.0002)*
yttrium	12183	0.0011 *(±0.0023)*		
zinc	12167	0.5564 *(±0.4207)*	0.6479	0.2338 *(±0.0279)*
zirconium	12185	0.0084 *(±0.0181)*		0.0004 *(±0)*
others	12999	4.2662 *(±3.1501)*	2.7633	0.7406 *(±0.1415)*

Species		Profile (weight Percentage, %)		
Name	SAROAD*	PM4001 GV with Catalytic Converter	PM4002 GV without Catalytic Converter	PM4003 Smoking GV
total		100.0000	100.0000	100.0000

Note: *ARB's arbitrary 5 digit chemical code; **Standard deviations are listed in the paraphrases with average values.

2.2 Size Fraction Profile Updates

A complete ARB PM profile includes two parts, the weight fraction of chemical species and the particle size fraction. The prior section covered the chemical species distribution. This section covers size fraction distribution.

In the current ARB Profile PM399, 90% of the total particulate matter emitted by non-catalyzed gasoline vehicle is PM_{10} and 68% is $PM_{2.5}$; while Profile PM400 indicates that 97% of the total particulate matter emitted by catalyzed gasoline vehicle is PM_{10} and 90% is $PM_{2.5}$. As the speciation part of these two profiles is being updated, their corresponding size fraction profiles need to be updated too.

The updated speciation profiles are based on analyses of $PM_{2.5}$ only because there are no available data for TPM and PM_{10} speciation. Of the studies listed in Table 1, only CRC E-24-2 collected limited particle size distributions. One reason for this is that it is well known that the majority of the exhaust-emitted PM from motor vehicles is in the $PM_{2.5}$ size range [4]. The average composite MOUDI (Micro-Orifice Uniform-Deposit Impactor) size distributions obtained from the CRC E-24-2 Study [5] are listed in Table 3. There appears to be a modest trend toward a larger fraction of the particulate below 10 and 2.5 um with older cars.

Table 3. Summary of size fractions of gasoline vehicles PM from source testing studies

Study Name	*Model Year Range*	*PM_{10}/TPM (%)*	*$PM_{2.5}$/TPM (%)*	*No. of test vehicles*
CRC E-24-2 [5]	1991-97	83.2	73.6	38
	1986-90	90.2	84.1	28
	1981-85	94.9	89	19
	Pre-1981	96.1	91.7	12
Smoking Vehicle Study [8]	Smoking Vehicles	97.1	93.5	18

- ***PM4001: Gasoline Vehicle Equipped with Catalytic Converter***

If corresponding emissions mass estimates for the different model year groups in Table 3 (i.e., 1991-97, 1986-90, and 1981-85) were available, an emission-weighted composite size fraction profile could be calculated for each calendar year. However, due to the lack of such information

in the current ARB inventory, an arithmetic mean has to be used for the composite size fraction profile for PM4001 (catalyzed gasoline vehicle) for now.

- ***PM4002: Gasoline Vehicle without Catalytic Converter***

Assuming all of the pre-1981 test cars/trucks are not equipped with a catalytic converter, the size fractions of the pre-1981 vehicles are used to make the size fraction profile for PM4002 (non-catalyzed gasoline vehicle).

- ***PM4003: Smoking Gasoline Vehicle***

Durbin et al. [8] found that 97.1% of the PM emitted by smoking gasoline vehicles is PM_{10} and 93.5% is $PM_{2.5}$. This result can be used as size fraction profile for PM4003 (smoking gasoline vehicle).

The three new size fraction profiles are provided in Table 4 with comparison of the current size fraction profiles. The ratios of $PM_{2.5}$ to PM_{10} are also calculated (91.9%, 95.4% and 96.3% for PM4001, PM4002 and PM4003, respectively), and they are in good agreement with what Cadle et al. [9] found in the Denver Study, which showed 91% of the gasoline vehicle PM_{10} mass is smaller than 2.5 um, and 97% for "smokers".

Table 4. Size fraction profiles for gasoline vehicles (GV)

Profile Name	*Profile No*	*PM_{10}/TPM (%)*	*$PM_{2.5}$/TPM (%)*
GV with Catalytic Converter	PM4001	89.4	82.2
	(current) PM400	*97*	*90*
GV without Catalytic Converter	PM4002	96.1	91.7
	(current) PM399	*90*	*68*
Smoking GV	PM4003	97.1	93.5

3 Impacts of Profile Update on Emissions

3.1 Changes caused by size fraction update

Profiles PM399 and PM400 are currently used for gasoline-powered categories such as motor vehicles, off-road equipment, recreational boats, and motor homes. The 2010 statewide annual average TPM emissions of categories associated with PM399 and PM400 are 18.0 and 17.9 tons/day [3], respectively. The PM_{10} and $PM_{2.5}$ annual average emissions are calculated by applying the size fractions of PM_{10}/TPM and $PM_{2.5}$/TPM to the TPM emissions. Therefore, for the non-catalyzed categories, the emissions of PM_{10} and $PM_{2.5}$ are 16.2 and 12.2 tons/day, respectively, when PM399 is used; and for the catalyzed categories, the emissions of PM_{10} and $PM_{2.5}$ are 17.4 and 16.1 tons/day, respectively, when PM400 is used.

If PM399 is replaced by the newly developed PM4002, the PM_{10} emissions will increase 1.1 tons/day and the $PM_{2.5}$ emissions will increase 4.3 tons/day based on the new size fractions in Table 4 and given TPM emissions of 18.0 tons/day. Similarly, if PM400 is replaced by PM4001, the emissions of PM_{10} and $PM_{2.5}$ will both decrease 1.4 tons/day. These changes are tabulated in Table 5.

Table 5. Changes in PM_{10} and $PM_{2.5}$ emissions of gasoline-fueled related categories (for 2010)

Category		Current (tons/day)	Updated (tons/day)	Change	
				Emissions (tons/day)	Percentage
Non-catalyzed	PM_{10}	16.2	17.3	+1.1	+6.8%
	$PM_{2.5}$	12.2	16.5	+4.3	+34.9%
Catalyzed	PM_{10}	17.4	16.0	-1.4	-7.8%
	$PM_{2.5}$	16.1	14.7	-1.4	-8.7%

3.2 Changes caused by speciation update

The newly developed speciation profiles are based on analyses of $PM_{2.5}$ only because there are no available data for TPM and PM_{10} speciation. Assuming there is no significant difference in the composition of TPM, PM_{10} and $PM_{2.5}$, the $PM_{2.5}$ profiles could be used for TPM and PM_{10}. If the currently used PM399 is replaced by PM4002, and PM400 is replaced by PM4001, the changes to the five PM modeling species from emissions of gasoline-powered categories (including on-road motor vehicles, off-road equipment, recreation boats, and motor homes) are estimated in Table 6 and Table 7. It should be noted that for a given TPM emission, the emissions of $PM_{2.5}$ or PM_{10} species are affected by both the size fraction profile and speciation profile. Applying the updated speciation and size fraction profiles to calendar year 2010, the $PM_{2.5}$-OM emissions increase 12.57 tons/day for all non-catalyzed categories, and 8.23 tons/day for all catalyzed categories; while the $PM_{2.5}$-sulfate emissions decrease 98.7% and 90.5% for all non-catalyzed and catalyzed related categories, respectively. The impacts on $PM_{2.5}$-EC emissions are less than 4.9% for non-catalyzed related categories but more than 14.9% for the catalyzed related categories.

Table 6. Changes on emissions of $PM_{2.5}$ species for non-catalyzed related categories (for 2010)

Statewide Annual Ave. Emissions	Current PM399 (tons/day)	Updated PM4002 (tons/day)	Change	
			Emissions (tons/day)	Percentage
OM	0.00	12.57	12.57	N/A
EC	2.44	2.32	-0.12	-4.9%
sulfate	5.49	0.07	-5.42	-98.7%
nitrate	0.07	0.02	-0.05	-71.4%
all other species	4.20	1.52	-2.68	-63.8%

Table 7. Changes on emissions of PM2.5 species for catalyzed related categories (for 2010)

Statewide Annual Ave. Emissions	Current PM400 (tons/day)	Updated PM4001 (tons/day)	Change	
			Emissions (tons/day)	Percentage
OM	0.00	8.23	8.23	N/A
EC	3.22	3.70	0.48	+14.9%
sulfate	7.25	0.69	-6.56	-90.5%
nitrate	0.09	0.16	0.07	+77.8%
all other species	5.55	1.92	-3.63	-65.4%

4 Version Control

This section will be completed after management approval and after the CEIDARS FRACTION table, PMPROFILE table and PMSIZEPROFILE table are updated. Version information from the CEIDARS FRACTION table will be copied here.

References

1. California Air Resources Board Main Speciation Profiles. In May 19, 2008 ed.; California Air Resources Board: 2008.
2. Taback, H. J.; Sonnichsen, T. W.; Brunetz, N.; Stredler, J. L. *Control of Hydrocarbon Emissions from Stationary Sources in the California South Coast Air Basin, Final Report*; KVB 5804-714; California Air Resources Board: Sacramento, June 1978, 1978.
3. CEPAM Databa. California Air Resources Board: 2011.
4. Kishan, S.; Burnette, A.; Fincher, S.; Sabisch, M.; Crews, W.; Snow, R.; Zmud, M.; Santos, R.; Bricka, S.; Fujita, E.; Campbell, D.; Arnott, P. *Kansas City PM Characterization Study*; EPA420-R-08-009; U.S. Environmental Protection Agency: Washington DC, 2008.
5. Norbeck, J. M.; Durbin, T. D.; Truex, T. J. *Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles*; CRC E-24-2; Coordinating Research Council, Inc.: 1998.
6. Fujita, E. M.; Lawson, D. R.; Campbell, D. E.; Zielinska, B.; Arnott, W. P.; Sagebiel, J.; Reinhart, L.; Chow, J. C.; Schauer, J.; Christensen, C.; Lough, G.; Gabele, P. A.; Clark, N. N. *Gasoline-Diesel PM Split Study*; National Renewable Energy Laboratory: Golden, CO, 2005.
7. Fujita, E. M.; Zielinska, B.; Campbell, D. E.; Arnott, P.; Sage, A. M.; Mazzoleni, L.; Chow, J. C.; Gabele, P. A.; Crews, W.; Snow, R.; Clark, N. N.; Wayne, W. S.; Lawson, D. R., Variations in Speciated Emissions from Spark-Ignition and Compression-Ignition Motor Vehicles in California's South Coast Air Basin. *Journal of Air & Waste Management Association* **2007,** *57*, 705-720.
8. Durbin, T. D.; Smith, M. R.; Norbeck, J. M.; Truex, T. J., Population Density, Particulate Emission Characterization, and Impact on the Particulate Inventory of Smoking Vehicles in the South Coast Air Quality Management District. *Journal of Air & Waste Management Association* **1999,** *49*, 28-38.

9. Cadle, S. H.; Mulawa, P.; Hunsanger, E. C.; Lawson, D. R.; Knapp, D.; Snow, R., Light-Duty Motor Vehicle Exhaust Particulate Matter Measurement in the Denver, Colorado, Area. *Journal of Air & Waste Management Association* **1999,** *49*, 164-174.

Appendix 1. Test Driving Cycles

- The Federal Test Procedure (FTP) cycle is a transient cycle that lasts for a total of 1879 seconds with an average speed of 21.2 mph, and a top speed of 56.7 mph. After 1374 seconds, the engine is turned off, the sampling is stopped and the engine is allowed to soak for 10 minutes before resuming the last 505 seconds, at an identical speed-time profile as the first 505 seconds (Figure A1).

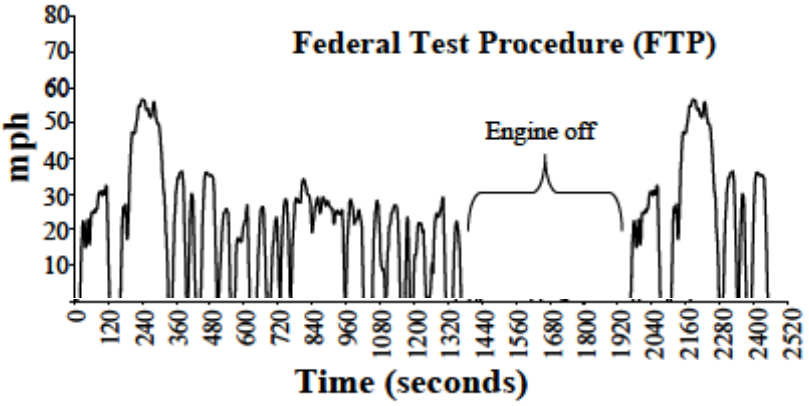

Figure A1. FTP driving cycle

- The Unified Cycle (UC) cycle is also a transient cycle, but with higher speeds and a total duration of 1735 seconds. It has an average speed of 22.8 mph with a top speed of 67.2 mph. After 1435 seconds the engine is turned off and allowed to soak for 10 minutes before resuming the last 300 seconds, at an identical speed-time profile as the first 300 seconds (Figure A2).

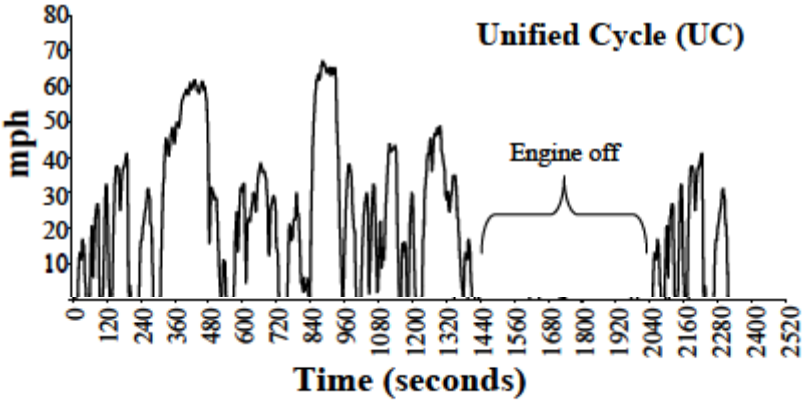

Figure A2. UC driving cycle