PM Speciation Profile for Piston-Engine Aircraft (Running Aviation Gasoline) —PM1415

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December 12, 2019

1. Introduction

Lead (Pb) is a well-known toxic metal. The exposure to Pb can result in a variety of adverse health effects. In 2008, USEPA significantly strengthened the national air quality standard for Pb. The revised standard is 10 times tighter than the previous standard to provide health protection for at-risk groups, especially children. The use of leaded aviation gasoline (avgas) in piston-engine aircrafts has become the major remaining source category of Pb emissions at the national level since Pb was banned from automotive gasoline [1]. Approximately over 50% of airborne Pb emissions in the US originate from general aviation (GA) airports, where the majority of the fleet is piston-engine aircrafts [2].

In the CARB inventory, the PM exhausts emitted from piston-engine aircrafts are described by Profile PM4002, which represents non-catalyzed gasoline vehicles based on source tests. However, this profile could not truly characterize the Pb emissions generated from piston-engine aircraft. Given the significance of potential public health risks of Pb and substantially high contribution from piston-engine emissions, it is important to update the current PM profile with better Pb characterization for avgas combustion.

This memo addresses the development of new profile PM1415 for piston-engine aircraft by updating PM4002 with improved assessment of Pb contribution. The new profile will be assigned to all avgas combustion related categories, including civil, commercial, and military piston powered aircrafts (Appendix 1) for all years.

2. Methodology

A complete PM profile has two indispensable components: size profile and chemical speciation profile.

2.1 Size Profile

The size profile of PM4002 will be kept for the new profile PM1415, i.e., the ratio of PM_{10} to TPM (total particulate matter) is 0.961 and the ratio of $PM_{2.5}$ to TPM is 0.917 [3].

2.2 Chemical Speciation Profile

Because the speciation source testing data for piston-engine aircraft emissions are lacking, this work aims to update the composition of Pb in emitted particles based on the available

information obtained from emission inventory. The new profile PM1415 will then be obtained by modifying the current profile PM4002 with improved weight fraction of Pb and consequently updated composition of other species.

The currently in-use PM4002 consists of 54.4% organic carbon (OC), 14.1% elemental carbon (EC) and only 0.1% Pb, which presented the source testing results on a pre-81 non-catalyzed motor vehicle running Phase 2 California Reformulated Gasoline (CaRFG2). In avgas, Pb is added as tetraethyl lead (TEL) to increases fuel octane and prevents knock in piston-engine aircraft. The most commonly available avgas, 100 low lead (100LL), containing up to 2.12 g of Pb per gallon. Obviously, the 0.1% Pb in PM4002 is much lower than what is expected in the exhaust particles generated from piston-engine aircrafts running on avgas.

The emission information of Pb and PM reported in the National Emission Inventory (NEI) is used for calculating the contribution of Pb in this work. In the NEI, Pb emissions are estimated based on the aircraft-specific emission factors and aircraft activity data, i.e., take-off cycle (LTO) [1]. For unspecific GA aircraft, the emission factors for Pb and $PM_{2.5}$ are 7.69E-06 and 8.17E-05 tons/LTO, respectively [4]. The emission factor of TPM is then calculated by dividing the emission factor of $PM_{2.5}$ with the size fraction of $PM_{2.5}$/TPM, 0.917, and the result is 8.91E-05 tons/LTO. Given the emission factor of Pb in NEI is for TPM, the weight percentage of Pb in TPM, 8.63%, is obtained by calculating the ratio of the emission factors of Pb to TPM. In order to keep a mass balance for the profile, the sum of the percentage of all other species should be 91.37%, which is the difference between 100% TPM and 8.63% Pb. To get the new profile, the weight percentage of all PM species except for Pb in PM4002 are renormalized by 91.37%. A homogeneous chemical composition is assumed for TPM, PM_{10} and $PM_{2.5}$. That is, the chemical speciation profiles for PM_{10} and $PM_{2.5}$ are assumed to be the same.

3. Results and Discussion

The detailed chemical compositions for profile PM1415 are summarized in Table 1. Compared to PM4002, the weight percentage of Pb dramatically increases from 0.1% to 8.63%, resulting in the decrease of percentage of all other species. In PM1415, the major species OC is 49.7725% and EC is 12.8604%.

Table 1. Profile PM1415 Piston-Engine Aircraft (Avgas)

Species Name	*SAROAD*	*TPM Weight Percentage (%)*	*PM_{10} Weight Percentage (%)*	*$PM_{2.5}$ Weight Percentage (%)*
Aluminum	12101	0.0921	0.0921	0.0921
Ammonium	12301	0.3019	0.3019	0.3019
Antimony	12102	0.0025	0.0025	0.0025
Barium	12107	0.0127	0.0127	0.0127
Bromine	12109	0.0038	0.0038	0.0038
Calcium	12111	0.3376	0.3376	0.3376

Species Name	*SAROAD*	*TPM Weight Percentage (%)*	*PM_{10} Weight Percentage (%)*	*$PM_{2.5}$ Weight Percentage (%)*
Chloride	12203	0.3445	0.3445	0.3445
Chlorine Insoluble	12202	0.1198	0.1198	0.1198
Chromium	12112	0.0363	0.0363	0.0363
Copper	12114	0.0334	0.0334	0.0334
Elemental Carbon	12116	12.8604	12.8604	12.8604
Iron	12126	1.8835	1.8835	1.8835
Lanthanum	12146	0.0069	0.0069	0.0069
Lead	12128	8.6300	8.6300	8.6300
Magnesium	12140	0.1651	0.1651	0.1651
Manganese	12132	0.0152	0.0152	0.0152
Nickel	12136	0.0968	0.0968	0.0968
Nitrates	12306	0.1169	0.1169	0.1169
Organic Carbon	11102	49.7725	49.7725	49.7725
Non-Carbon Organic Matter	11103	19.9090	19.9090	19.9090
Phosphorus	12152	0.3017	0.3017	0.3017
Potassium	12180	0.0056	0.0056	0.0056
Silicon	12165	1.3162	1.3162	1.3162
Sodium	12184	0.0065	0.0065	0.0065
Sulfate	12403	0.3819	0.3819	0.3819
Non-Sulfate Sulfur	12404	0.1234	0.1234	0.1234
Tin	12160	0.0027	0.0027	0.0027
Zinc	12167	0.5926	0.5926	0.5926
Others	12999	2.5285	2.5285	2.5285
Total		*100.0000*	*100.0000*	*100.0000*

4. Estimated Impacts of Profile Update

The newly developed profile, PM1415, will replace the current profile PM4002 for the inventory categories associated with piston-engine aircrafts operating on avgas. The affected SCCs/EICs are summarized in Appendix 1.

Given the 2016 statewide annual average TPM emissions from piston-engine aircrafts of 0.5896 tons/day (0.02% of grand total with natural sources excluded) [5], the estimated $PM_{2.5}$ emissions will be 0.5407 tons/day based on the size profile of PM1415.

According to the new chemical composition exhibited in PM1415, the $PM_{2.5}$ OC and EC will decrease almost 9%, but the Pb emission will substantially increase from 0.0006 to 0.0467 tons/day, a 77 times rise due the profile change (Table 2).

Table 2. Changes on emissions of $PM_{2.5}$ species for piston-engine aircraft (2016)

Statewide Annual Ave. Emissions	*Current PM4002 (tons/day)*	*New PM1415 (tons/day)*	*Change of Emissions (tons/day)*	*Percentage Change*
Pb	0.0006	0.0467	+0.0461	+7683.3%
OC	0.2942	0.2691	-0.0251	-8.5%
EC	0.0760	0.0695	-0.0065	-8.6%

References:

1. Heiken, J., et al., *Quantifying Aircraft Lead Emissions at Airports*, 2015, Federal Aviation Administration: Washington, DC. p. 217.
2. Miranda, M.L., R. Anthopolos, and D. Hastings, *A geospatial analysis of the effects of aviation gasoline on childhood blood lead levels.* Environmental Health Perspectives, 2011. **119**(10): p. 1513-1516.
3. *California Air Resources Board Main Speciation Profiles,* 2019, California Air Resources Board, *Accessed*: Oct 15, 2019.
4. Chang, R., et al., *Development of 2014 Aircraft Component for National Emissions Inventory*, 2016, US EPA.
5. *CEPAM,* 2019, California Air Resources Board, *Accessed*: Oct 20, 2019.

Appendix 1. SCCs/EICs associated with piston-engine aircraft (avgas combustion)

SCC/EIC	*Name 1*	*Name 2*	*Name 3*
27501001	fixed wing aircraft	military	fixed wing: avgas
27502001	fixed wing aircraft	commercial	fixed wing: avgas
27505001	fixed wing aircraft	civil	fixed wing: avgas
27601001	rotary wing aircraft	military	rotary wing: avgas
27602001	rotary wing aircraft	commercial	rotary wing: avgas
27605001	rotary wing aircraft	civil	rotary wing: avgas
81080011400000	piston aircraft – military	aviation gasoline	sub-category unspecified
81080211400000	piston aircraft – commercial	aviation gasoline	sub-category unspecified
81080211400044	piston aircraft – commercial	aviation gasoline	take-off
81080211400045	piston aircraft – commercial	aviation gasoline	landing
81080211400046	piston aircraft – commercial	aviation gasoline	taxing
81080411400000	piston aircraft – civil	aviation gasoline	sub-category unspecified
81080411400044	piston aircraft – civil	aviation gasoline	take-off
81080411400045	piston aircraft – civil	aviation gasoline	landing
81080411400046	piston aircraft – civil	aviation gasoline	taxing
81080611400000	agricultural aircraft (crop dusting)	aviation gasoline	sub-category unspecified