Benzene VCCEP Tier 1 Submission

Appendix B

Derivation of Mobile Source Benzene Evaporative and Refueling Emission Factors

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DERIVATION OF MOBILE SOURCE BENZENE EVAPORATIVE AND REFUELING EMISSION FACTORS

A normalization factor was derived to adjust historical benzene air concentrations during refueling to account for current day fleet improvements and benzene content in reformulated gasoline. Specifically, EPA's MOBILE6.2 model (released February 2004 and available at www.epa.go.otaq/m6.htm) was used to model the emission rate change of benzene from vehicles due to improved emission controls and the reduced benzene content in gasoline. MOBILE is an EPA emissions factor model for estimating pollution from on-road motor vehicles. The model accounts for the emission impacts of factors such as changes in vehicle emission standards, changes in vehicle populations and activity, and variation in local conditions such as temperature, humidity, fuel properties, and air quality programs.

MOBILE is used to calculate current and future inventories of motor vehicle emissions at the national and local level. These inventories are used to make decisions about air pollution policies and programs at the local, state and national level. Inventories based on MOBILE are also used to meet the federal Clean Air Act's state implementation plan (SIP) and transportation conformity requirements. MOBILE6.2 calculates emissions of volatile organic compounds (VOCs), nitrogen oxides (NO_X), carbon monoxide (CO), PM, gaseous SO_2, ammonia, and air toxics from passenger cars, motorcycles, buses, and light-duty & heavy-duty trucks.

For a given calendar year (1970 through 2050), and season (winter or summer), MOBILE6.2 estimates fleet average emissions factors for each of 16 vehicle classes represented in the fleet. The fleet average typically represents the age- and travel-weighted contribution of 25 model years of vehicles in-use in any given calendar year. VOC emissions are estimated both in the aggregate as well as disaggregate by pollutant process (i.e., exhaust VOC, diurnal evaporative VOC, hot soak VOC, running loss VOC, resting loss VOC and refueling VOC).

In this analysis, the MOBILE6.2 model was run to produce "winter" (month = "1") emissions estimates for the fleet of vehicles in operation in a given base calendar year corresponding to the year of the study being addressed (1990, 1995, and/or 1999) and also for calendar year 2003.

MOBILE6.2 emissions estimates were generated for the following cities and study years:

City	Base Year	Current Year
Los Angeles, CA	1990	2003
Cincinnati, OH	1990	2003
Phoenix, AZ	1990	2003
Fairbanks, AK	1995	2003
Toronto, CA	1999	2003

In order to characterize the relative effects of changes in fuel properties versus changes in fleet characteristics on benzene emissions over time, three runs of MOBILE6.2 were generated for each of the above cities:

Run 1: Base year fleet characteristics and Base year fuel parameter values
Run 2: Base year fleet characteristics and 2003 fuel parameter values
Run 3: 2003 fleet characteristics and 2003 fuel parameter values

National average "default" model parameters [age and vehicle-miles-traveled (VMT) distribution by model year] were used to characterize the fleet in each city.

The characteristics of the US national average fleet (with respect to vehicle age distribution by model year, VMT distribution, and technology characteristics were assumed to be representative of the fleet of vehicles in use in US cities and in Toronto, Canada.

Estimates of daily minimum and daily maximum winter average temperatures for each city were drawn either from National Weather service data and/or county-specific inputs used for the 2002 EPA National Emissions Inventory (NEI). Effort was made to match as closely as possible the month(s) in which each study was performed with respect to the selection of temperature inputs for MOBILE6.2. These temperature inputs were held constant for MOBILE6.2 model runs of the base calendar year in each city and for 2003.

City	Minimum Temperature (^oF)	Maximum Temperature (^oF)
Los Angeles, CA	47.0	64.0
Phoenix, AZ	52.0	78.0
Cincinnati, OH	28.0	43.0
Fairbanks, AK	19.0	29.0
Toronto, Canada	12.0	28,0

The fuel parameter values necessary to produce mobile source air toxics output using MOBILE6.2 were drawn from winter gasoline surveys performed by the Alliance of Automobile Manufacturers for each city. The average reported fuel parameter values for regular gasoline were used in each case – with the exception of the "base year" values for gasoline benzene content. The "base year" gasoline benzene values were drawn from reported benzene levels in the fuels sampled in the various studies being addressed. Key fuel property values used in the MOBILE6.2 runs are shown below:

Summary of Fuel Properties used in Model

City/Year	RVP (psi)	E200	E300	Aromatics (vol %)	Olefins (vol %)	Benzene (vol %)
Los Angeles						
1990	12.3	48.9	81.3	25.6	7.4	2.35
2003	11.4	52.2	86.7	21.7	4.4	0.7
Phoenix						
1990	10.9	57.8	83.1	24.2	6.1	1.8
2003	9.0	52.4	90.0	15.1	3.3	0.8
Cincinnati						
1990	14.0	57.3	82.4	25.5	9.7	0.92
2003	14.9	53.9	82.0	25.6	9.8	1.00
Fairbanks						
1995	14.3	47.0	83.3	34.9	1.5	3.57
2003	14.3	53.9	82.0	34.4	0.9	3.30
Toronto						
1999	15.1	55.2	83.7	24.9	8.1	2.0
2003	15.2	57.7	85.1	21.5	6.8	0.7

No data were available for Cincinnati, OH from the fuel surveys. Fuel parameter data representing Cleveland, OH were used as a surrogate for Cincinnati for the MOBILE6.2 runs involving this city.

It is important to note that these MOBILE6.2 runs incorporate the effects of changes in federal emissions standards on the vehicle fleet in operation. The effects of local and/or state vehicle-related emissions controls (such as vehicle Inspection/Maintenance programs in Fairbanks, Los Angeles, and Phoenix and Stage II vapor recovery in Los Angeles) are not included in the modeling runs.

The model was run to include LDGV and LDGT. The emission rates modeled based on the three runs described previously are presented below.

Summary of MOBILE6.2 Runs for Various Refueling Studies

Run No.	Run/bz-mg/mi-LDGV	Fleet Year	H/L Temps (F)	Fuel Benzene (%)	Weighted average of LDGV and LDGT 1,2,3,4emission rate (mg/mi) during refueling
Mobile 6 Runs for the API (1993) study – Los Angeles, CA					
1	(Los Angeles Winter 1990 Fleet with Los Angeles Winter '90 Fuel Properties)	1990	64/47	2.35	4.0030
2	(Los Angeles Winter 1990 Fleet with Los Angeles Winter 2003 Fuel Properties)	1990	64/47	0.7	1.0107
3	(Los Angeles Winter 2003 Fleet with Los Angeles Winter 2003 Fuel Properties)	2003	64/47	0.7	0.7348
Mobile 6 Runs for the API (1993) study – Phoenix, AZ					
1	(Phoenix Winter 1990 Fleet with Phoenix Winter '90 Fuel Properties)	1990	78/52	1.80	2.6973
2	(Phoenix Winter 1990 Fleet with Phoenix Winter 2003 Fuel Properties)	1990	78/52	0.8	0.9011
3	(Phoenix Winter 2003 Fleet with Phoenix Winter 2003 Fuel Properties)	2003	78/52	0.8	0.6529
Mobile 6 Runs for the API (1993) study – Cincinnati, OH					
1	(Cincinnati Winter 1990 Fleet with Cincinnati Winter '90 Fuel Properties*)	1990	43/28	0.92	1.4254
2	(Cincinnati Winter 1990 Fleet with Cincinnati Winter 2003 Fuel Properties*)	1990	43/28	1.0	1.5430
3	(Cincinnati Winter 2003 Fleet with Cincinnati Winter 2003 Fuel Properties*)	2003	43/28	1.0	1.1125
Mobile 6 Runs for the Backer et al. (1997) study – Fairbanks, AK					
1	(Fairbanks Winter 1995 Fleet with Fairbanks Winter '95 Fuel Properties)	1995	29/19	3.57	4.9494
2	(Fairbanks Winter 1995 Fleet with Fairbanks Winter 2003 Fuel Properties)	1995	29/19	3.3	4.5730
3	(Fairbanks Winter 2003 Fleet with Fairbanks Winter 2003 Fuel Properties)	2003	29/19	3.3	3.5694
Mobile 6 Runs for the Smith (1999) study – Toronto, Canada					
1	(Toronto Winter 1999 Fleet with Toronto Winter '99 Fuel Properties)	1999	28/12	2.0	2.8856
2	(Toronto Winter 1999 Fleet with Toronto Winter 2003 Fuel Properties)	1999	28/12	0.7	0.8727
3	(Toronto Winter 2003 Fleet with Toronto Winter 2003 Fuel Properties)	2003	28/12	0.7	0.7075

Each of the emission factors shown above are representative of the change in emission rates attributable to reduction of benzene content in gasoline or the combined effect of fleet improvements in emission controls and reduced benzene content. Therefore, the emission factor due to fleet improvements was calculated as follows:

$$\text{Emission Factor}_{FL} = \text{Run 1 EF} - (\text{Run 2 EF} - \text{Run 3EF})$$

Next the total change in emissions factor was calculated for each study by summing the emission factor change attributable to the benzene decrease and the emission factor change attributable to the fleet improvements. A summary of the total change in emissions factors for each of the studies is shown below.

Description	Emission Rate (mg/mi)	% of total reduction
Mobile 6 Runs for the API (1993) study - Los Angeles		
Emission factor change attributable to bz ct decrease (dEb)	-2.992328814	92%
Emission factor change attributable to fleet improvment (dEf)	-0.275894809	8%
Total change in emission factor (dEt)	-3.268223623	100%
Mobile 6 Runs for the API (1993) study - Phoenix		
Emission factor change attributable to bz ct decrease (dEb)	-1.796209411	88%
Emission factor change attributable to fleet improvment (dEf)	-0.248181079	12%
Total change in emission factor (dEt)	-2.04439049	100%
Mobile 6 Runs for the API (1993) study - Cincinnati		
Emission factor change attributable to bz ct decrease (dEb)	0.117615358	--a
Emission factor change attributable to fleet improvment (dEf)	-0.430482261	100%
Total change in emission factor (dEt)	-0.312866903	100%
Mobile 6 Runs for the Backer et al (1997) study - Fairbanks		
Emission factor change attributable to bz ct decrease (dEb)	-0.376423283	27%
Emission factor change attributable to fleet improvment (dEf)	-1.003543714	73%
Total change in emission factor (dEt)	-1.379966997	100%
Mobile 6 Runs for the Smith (1999) study - Toronto		
Emission factor change attributable to bz ct decrease (dEb)	-2.012954831	92%
Emission factor change attributable to fleet improvment (dEf)	-0.165141765	8%
Total change in emission factor (dEt)	-2.178096597	100%

[a]Benzene content increased slightly from 1990 to 2003.

The change in the total emission factor is equal to the change in the emissions refueling factor. Therefore, the refueling factor is calculated as follows:

$$RF = \frac{H}{(H + dRF}$$

Where;

RF = Refueling factor (unitless)
H = Historical emissions factor or Run 1 emissions factor (mg/mi)

dRF = change in the emissions refueling factor (mg/mi)

The historical air concentrations can therefore be normalized by dividing the measured air concentration by the refueling factor. The table below summarizes the refueling normalization factor calculated for each study and the resulting normalized air concentrations.

Normalized Refueling Benzene Air Concentrations

			Study Concentration for the Year of Data Collection (Historical Fleet and Benzene Content)		Refueling Factor (RF)	Study Estimate Normalized to Year 2003 Fleet and Benzene Content[a]	
Study	City	Year of Data Collection	Mean	Maximum		Mean	Maximum
Smith, 1999	Toronto	1999	1.1	4.1	4.08	0.27	1.01
API, 1993	Cincinnati	1990	0.49	2.5	1.28	0.38	1.95
	Phoenix		1.725	8.4	4.13	0.42	2.03
	Los Angeles		0.965	3.9	5.45	0.18	0.72
Backer, et. al., 1997	Fairbanks (RG)	1995	1.21	2.36	1.39	0.87	1.7
	Fairbanks (E10)		0.83	2.7	1.39	0.6	1.9
		Average	1	4		0.45	1.6