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Cold Temperature Effects on Vehicle HC Emissions

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Assessment and Standards Division
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Background

The EPA highway mobile source emission factor model, MOBILE6 (MOBILE6.2.03), applies a multiplicative adjustment to the base (75 degree Fahrenheit) HC emission rates for engine starts from all 1981 and later model year light duty cars and trucks to account for the effects of different temperatures. As a result, as the emissions from vehicles have been reduced as a result of more stringent emission certification standards, MOBILE6 predicts a corresponding proportional reduction in the increase in emissions resulting from engine starts at temperatures below 75 degrees Fahrenheit.

In recent years, vehicle manufacturers have provided FTP test procedure results from testing at 20 degrees Fahrenheit in compliance with requirements for certification for cold temperature CO standards. The HC results included in some of these submissions demonstrate clearly that the effect of more stringent standards at 75 degrees has not resulted in a proportional reduction in engine start emissions at colder temperatures.

This analysis was done to evaluate an initial assessment of the impact of this new information on expected HC emission rates at low temperatures for the most recent model year vehicles. A more thorough analysis than we have made in this report will be needed in order to fully account for this information in inventories based on the MOBILE6 model.

Data

Cold temperature measurements at 20 degrees Fahrenheit using the FTP testing procedure are provided by the manufacturers as part of the cold temperature carbon monoxide (CO) emissions certification procedure. In some cases, the data provided by the manufacturers also includes measurements of total hydrocarbons (HC) as well as CO. The data was obtained for this evaluation from the EPA Certification and Fuel Economy Information System[1] (CFEIS) for model years 2000 through 2006 in yearly spreadsheets. Each year contains the certification emission class and the deteriorated 75 degree and 4k 20 degree Fahrenheit FTP HC results.

Certification for California is also done at 50 degrees Fahrenheit. Test results from vehicles certified to the California standards were extracted from the CFEIS data for the 2005 model year. The data includes NMOG levels reported at 50 and 75 degrees Fahrenheit for vehicles certified to the Low Emitting Vehicle (LEV), Ultra-Low Emitting Vehicle ULEV and LEV2 standards. The values are from the undeteriorated reported results at both temperatures.

Expected emission trends at zero degrees Fahrenheit were also collected in two separate EPA test programs. The most recent test program[2] at Southwest Research Incorporated (SwRI) comprised of four Tier 2 vehicles of different configurations (small car, minivan, pickup and crossover). The testing done at the National Exposure Research Laboratory[3] (NERL) included two Tier 1 vehicles and two vehicles certified to LEV standards.

Analysis

Not all engine families tested at cold temperatures included reported measurements of HC emissions and not all engines are certified for sale in California, which would include emissions testing at 50 degrees Fahrenheit. For this analysis, all available test results were weighted equally, rather than devising a scheme to weight results based on projected or actual engine sales, since not all engine families can be represented in any scheme. The variability of the results does not suggest that just using the available vehicles will significantly affect the averages we calculate.

The emission test results used in this analysis are all measurements using the emission certification Federal Test Procedure (FTP). This procedure measures emissions in three “bags” which represent different portions of typical driving. The first and third bags use the identical driving schedules and include an engine start (key on), but the first bag is measured after a 12 hour “soak” (key off period) and the third bag is measured after a 10 minute soak.

Most of the CFEIS data reported to EPA is not separated by bag. The available testing results with bag measurements show clearly that nearly all of the extra emissions over the measurements at 75 degrees versus 20 degrees in the FTP test procedure come from the cold start (Bag 1). There is comparatively little change in the emissions from either Bag 2 or Bag 3. This suggests that once the engine becomes fully warmed, the ambient temperature is less significant. For this analysis, we assumed that all of the change in FTP emissions from 75 degrees to 20 degrees Fahrenheit is a result of an increase in Bag 1 emissions. All of the increase in Bag 1 can be attributed to the engine start, since the emissions that occur once the engine becomes warm are not significantly affected by the change in temperature. The calculation of grams per engine start increase from 75 to 20 degrees Fahrenheit from the FTP grams per mile then becomes:

Additional grams per cold start at 20 degrees = (FTP20-FTP75)*7.5/0.43

Where :

- FTP20 is the FTP grams per mile at 20 degrees Fahrenheit.
- FTP75 is the FTP grams per mile at 75 degrees Fahrenheit.
- The nominal length of the FTP driving schedule is 7.5 miles.
- The weighting of cold start trips versus hot start trips in the FTP is 0.43.

The resulting grams represent the extra emissions emitted by a vehicle after a 12 hour soak at 20 degrees over emissions emitted at 75 degrees. All of these emissions are assumed to occur during the engine start. For emission factor modeling, the added HC emissions would be added to the estimate of engine start emissions at 75 degrees to model the impact of temperature on engine start emissions.

This is significantly different from the methods used in MOBILE5[4] and MOBILE6[5], where exhaust emissions for HC are increased using a multiplicative adjustment as a function of temperature. However, the temperature adjustments for CO emissions already use an additive factor for temperatures below 75 degrees Fahrenheit. Modeling temperature adjustments as an additive adjustment makes the increase in emissions attributed to changes in temperature independent of other changes (i.e., gasoline sulfur content) made to the base emission rate at 75 degrees.

Results at 20 Degrees Fahrenheit

Matched sets of FTP emission results, both at 20 degrees and 75 degrees Fahrenheit for the same vehicle engine family (test group), were used in the analysis. The average HC start emissions were determined separately for vehicles (passenger cars and light trucks combined) certified to the Tier 1 standards, the transitional low emission vehicle (TLEV) standards, the low emission vehicle (LEV) standards, the ultra-low emission vehicle (ULEV) standards and Tier 2 standards.

The HC emissions data reported by manufacturers at 20 degrees Fahrenheit is always in units of total hydrocarbons (THC), reflecting use of the flame ionization detection (FID) method of hydrocarbon measurement. The HC emission measurements at 75 degrees Fahrenheit were usually adjusted to reflect the speciation of the hydrocarbons required for emission certification. Most results were reported in units of non-methane organic gases (NMOG), which includes ethane and aldehydes, but excludes methane. However, some results at 75 degrees were reported in units of THC and in units of non-methane hydrocarbons (NMHC), which only excludes methane. Since the grams of hydrocarbons from engine starts is large, compared to running emission rates, and mostly NMHC, rather than attempt to adjust all of the data to a common definition of hydrocarbons, all data was treated as THC for this analysis. Adjustments would have made only small differences in the average results.

Since Tier 2 standards phase in over a number of years, the average HC start emissions for Tier 2 vehicles were determined separately for each model year, beginning with the 2004 model year. This more appropriately accounts for the fact that "early" conversions to Tier 2 standards reflect the ability of specific engine families to more easily achieve Tier 2 emission performance.

FTP HC Data From Federal Certified Vehicles
(grams per mile)

		75 Degrees		20 Degrees	
Emission Standard	Sample Size	Mean	Std. Dev.	Mean	Std. Dev.
Tier 1	410	0.1190	0.0553	0.8630	0.7269
TLEV	64	0.0804	0.0286	0.6996	0.2778
LEV	695	0.0501	0.0209	0.6402	0.3723
ULEV	132	0.0335	0.0214	0.4675	0.2727
LEV2	119	0.0296	0.0123	0.5035	0.2549
2004 Tier 2	172	0.0406	0.0169	0.5641	0.3269
2005 Tier 2	190	0.0415	0.0203	0.5651	0.3247
2006 Tier 2	90	0.0408	0.0239	0.5502	0.3107

Results at 50 Degrees Fahrenheit

The following table shows the ratios of the average 50 degree measurements divided by the average 75 degree measurements. The measurements were extracted from the 2005 CFEIS data for vehicles certified to California standards. It is based on the HC emission levels in grams per mile reported at 50 and 75F for LEV, ULEV and LEV2 California certified vehicles. The ratios are based on the undeteriorated reported results at both temperatures.

FTP HC Emissions Data from California Certified Vehicles (grams per mile)						
		75 Degrees		50 Degrees		
Emission Standard	Sample Size	Mean	Std. Dev.	Mean	Std. Dev.	Ratio of Averages
LEV	53	0.0397	0.0259	0.0988	0.0631	2.49
ULEV	14	0.0162	0.0043	0.0403	0.0176	2.48
LEV2	21	0.0346	0.0097	0.0843	0.0310	2.44

The emission impact of temperature on engine start emissions was estimated for Tier 1 and LEVs by applying this ratio to the average emissions (in grams at 75 degrees) from the larger sample of federally certified vehicles used in the 20 degree analysis to determine the increase (in grams) due to temperature at 50 degrees Fahrenheit.

Additional grams per cold start at 50 degrees = ((Ratio-1.0)*FTP75)*7.5/0.43

Tier 1 and TLEV certified vehicles our analysis will assume the LEV ratio, but Tier 1 vehicles may actually perform worse, since there is no 50 degree Fahrenheit test requirement for Tier 1 vehicles in California.

For Tier 2 vehicles, 25.5% of vehicles were assumed to already be certified to the California 50 degree standard. This number is based on the 2003 model year new registrations and accounts for registrations in California and states which require California vehicles. We assume these vehicles will achieve the 0.0843 gram per mile emission rate achieved by the California LEV2 vehicles in the sample. The remaining vehicles (74.5%) were assumed to be unaffected by California standards. The non-California vehicles are assumed to have emissions at 50 degrees Fahrenheit which are a linear interpolation between their 75 degree emissions (0.71 grams or 0.041 grams per mile) and their 20 degree emissions (0.56 grams per mile), which was determined to be 0.277 grams per mile.

Additional grams per cold start for Tier 2 vehicles at 50 degrees =

((0.0843*0.255+0.277*0.745)*7.5/0.43)-0.71 = 3.27 grams

The adjustment to account for vehicles not certified to California standards was not made for vehicles standards other than Tier 2. Making the adjustment for all standards would tend to increase the overall emission effect of temperature at 50 degrees. The following table shows the effects assumed for each emission standard.

Increase in HC Emissions From California Certified Vehicles at 75 and 50 Degrees Fahrenheit

Standard	Sample Size	Ratio of Averages	FTP at 75 Degrees (grams)	Increase (grams)
Tier 1**	N/A	2.49*	2.08	3.09
TLEV**	N/A	2.49*	1.40	2.09
LEV	53	2.49	0.87	1.30
ULEV	14	2.48	0.58	0.87
LEV2	21	2.44	N/A	N/A
Tier 2**	N/A	N/A	0.71	3.27

* Ratios assumed from other emission standard groupings.
** No vehicles of this type tested for California standards at 50 degrees.

Results Below 20 Degrees Fahrenheit

The effects of temperatures below 20 degrees Fahrenheit is taken from a small sample of vehicles tested at temperatures down to zero degrees Fahrenheit. Two Tier 1 vehicles and two NLEV vehicles were tested in the NERL Program and four Tier 2 vehicles were tested in the SWRI Program.

Increase in Vehicle HC Emissions From 20 to Zero Degrees Fahrenheit (FTP grams per mile)

		20 Degrees		Zero Degrees		
Vehicle Sample	Sample Size	Mean at 20 degrees	std dev	Mean at zero degrees	std dev	Ratio of Means
Tier 1 / LEV	4	0.7375	0.2455	1.2500	0.3909	1.69
Tier 2	4	0.3593	0.1783	0.7958	0.4730	2.22
All	8	0.5484	0.2834	1.0229	0.4694	1.87

The increase in the average FTP HC emissions from these vehicles at zero degrees ranged from 1.7 to 2.2 times the emissions at 20 degrees. The sample sizes are very small but the increase is reasonably consistent across all of the vehicles in the samples. For this analysis, the increase in engine start emissions at zero degrees will be assumed to be twice the emission increase measured at 20 degrees Fahrenheit for all of the vehicle technologies (Tier 1, LEV and Tier 2).

Results for High Emitting Vehicles

A significant amount of HC inventory emissions comes from vehicles referred to as "high" emitters. These vehicles are not operating properly and may have emission levels many times that of normally emitting vehicles. None of the low temperature data available included the effects of engine starts on vehicles which grossly exceed their emission certification standards (high emitters). The assumptions about the temperature effects on HC emissions for Tier 1 and LEV high emitting vehicles used in MOBILE6 were not changed for this analysis. However, since any proposed control strategies will affect Tier 2 vehicles, the effect of cold temperatures on the HC emissions from Tier 2 high emitters was estimated as well.

The default MOBILE6 additive impact on high emitter engine start emission rates for Tier 2 vehicles was made for 20 degrees Fahrenheit by running the model. It was assumed that, in light of the higher emission impact at cold temperatures for normal emitting vehicles, the emission impact for high emitters would be increased as well. Twice the impact of low temperatures on normal emitting vehicles was added to the base (MOBILE6 default) temperature impact to represent the overall impact of temperature on the HC emissions of high emitting vehicles at low temperatures. The emission impact at zero degrees was assumed to be twice the impact at 20 degrees and the impact at 50 degrees was assumed to be half the impact at 20 degrees. The following table shows the engine start emission impacts used for high emitting Tier 2 vehicles.

Tier 2 High Emitter HC Adjustment
Based on 2005 Model Year MOBILE6 Results in Calendar Year 2005

Temperature Degrees Fahrenheit	0	20	50
Default MOBILE6 grams	62.68	31.34	15.67
Normal Emitter Adjustment grams	18.26	9.13	3.27
Total High Emitter Adjustment grams	99.20	49.60	22.21

Final Temperature Effects

The following tables show a summary of the results of the analysis. Each values represents the average increase in engine start HC emissions in grams per engine start from a base emission rate of a 12 hour soak before key on at 75 degrees Fahrenheit for Tier 1, LEV, ULEV and Tier 2 standard vehicles. This value is added to the base engine start emission rate to account for the impact of the colder temperature on the total HC emissions from an engine start. This adjustment would completely replace the default temperature adjustment used by MOBILE6 for these vehicles.

Increase in Engine Start Hydrocarbon Emissions
Over the 75 Degree Fahrenheit Baseline at Low Temperatures
(grams per engine start after 12 hours of soak)

Description	**Degrees Fahrenheit**		
	0	**20**	**50**
Tier 1	25.96	12.98	3.09
Transitional Low Emission Vehicle	21.60	10.80	2.09
Low Emission Vehicle (LEV)	20.59	10.29	1.30
Ultra Low Emission Vehicle (ULEV)	15.14	7.57	0.87
Tier 2 Model Year 2004	18.26	9.13	3.27
Tier 2 Model Year 2005	18.27	9.13	3.27
Tier 2 Model Year 2006 and Later	17.77	8.88	3.27
Tier 2 High Emitting Vehicles	99.20	49.60	17.71

Comparison with the default MOBILE6 case is difficult, since the multiplicative approach used by MOBILE6 makes the effect of temperature (in grams) vary significantly depending on the base emission rate on which it is applied. The default multiplicative temperature correction factor equation for bag 1 (cold start) HC emissions for 1992 and later model years is:

$$TCF(1) = EXP\ [\ TC(1)*(T - 75.0)\ ] = 3.7$$

Where:

- TCF(1) is the multiplicative temperature correction factor for bag 1 HC emissions.
- TC(1) is the coefficient for segment 1 (bag 1) for HC emissions (-0.023768)
- T is the ambient temperature of interest in degrees Fahrenheit. The base emission rate is at 75 degrees.

When compared to the base engine start emission rates at 75 degrees Fahrenheit estimated by the MOBILE6 model[6], the new estimates are very large increases in emissions. Tier 2 (Bin 5) engine start emissions at zero miles is 0.8 grams (10.752*0.075, NMOG) per engine start at 75 degrees. Adding 9.13 grams to adjust the engine start emissions to 20 degrees will increase these engine start emissions by a factor of 11, if a multiplicative factor were to be used. This is a much larger factor than suggested by the default MOBILE6 temperature correction factors. The factors for the Tier 1 and LEVs are smaller, which is consistent with the observation that the reduction in HC emissions at lower temperatures (primarily engine start emissions) has not been proportional to the decrease in overall vehicle HC emissions at 75 degrees due to the new lower HC emission standards.

Results

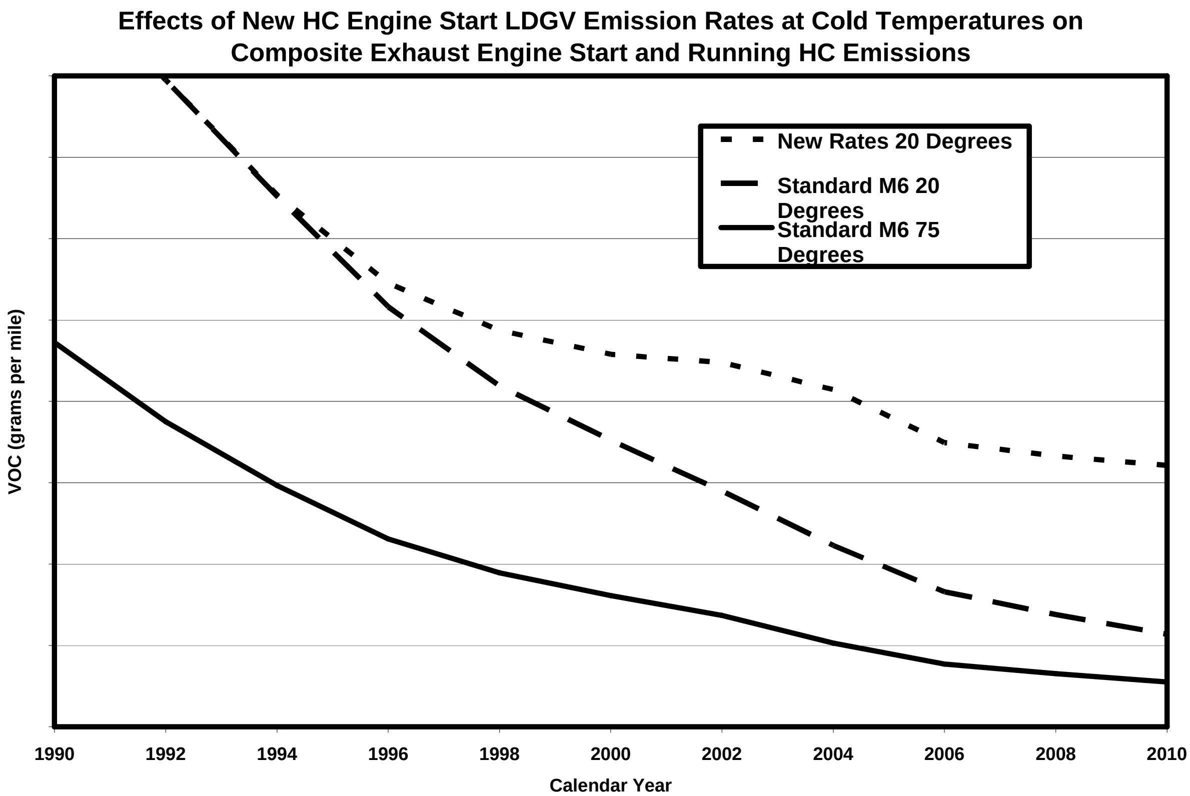
An analysis was performed using the new estimates for the effects of cold temperatures on HC emissions by substituting the new estimates for the default temperature adjustments in the MOBILE6 highway emission factor model. MOBILE6 estimates emission rates by starting with a base emission rate measured at base conditions, fuels and operation and then uses correction factors to adjust the base emission rate to better reflect the conditions, fuels and vehicle operation designated by the user. The calculation of the default temperature and soak time adjustments to HC engine start emissions in MOBILE6 is very complex. The default MOBILE6 adjustment factors are skipped and the new adjustments are applied whenever the temperature to be modeled falls below 75 degrees.

The additional engine start emissions for a given temperature is the value linearly interpolated between 50 and 75 degrees for temperatures in this range, linearly interpolated between 20 and 50 degrees for temperatures in this range or linearly interpolated between zero and 20 degrees for temperatures in this range. MOBILE6 will not model temperatures below zero degrees Fahrenheit. Emission estimates for temperatures above 75 degrees are not affected. No changes were made in the method used to adjust the engine start emissions to reflect differing engine soak times.

To summarize, the effects of these changes in MOBILE6:

- Affects only HC emissions.
- Affects only gasoline fueled engines.
- Affects only light duty cars and trucks.
- Only affects engine start emissions at temperatures less than 75 degrees Fahrenheit.
- Affects only vehicles certified to Tier 1, LEV and Tier 2 standards (1994 and later model years).
- Varies by model year for Tier 2 vehicles.
- Affects only the Tier 2 high emitting vehicles.

The following chart shows the impact of these new estimates for the effect of cold temperatures on HC engine start emissions on the fleet wide emissions of gasoline fueled passenger cars by calendar year. The default MOBILE6 adjustment for temperature already shows that exhaust emissions (running and engine start combined) at 20 degrees Fahrenheit are much higher than at 75 degrees. Once the new estimates are applied beginning with the 1994 model year, the average exhaust emissions of the fleet (all model years) begins to diverge from the default values, and show less improvement in emissions due to the introduction of new exhaust emission standards. By calendar year 2010, the fleet emissions at 20 degrees are much less improved than predicted by MOBILE6.



This chart includes only passenger cars. If we include diesel fueled vehicles and heavy duty vehicles and assume that their engine start emission estimates will not need an adjustment, the overall impact of these changes on the fleet wide inventory, including all highway vehicle types, will be less. However, since gasoline fueled, light duty vehicles are such a large part of the fleet, the impact on inventory estimates at low temperatures will still be large. This impact is mitigated by the fact that the additional HC emissions we have estimated occurs at low temperatures which are not as important for ozone formation as HC increases during hot days and the fact that many areas do not experience extremely cold temperatures, even in winter. A more detailed analysis of these changes in the estimates for the effects of cold temperatures on exhaust HC emissions would need to account for the variation in temperatures across the nation and include all sources of HC, such as other vehicle classes and evaporative HC. Any increases in HC emission inventory estimates, even at just at low temperatures, will still be of concern for other health related reasons.

References

1. Certification and Fuel Economy Information System (CFEIS). http://www.epa.gov/omswww/cfeis.htm

2. "VOC/PM Cold Temperature Characterization and Interior Climate Control Emissions/Fuel Economy Impact," Draft Final Report Volume I, EPA Contract 68-C-05-018, Work Assignment No. 0-4, SwRI Project No. 03.11382.04, Alan P. Stanard, October 2005.

3. "Characterization of Emissions from Malfunctioning Vehicles Fueled with Oxygenated Gasoline," (Parts I, II & III) Fred Stump, Silvestre Tejada, and David Dropkin, National Exposure Research Laboratory, U. S. Environmental Protection Agency and Colleen Loomis, Clean Air Vehicle Technology Center, Inc.

4. AP-42: Compilation of Air Pollutant Emission Factors, Appendix H: Highway Mobile Source Emission Factor Tables. http://www.epa.gov/otaq/ap42.htm

5. "Exhaust Emission Temperature Correction Factors for MOBILE6: Engine Start and Running LA4 Emissions for Gasoline Vehicles," M6.STE.004 (EPA420-R-01-029, April 2001). http://www.epa.gov/otaq/models/mobile6/m6tech.htm

6. "Determination of NOx and HC Basic Emission Rates, OBD and I/M Effects for Tier 1 and Later LDVs and LDTs," M6.EXH.007 (EPA420-R-01-056, November 2001). http://www.epa.gov/otaq/models/mobile6/m6tech.htm