EFFECTS OF SULFUR ON EXHAUST EMISSIONS

SUMMARY OF A DRAFT PROPOSAL FOR MOBILE6

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This document summarizes our initial analyses of sulfur's effect on exhaust emissions. The summary includes proposals for how best to incorporate the effects of sulfur on exhaust emissions into MOBILE6. It is intended to be only a summary and thus no figures are included in this document. It is expected that at the workshop, or soon thereafter, a detailed report on our proposed methodology for sulfur's effects on exhaust emissions will be available, both electronically and in hard copy.

EPA is considering sulfur impacts in its Tier2 study and rulemaking. If EPA has not adopted a definitive estimate (especially on sulfur's effects on advanced technology vehicles) through those processes by the time MOBILE6 is issued, MOBILE6 might not incorporate any sulfur effects estimate itself.

We welcome any and all comments on the methodologies used, additional data availability, and on the proposals made below.

Objectives

- Identify valid data
- Develop correlations between sulfur and exhaust emissions as a function of pollutant type, emitter class, and type of emissions
- Determine valid fuel sulfur ranges and how best to incorporate effects computed from the correlations into MOBILE6

Relevant Data

- EPA's Automotive Testing Laboratory (ATL)-Phase I testing program
  - 20 normal emitters
  - 16 higher emitters
  - Tier0 vehicles; mostly 1987 and later model years
  - Two fuels in which sulfur only variable targeted to be altered (112 & 371 ppmW)
  - Data & analysis have been peer reviewed

- EPA's ATL-Phase II testing program
  - 27 normal emitters
  - 12 higher emitters
  - Tier0 vehicles; mostly 1986 and later model years
  - Two fuels in which sulfur only variable significantly altered (59 & 327 ppmW)
  - Data & analysis have been peer reviewed

- EPA's ATL-Phase III testing program
  - 11 normal emitters
  - 8 higher emitters
  - Tier0 vehicles; mostly 1987 and later model years
  - Three fuels in which sulfur was only fuel parameter significantly altered (9.3, 315, & 782 ppmW)
  - Data & analysis peer reviewed
  - Bag data not available for start/running emission analysis

- Auto/Oil studies
  - 10 normal emitters
  - No higher emitters
  - Tier0 vehicles
  - Sulfur systematically varied from 11 to 466 ppmW (10 different levels)
  - An "extension" fuel (S=901 ppmW) was also tested on the same set of vehicles
  - We could not access the bag data for any of the emissions for this "extension" fuel and thus running/start analyses could not be performed on the data from this fuel
  - We would like to receive this data as soon as possible to be able to incorporate it into the final analysis for determining sulfur's effects on exhaust emissions
  - All data, except "extension" fuel data, have undergone peer review

- SAE technical paper 950778
  - Older technology Tier0 vehicles: post-1983 but pre-1990 model years
  - 9 normal emitters
  - 1 higher emitter
  - Three different levels of sulfur tested (61, 338, & 685 ppmW)

- SAE technical paper 952510
  - Tier1 production vehicles
  - 6 vehicles tested--normal emitters
  - Two different levels of sulfur tested (31 & 317 ppmW)

- Waiting for final data on effects of sulfur on emissions from Tier1, LEV and advanced technology vehicles (there are currently two different studies underway to evaluate these effects--AAMA/AIAM test program and the CRC test program)--both of these data sets are expected to be finalized, reviewed, and be available for incorporation into our

analyses in the very near future

Data Analysis

- Since sulfur's effect on exhaust emissions is known to be a "catalyst phenomena," data will not be stratified by fuel injection systems (PFI, TBI, or CARB)

- Based on construction of previous fuel emission models, it will be assumed that sulfur's effects on exhaust emissions has no interaction with other fuel parameters

- For this analysis, it will also be assumed that sulfur's effects are independent of the emission level within the normal and high emitter groupings

- Where possible, emissions data will be stratified by composite, start, and running emissions & by emitter class

- High emitters are defined as those vehicles emitting greater than or equal to twice the hydrocarbon standard on base fuel ($\geq$0.82 grams/mile) on the FTP

- Start and running emissions are calculated using the correlations developed from bag data and contained in the report "Coefficients for he Determination of Engine Start and Running Emissions from FTP Bag Emissions," Report Number M6.STE.002 by David J. Brzezinski

- Several different methodologies for plotting and analyzing the data were attempted, including:

    * Averaging percent changes in emissions for given changes in fuel sulfur content across studies
    * Developing regressions similar to those shown here (in g/mile space), calculating percent effects (for given changes in fuel sulfur content) for each of the studies, and weighting them appropriately
    * Working (generating regressions) in percent reduction space to calculate sulfur's effect on emissions
    * Working in averaged g/mile space (for given levels of sulfur, g/mile numbers were averaged within studies, plotted, and the resulting correlations best-fit by vehicle technology)

    All these methodologies resulted in estimates of sulfur's effects on all emissions being reasonably close across emitter classes. The last option produced results (emission effects) that matched previous analyses the best; because of that reason and its inherent simplicity, it was used. Thus, for the most part, correlations will be developed simply by plotting group mean levels of exhaust emissions as a function of sulfur level and study

and fitting best-fit curves through those functionalities. We would like your comments on how best to represent the data and calculate effects from it.

- These correlations will be used to calculate sulfur's effect on composite, start, and running emissions by vehicle technology (Tier0 or Tier1) and by emitter class

- It was found that the form Emissions=A*ln(S)+B fit all of the data the best

[PLOTS NOT INCLUDED HERE; WILL BE PART OF FINAL REPORT AND PART OF THE PACKAGE DISTRIBUTED AT THE WORKSHOP ON 10/1/97]

- Summary of proposals for correlations relating sulfur to exhaust emissions are shown below for normal and higher emitting vehicles:

SUMMARY OF PROPOSALS FOR CORRELATIONS RELATING SULFUR TO EXHAUST EMISSIONS (DRAFT)

NORMAL EMITTING VEHICLES

Emissions Type	Technology	HC (g/m)	NOx (g/m)	CO (g/m)
Composite	Tier0	0.02871*ln(S)+0.1577	0.02144*ln(S)+0.5911	0.3945*ln(S)+1.597
Composite	Tier1	0.01152*ln(S)+0.1622	0.01146*ln(S)+2693	0.1352*ln(S)+0.9659
Start	All	No Effect	No Effect	No Effect
Running	Tier0	0.02247*ln(S)-0.00131	0.02787*ln(S)+0.4055	0.2894*ln(S)+0.1824
Running	Tier1	0.01078*ln(S)-0.0111	0.0083*ln(S)+0.1992	0.1432*ln(S)+0.1703

- All correlations for composite emissions are based on curve fit through either all tier0 data or through all tier1 data

- The slopes through all the data for start emissions was, at minimum, two orders of magnitude lower than the smallest of any of the other slopes, so it was assumed that start emissions were not affected by sulfur content in the fuel

- All correlations for running emissions are based on curve fits through either all tier0 data or through all tier1 data

HIGHER EMITTING VEHICLES (DRAFT)

Emissions Type	Technology	HC (g/m)	NOx (g/m)	CO (g/m)
Composite	Tier0	0.01686*ln(S)+1.522	0.01404*ln(S)+1.671	0.27019*ln(S)+15.989
Composite	Tier1	0.01686*ln(S)+1.522	0.01404*ln(S)+1.671	0.27019*ln(S)+15.989
Start	All	No Effect	No Effect	No Effect
Running	Tier0	0.1525*ln(S)+1.134	0.08728*ln(S)+1.112	3.072*ln(S)+11.77
Running	Tier1	0.1525*ln(S)+1.134	0.08728*ln(S)+1.112	3.072*ln(S)+11.77

- All high emitting composite correlations were based on best curve fits through all of the data

- For running emissions from higher emitting vehicles, all data were used to determine correlations with the exception of the correlation relating running HC to sulfur for Tier0 vehicles. In this case, the older technology data (data from SAE paper 950778) was omitted because of inconsistent behavior as sulfur was increased

- The following tables summarize the actual emission effects of varying sulfur (in three different regimes) in the correlations listed above for both normal and higher emitters:

SUMMARY OF PERCENT REDUCTIONS CALCULATED FROM CORRELATIONS FOR VARYING SULFUR LEVELS (DRAFT)
NORMAL EMITTING VEHICLES

Type of Emis	Tech	Percent Reduction in Exhaust HC Emissions when sulfur (ppmW) changed from:			Percent Reduction in Exhaust NOx Emissions when sulfur (ppmW) changed from:			Percent Reduction in Exhaust CO Emissions when sulfur (ppmW) changed from:		
		700→400	400→200	200→50	700→400	400→200	200→50	700→400	400→200	200→50
Comp	Tier0	4.8	6.0	12.8	1.64	2.08	4.20	5.28	6.92	14.8
Comp	Tier1	2.8	3.4	7.1	1.87	2.40	4.80	7.50	5.23	11.1
Comp	CMPX model	14	9.9	7.5	2.90	5.70	7.40	14.4	9.6	7.26
Runn	Tier0	8.6	11.7	26.3	2.66	3.38	7.00	7.80	10.5	23.3
Runn	Tier1	10.1	13.4	32.5	1.84	2.30	4.71	7.20	9.72	21.4

HIGHER EMITTING VEHICLES (DRAFT)

Type of Emis	Tech	Percent Reduction in Exhaust HC Emissions when sulfur (ppmW) changed from:			Percent Reduction in Exhaust NOx Emissions when sulfur (ppmW) changed from:			Percent Reduction in Exhaust CO Emissions when sulfur (ppmW) changed from:		
		700→ 400	400→ 200	200→50	700→ 400	400→ 200	200→50	700→ 400	400→ 200	200→50
Comp	Tier0	0.55	0.72	1.43	0.45	0.55	1.10	0.85	1.10	2.20
Comp	CMPX model	-1.60	-1.00	-0.80	7.00	4.80	3.60	11.8	6.90	6.10
Runn	Tier0	4.00	5.04	10.8	2.91	3.70	7.66	5.37	6.97	15.2
Runn	Tier1	4.00	5.04	10.8	2.91	3.70	7.66	5.37	6.97	15.2

- For normal emitters, the sulfur curve has flattened out (in comparison to the complex model) past 450 ppmW sulfur because of the data added from the "extension fuel." Similarly, at the lower end of the sulfur range, addition of data not included in the complex model database has made the effects steeper (i.e., lower sulfur, greater effects)

- If the data from the "extension fuel" and data from the low sulfur fuels used in the Auto/Oil program are removed from this database before conducting this analysis, the resulting effects of sulfur on all exhaust emissions match very closely with predictions made by the complex model (the complex model database did not contain emissions data from these fuels)

- While the high emitter results do not match the complex model estimates very closely, they are consistent with the theory that higher emitters will tend to be less affected by sulfur changes because of deterioration or breakdown of the catalyst and the catalytic converter

Proposals for how to incorporate effects into MOBILE6 and issues:

- We propose that sulfur's effects on exhaust emissions be computed based on the entries in the tables shown above using 339 ppmW (the current national average sulfur level) as the baseline

- The correlations shown above will be used to calculate percentage change effects only. The correlations listed in the previous tables will be used to get a sulfur correction with S=339 ppmW being set to unity, then these corrections will be applied to MOBILE6 emission factors.

- Due to logistical problems of using the sulfur dial for RFG areas, we propose that the sulfur dial can only be used to compute sulfur adjustments in non-RFG (conventional gasoline) areas. We would especially like your comments on this issue.

- When the sulfur dial is used to determine benefits of reducing sulfur in non-RFG areas,

this analysis does not address the issue of other parameters remaining unchanged enough (due to sulfur being reduced) to comply with anti-dumping regulations. It must be shown (through the use of the Complex Model, for example) that non-sulfur changes in fuel parameters (resulting from the reduction in sulfur) does not increase emissions over what is allowed.

- Eventually, if MOBILE is going to be capable of estimating actual in-use emission impacts from sulfur changes, it should also be able to address effects of other fuel parameters as well. In short, a emissions model such as the complex model (with capabilities of predicting effects across all technologies and vehicle model years), needs to embedded in MOBILE. To date, we do not have enough data to undertake this type of analysis. However, the rationale for having capabilities for sulfur input for non-RFG areas in MOBILE6 is due to the fact that we may consider sulfur control in the future; and if we do, it will important to have a more accurate understanding of what sulfur levels actually exist in the uncontrolled scenario (non-RFG). We would like your comments on this issue.

- At this time, we propose the following valid ranges for using the sulfur dial in MOBILE6:

  * For Tier0 vehicles: 25 ppmW<S<900 ppmW
  * For Tier1 vehicles: 30 ppmW<s<339 ppmW

  Oxidation catalysts (pelletized/beaded) were used even in pre-Tier0 vehicles (1975-1980); however, we propose to ignore these effects since there is a lack of data and most of these vehicles would have deteriorated to the extent that they will no longer be in-use. The alternative proposal would be to use Tier0 effects for HC and CO only for these class of vehicles since no NOx standard existed for pre-Tier0 vehicles. We would like your comments on this issue.

- Once the data from the CRC and AAMA/AIAM testing programs become available, the accuracy and range of sulfur's effects on emissions from both Tier1 and advanced technology (LEVs) vehicles can be vastly improved and extended