Air Conditioning Effects in MOBILE6
Status Update
September 25, 1997

1. Overview

As currently proposed, MOBILE6 will generate air conditioning emission factors for start and running operation which will be adjusted using temperature and humidity levels input by the user. Emission and activity components of the model are being developed individually, and will be brought together in the model. Emission characterization is focused on developing the emission factors representing 100% (full) usage for each pollutant. These factors will be developed in a similar manner to the A/C-off speed correction (for running) and soak correction (for start) factors. The need for separate emission factors across driving cycle, vehicle class, technology, model year, standard and emitter category are currently under investigation.

The activity component will determine how the full-usage emission factors should be scaled to reflect actual usage patterns, focusing on changes in ambient temperature and humidity. The scaling of full-usage emission factors according to temperature and humidity will be based on default relationships developed between these parameters and A/C system behavior. A 1994 survey of A/C usage patterns conducted in Phoenix as part of the Supplemental Federal Test Procedure (SFTP) rulemaking process will be used to develop these relationships.

The emission and activity factors proposed for use in the model have not been finalized. However, preliminary analysis of available data has given a sense of data trends. This document discusses these trends and proposes initial methodology for incorporating A/C effects into MOBILE6.

2. Testing

Testing is complete on 25 vehicles at EPA's National Vehicle and Fuel Emissions Laboratory (NVFEL) and 11 of 12 vehicles at Automotive Testing Laboratories (ATL), a test facility in Ohio contracted by EPA. The datasets from both programs are currently being finalized. All vehicles tested were model year 1990 or newer. Each vehicle was run with the A/C on and off over the same sequence of driving cycles used in developing the A/C-off speed correction factors. A cold ST01 cycle[1] was also run in both conditions for the purpose of developing start A/C factors. The EPA tests were run on a 48-inch electric dynamometer, while the ATL testing used a twin 20-inch electric dynamometer. The 10% A/C loading factor was not applied to either A/C condition. The A/C-on tests were conducted in a standard test cell at 95° F and 50 grains/pound of humidity

[1]ST01 is a 1.4 mile cycle developed to specifically characterize driving behavior following startup. The cycle was developed from an in-use driving survey conducted in Baltimore, Spokane and Los Angeles as part of the SFTP rulemaking process.

with the driver window down. These conditions were meant to simulate the real-world emission response under the conditions of the new certification test procedures (95° F, 40% Relative Humidity, 850 Watts/Meter^2 solar load). The A/C-off tests were run in standard FTP ambient conditions (75° F, 50 grains/pound). Both modal and bag data were collected.

3. Preliminary Analysis of Emission Data

Preliminary analyses have been performed using unofficial results from 24 vehicles tested at EPA and eight vehicles tested at ATL. The analyses thus far have focused on correlation with available environmental cell data, overall effects by speed on each pollutant, and effects across technology, vehicle class, standard and emitter strata. In order to compare A/C-on with A/C-off results on an equal temperature basis, the A/C-off results were corrected from 75° to 95° using MOBILE5 temperature corrections for Bag 2 (running cycles) or Bag 1 (ST01).

a. Determination of Appropriate Full-Usage Dataset

A key issue is whether the EPA/ATL dataset can be used directly for establishing the full-usage emission factors, or whether these data will need to be scaled up to adequately represent the full usage level. Analysis of A/C compressor behavior during industry environmental cell testing and in the Phoenix A/C survey suggests that the certification test conditions (95° F, 40% Relative Humidity, 850 Watts/Meter^2 solar load) represent maximum A/C system load across a range of vehicles; hence, the emission results obtained in a full environmental chamber under these conditions are assumed to represent the full-usage effect. Determining correlation of the emission increase due to A/C operation between the EPA/ATL testing and an environmental chamber under the certification test conditions is therefore important to determine the appropriateness of using the EPA/ATL data to represent full-usage effects.

b. Correlation Analysis

Initial comparison of the EPA results and environmental cell data gathered during the SFTP rulemaking shows good correlation of the relative A/C emission increase for CO_2, HC and CO. The relative NOx increase, however, is lower for the EPA testing. Since good CO_2 correlation indicates that the increased load due to A/C operation is similar between the two test conditions, differences in the vehicle sample may be causing the NOx offset. To eliminate vehicle effects, further analysis will look at the emission results of individual vehicles which are similar in make and model year between the two samples. If the NOx difference between the two samples can be attributed to factors other than A/C system loading, the CO_2 results lend support to using the EPA data to develop the full-usage emission factors.

ATL results analyzed thus far show a consistently lower A/C impact for all pollutants (including CO_2) relative to both the EPA and environmental cell results. The CO_2 results point towards a systematic underloading of the A/C system during testing at ATL, although differences in the vehicle sample are also being investigated. A correlation vehicle instrumented with several A/C-

related parameters will be tested at ATL, EPA and possibly in a full environmental chamber for further investigation. If a loading offset is demonstrated, the ATL data will not be used in generating the full-usage emission factors.

c. Overall Emission Results

Running A/C factors by average speed were developed for each pollutant by ratioing sample-averaged A/C-on and A/C-off emissions over each cycle. The EPA and ATL data were analyzed separately because of the concern with underloading at ATL. However, the overall emission increases are fairly significant at both sites for NOx and CO. The average percentage increase for NOx is dependent on average cycle speed (particularly at lower speeds) for both sites. The average increase for the EPA data ranges from approximately 70% at 10 mph to 20% above 50 mph (40% to 10% for ATL). The impact of speed on the HC and CO effects is less clear. There is a suggestion that the emission increase is higher at the low and high ends of the speed range, but enough variability exists that a straight average (i.e. no speed impact) may be more appropriate. Using the latter approach, the average CO increase across all cycles is approximately 60% at EPA and 30% at ATL. HC results analyzed in a similar manner vary directionally by site; the EPA sample increased by 7% over all cycles, while the ATL sample decreased by 9%.

ST01 data from both sites indicate that the relative A/C impact over cold starts is lower than over warmed-up operation. The A/C NOx impact over ST01 (with an average speed of approximately 20 mph) for the EPA sample is approximately 30% compared to 50% for running (roughly 10% vs. 20% for ATL). CO impacts are below 10% at ATL and negligible for EPA, while HC impacts are negligible at both sites. These data suggest that separate start A/C emission factors are warranted.

d. Stratification

Strata which will be investigated for differences in A/C emission factors are driving cycle (running only), technology type (TBI and PFI), vehicle class (LDV and LDT), emission standard (Tier 0 and Tier 1), and emitter category (Normal and High). Stratification by model year group is not viable since all vehicles tested were model year 1990 or newer; A/C factors developed for 1990 and later vehicles will be applied to pre-1990 model year groups unless compelling evidence to do otherwise is brought forward.

Preliminary Analysis of Variance on the running results indicate the following strata merit further investigation:

- NOx: Vehicle class, standard
- HC: Vehicle class, standard, technology, facility, emitter
- CO: Vehicle class, technology

Vehicle class and standard level are of particular interest. The relative A/C impact on LDT's may be less than on LDV's due to smaller cabin volume for pickups (although this may be offset by minivans and SUV's), and lower relative load placed on the engine by the A/C system. Standard level is of interest since the data seem to indicate that relative A/C NOx impact increases as absolute emission level decreases.

4. Emissions at Intermediate Conditions

MOBILE6 will need to predict emission levels at intermediate ambient conditions for which it is not appropriate to apply the full-usage emission factors. Unfortunately, EPA is not aware of any emission data which allow the direct modeling of A/C emission increase with changes in ambient temperature, humidity or solar load. In addition, available activity data is limited in terms of A/C system behavior, monitoring only whether the A/C compressor is on or off. Therefore, EPA proposes to develop intermediate condition emission factors by scaling down the full-usage emission factor (assumed to represent 100% compressor-on) according to compressor-on percentage. In other words, if the compressor is engaged only 50% of the time, 50% of the full-usage emission factor would be applied. Available activity data will be used to develop a relationship between temperature/humidity and compressor-on percentage. The key to this approach is the assumption that the relative emission impact due to A/C is linearly proportional to compressor-on percentage for all pollutants.

5. Activity

a. Usage

The Phoenix A/C survey conducted as part of the SFTP rulemaking is the source for activity data. This survey collected A/C and compressor usage information on 20 vehicles from August-October 1994. Weather information from the National Climatic Data Center allows temperature and humidity levels to be determined for each trip taken during the survey (unfortunately solar load data is not reliable, so this parameter cannot be similarly linked).

Analysis of the Phoenix dataset shows a strong correlation between temperature and compressor-on time. The relationship between humidity and compressor-on time is weaker, and when modeled in conjunction with temperature it is not a significant variable. However, as indicated in comments received during and since the March 1997 MOBILE6 workshop, humidity is believed to have a strong impact on air conditioner operation and should be accounted for in the model. Since humidity data from Phoenix is limited, an approach using a combined temperature and humidity measure may be preferable to modeling humidity directly. The "heat index" measure developed by the National Weather Service combines dry bulb temperature and relative humidity into a single "effective temperature". An attractive feature of this measure is that it provides a basis for quantifying driver discomfort, and thus is most likely to impel a driver's A/C behavior. Two approaches for using heat index are being considered. The first is to calculate heat index directly from the Phoenix data and use it to model compressor-on time. The second is

to model only temperature with compressor-on time and use the humidity level provided by the user to calculate heat index, which is treated by the model as if it were a higher "temperature". The second approach would likely result in a greater humidity impact than the first.

EPA is currently proposing not to include adjustments for solar load. An initial assessment of Phoenix data shows no strong difference between day and night operation at similar temperatures, suggesting that solar load did not have a strong impact. Compressor operation by time of day will be assessed to investigate further whether any solar load impact can be discerned. Overall, however, sufficient data to develop a solar load adjustment does not appear to exist. Because A/C effects will be based on the certification test conditions (850 Watts/Meter^2 solar load), full solar load will be implicitly assumed in the model. This is appropriate since it reflects the condition most likely to contribute to ozone exceedences. If solar load adjustments are strongly desired, the heat index approach may provide some basis for estimating this effect. The heat index at a given temperature and humidity varies with sun exposure, so varying solar load could be accounted for by adjusting the heat index accordingly.

Soak time and trip duration do not show a strong correlation with compressor-on time. Although these parameters may impact actual A/C behavior, the Phoenix data is not sufficient to assess their effects. Soak duration adjustments will be developed since it is likely separate start A/C factors will be proposed. This adjustment will be based on an interpolation between the start A/C factor and appropriate running A/C factor as a function of soak duration. Whether this interpolation should be related to soak duration in a linear manner or some other form needs to be resolved.

b. Market penetration

Market penetration data (i.e. the percent of vehicles equipped with A/C) by model year will be gathered from Ward's and AAMA Facts & Figures for cars and trucks separately. Projections will need to be made for future model years using historical data. The data indicate that A/C penetration has risen gradually over the past 25 years to over 90% for cars and trucks in 1996, so future estimates will likely fall between 90 and 100%.

c. Guidance for using improved intermediate condition data

Given the importance of developing improved data for the effect of intermediate ambient conditions on A/C emission impact, MOBILE6 will be structured such that improved relationships could be used when more comprehensive information becomes available. Guidance will be developed when improved datasets are available, and EPA approval would be necessary to use alternate information in lieu of the default relationships.

6. Proposal for SFTP Control

The SFTP rulemaking assumed that on average vehicles would be required to reduce running

A/C-on NOx emissions 50% to comply with the A/C standards. This assumption will be incorporated into MOBILE by reducing the calculated A/C NOx emission factor by 50% on vehicles complying with the SFTP standards. No HC and CO benefits were given to A/C control as part of the rulemaking, primarily because it was assumed stoichiometric calibration required for US06 control would also eliminate A/C HC and CO increases. To reflect this assumption in MOBILE6, no HC emission factor will be assigned to SFTP-complying vehicles. For CO, however, it is expected that increased loading due to the A/C system will increase CO even with stoichiometric operation. Therefore the CO emission factor will not be eliminated completely but reduced to equal the level of CO_2 increase as a surrogate for load.

SFTP credits need to be developed independently for starts since the SFTP requirement applies to warm operation only. Further investigation is required to assess whether the running credits are also appropriate for starts.

7. Summary of Current Proposals and Open Issues

Although this document discusses several preliminary trends of the emission and activity elements of the MOBILE6 A/C component, actual A/C emission factors cannot be developed until the EPA and ATL datasets are finalized. Some concepts are currently being proposed, however, which will frame the development of the A/C emission factors. These are as follows:

- Emission levels from testing conducted at 95° F, 40% Relative Humidity, and 850 Watts/Meter^2 solar load represent full-usage (i.e. 100% A/C) levels.
- MOBILE6 will model changes in temperature and humidity only.
- The factor used to scale full-usage emission factors down for intermediate temperature and humidities will correlate 1:1 with compressor-on percentage.
- MOBILE6 will be structured to handle improved intermediate ambient data when it becomes available.
- Emission factors developed for 1990 and later model year vehicles will apply to pre-1990 vehicles as well.
- Running A/C emission factors on vehicles complying with the SFTP will be reduced by 50% for NOx and 100% for HC. The controlled CO increase will be equated with A/C-on CO_2 increases.

The following are open issues regarding the development of final emission factors:

- Appropriate dataset for developing the full-usage A/C emission factors
- Development of full-usage emission factors by speed
- Strata for which separate A/C emission factors are appropriate
- Separation of start and running A/C emission factors
- Development of soak adjustments for start emission factors if separate from running
- Appropriate methodology for modeling compressor-on percentage based on temperature and humidity

- Development of market penetration estimates
- Reductions in start A/C impacts for vehicles complying with the SFTP

Stakeholder comments are encouraged for both the current proposals and the open issues. Comments should be forwarded by hardcopy or email to:

John Koupal
EPA National Vehicle and Fuel Emissions Laboratory
Assessment and Modeling Division
2565 Plymouth Road
Ann Arbor, MI 48105
Fax: (313) 741-7939
Email: mobile@epamail.epa.gov