EMISSIONS ANALYSIS OF 54 FLEET-TYPE
PASSENGER VEHICLES

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Division of Advanced Automotive
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INTRODUCTION

Fifty-four 1970-model fleet cars of different makes and mileages were tested by EPA using both the CVS cold-start and the CVS hot-start test conditions. On November 15, 1971, CAL received from EPA the results of these emission tests with the following remarks: "A two-bag cold start test was run on each car followed by a two-bag hot start test. To obtain three-bag data, it is necessary to weight and assemble the data from the two cold start bags with the first bag of the hot start test using the procedure described in the Federal Register." The identity of the vehicles could not be disclosed by EPA in any way other than by range of engine displacement, number of cylinders, accumulated mileage, and car weight.

The emission data listed in the computer print-outs gave occasion to study the following questions:

- To what extent does the accumulated mileage influence the emissions level?
- Is there a significant difference between the emissions levels for cold start and hot start?
- What is the numerical relation between the CVS-C and the CVS-CH testing procedure?

The answers to these questions were felt to provide, by inference, some inputs into the planning of Stratified-Charge-Engine tests.
INFLUENCE OF ACCUMULATED MILEAGE ON EMISSIONS LEVEL

The accumulated mileage of the cars tested ranged from approximately 4,000 miles to 35,000 miles. A visual inspection of the emissions data from an analysis of each bag plotted versus accumulated mileage strongly suggested negligible correlation between the two variables, Figures 1 through 12. An analysis of variance, described elsewhere, also failed to reveal a mileage trend (nor did it confirm any other trend associated with number of cylinders, displacement, and car weight). Hence, all cars can be considered as drawn from the same homogeneous population.

As an interesting aside, it may be mentioned that in contrast to the toxic emission components (CO, HC, and NOx), the non-toxic component of CO2 did indeed reveal a mileage correlation. Figure 13 shows CO2 data in gr/mi for the first cold bag as a function of mileage suggesting an upward trend of emissions with mileage. An analysis of variance, Table 1, confirmed the significant contribution of mileage to the overall variability of CO2.

Table 1
Analysis of Variance on CO2 Emissions (gr/mi) of Fifty-four Cars, Divided into Three Mileage Classes (< 10,000; 10,000 - 20,000; > 20,000 miles)

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degree of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between mileage classes</td>
<td>14.92 x 10^4</td>
<td>2</td>
<td>7.69 x 10^4</td>
</tr>
<tr>
<td>Within mileage classes</td>
<td>65.80 x 10^4</td>
<td>51</td>
<td>1.29 x 10^4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>81.72 x 10^4</td>
<td>53</td>
<td>F = 6.17, F^2,51,99% ≥ 5.0</td>
</tr>
</tbody>
</table>
INFLUENCE OF START CONDITIONS ON EMISSIONS LEVEL

Figures 14 through 17 depict the means and the standard deviations of the HC, CO, NO$_x$, and CO$_2$ constituents for each of the four bags. The mean is indicated by a small circle, the standard deviation by the length of the vertical bar extending from the mean value in both directions. Obviously, the HC and the CO contents (in gr/mi) of the first (cold-transient) bag are significantly higher than those of the rest. In fact, the differences between the second (cold-stabilized), third (hot-transient), and fourth (hot-stabilized) bag are so slight as to suggest a constant level of CO and HC emissions after the first bag. Thus, the HC level of the first bag is approximately 1.6 times higher than the average level of subsequent bags, and the CO level of the first bag approximately 3.4 times higher. The situation is different for NO$_x$. Here, the NO$_x$ content of the first bag is always higher than that of the subsequent bag regardless of whether the engine is started after a cold soak or a hot soak. The CO$_2$ level is of lesser importance. We note that it remains approximately unchanged.

Another descriptor of interest is the standard deviation. In HC and CO emissions, the standard deviation seems to change proportionally with the mean, an observation confirmed by analyses of aircraft emission data (Reference 1). The standard deviations of both NO$_x$ and CO$_2$, however, indicate no dependence on the mean.

For comparison, the emission data of the 54 cars were contrasted with the emission data of an FCP engine installed in a jeep (Reference 2). The FCP data are listed in Table 2 and indicated in Figures 14 through 17 by black bars; the bar center is identical with the mean, the bar length with twice the standard deviation. The general trends of both plots are
similar although the HC, CO, and NO\textsubscript{x} values of the FCP engine are strikingly lower than those of the 54 cars (due to effective emission control and lack of variance between engines).

**Table 2**

Constant Volume Sampler Results of FCP Engine
EPA, October 7, 1971 (Reference 2)

<table>
<thead>
<tr>
<th>Bag</th>
<th>Size</th>
<th>Gas</th>
<th>Mean gr/mi</th>
<th>Standard Deviation gr/mi</th>
<th>Rel. Variation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Start</td>
<td>14</td>
<td>HC - FID</td>
<td>0.97</td>
<td>0.16</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO - IR</td>
<td>1.30</td>
<td>0.43</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO\textsubscript{2} - IR</td>
<td>48.0</td>
<td>45.</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO\textsubscript{x} - CI</td>
<td>0.40</td>
<td>0.13</td>
<td>33</td>
</tr>
<tr>
<td>Stabilized</td>
<td>14</td>
<td>HC - FID</td>
<td>0.18</td>
<td>0.05</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO - IR</td>
<td>0.78</td>
<td>0.28</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO\textsubscript{2} - IR</td>
<td>509.</td>
<td>37.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO\textsubscript{x} - CI</td>
<td>0.28</td>
<td>0.06</td>
<td>22</td>
</tr>
<tr>
<td>Hot Start</td>
<td>14</td>
<td>HC - FID</td>
<td>0.27</td>
<td>0.03</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO - IR</td>
<td>0.76</td>
<td>0.26</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO\textsubscript{2} - IR</td>
<td>451.</td>
<td>53.</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NO\textsubscript{x} - CI</td>
<td>0.39</td>
<td>0.12</td>
<td>30</td>
</tr>
</tbody>
</table>
CVS-C VERSUS CVS-CH TEST PROCEDURE

The Constant Volume Sampling Procedure for 1972 prescribes a 1369 second, 7.5 mile, non-repetitive driving cycle with a 12-hour cold soak before testing and a cold start (Notation: CVS-C).

The Constant Volume Sampling Technique for 1975-76 prescribes the same 7.5 mile driving pattern as the 1972 procedure. The emissions of the first 505 seconds are collected in a "cold transient" bag, those of the next 864 seconds in a "stabilized" bag. After ten minutes hot soak with engine off, the 7.5 mile driving cycle is repeated with the emissions of the first 505 seconds collected in a "hot transient" bag (Notation: CVS-CH). The first cold bag is weighted by a factor of 0.43, the second transient bag by a factor of 1, and the third hot bag by 0.57. All weighted emissions are then added and the sum divided by 7.5 to give the emissions in gr/mi.

In order to compare the CVS-C and the CVS-CH procedures, the four-bag data of the 54 cars (a cold-transient bag, a cold stabilized bag, a hot-transient bag, and a hot-stabilized bag) were assembled in two ways.

\[
\begin{align*}
\text{CVS-C} & \quad (Y_{ct} + Y_{cs})/7.5 = Y_m \text{ in gr/mi} \\
\text{CVS-CH} & \quad (0.43 Y_{ct} + Y_{cs} + 0.57 Y_{ht})/7.5 = Y_{wm} \text{ in gr/mi}
\end{align*}
\]

\[Y_{ct} \text{ = mass emissions of pollutant (CO, HC, NO}_x\text{) as calculated from the cold-transient phase (bag) of the cold-start test, in grams}\]

\[Y_{cs} \text{ = mass emissions of pollutant (CO, HC, NO}_x\text{) as calculated from the cold-stabilized phase (bag) of the cold-start test, in grams}\]
\[ Y_{ht} = \text{mass emissions of pollutant (CO, HC, NO}_x\text{) as calculated from the hot-transient phase (bag) of the hot-start test, in grams} \]

\[ Y_m = \text{mass emissions of pollutant in gr/mi; CVS-C test procedure} \]

\[ Y_{wm} = \text{weighted mass emissions of pollutant in gr/mi; CVS-CH procedure} \]

These computations were performed for each of the 54 cars (actually only 53 because one car's data were quite erratic and had to be omitted). For each car, the ratio of \( Y_{wm} / Y_m \) was then calculated, and the mean and the standard deviation of the distribution of these ratios computed. The results are listed in Table 3 together with the standard deviation of the mean \( (s_{\text{mean}} = s / \sqrt{53}) \).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>( Y_{wm} / Y_m ) Mean</th>
<th>( Y_{wm} / Y_m ) Standard Deviation</th>
<th>Number of Cars</th>
<th>( Y_{wm} / Y_m ) Standard Deviation of Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>0.88</td>
<td>0.07</td>
<td>53</td>
<td>0.01</td>
</tr>
<tr>
<td>CO</td>
<td>0.71</td>
<td>0.13</td>
<td>53</td>
<td>0.02</td>
</tr>
<tr>
<td>NO\textsubscript{2}</td>
<td>1.01</td>
<td>0.05</td>
<td>53</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 3 demonstrates clearly the attenuating effect of bag weighting as regards to HC and CO. The HC level is reduced by 12% and the CO level by even 29%. The NO\textsubscript{x} level, on the other hand, remains unaffected.
SUMMARY

Fifty-four fleet cars of different makes and mileages, all 1970 models, were tested by EPA using both the CVS cold-start and the CVS hot-start test conditions. Although the accumulated mileage of the cars tested ranged from approximately 4,000 to 35,000 miles, a correlation between mileage and level of CO, HC, NOₓ emissions was not detectable. (There was a slight but significant increase of CO₂ with mileage, however.) The mean and the standard deviations of the CO and HC emissions sampled in the cold-start bag were significantly higher than those of subsequent bags. The HC mean of the cold-start bag was approximately 1.6 times higher; the CO mean, 3.4 times. Also, the standard deviation of both emissions seemed to change approximately proportional with the mean. The situation was different for NOₓ. Here, the mean of the first bag was always higher than that of the subsequent bag regardless of starting conditions. The CO₂ level remained approximately constant for all bags. The results were qualitatively corroborated (except for mileage effects) by results of emission tests performed by EPA on one FCP engine installed in a jeep.

An investigation of the effect of bag weighting on the measured emission level revealed that the CVS-CH technique produces a 12% lower HC level than the CVS-C procedure and a 29% lower CO level. The NOₓ level remains unaffected.
REFERENCES


2. Private Communication: Computer Printout of EPA.
Figure 1 – CO Emissions of Cold-Start Bag 1
Versus Accumulated Mileage

Figure 2 – CO Emissions of Cold-Start Bag 2
Versus Accumulated Mileage
Figure 3 - CO Emissions of Hot-Start Bag 1
Versus Accumulated Mileage

Figure 4 - CO Emissions of Hot-Start Bag 2
Versus Accumulated Mileage
Figure 5 - HC Emissions of Cold-Start Bag 1
Versus Accumulated Mileage

Figure 6 - HC Emissions of Cold-Start Bag 2
Versus Accumulated Mileage
Figure 7 - HC Emissions of Hot-Start Bag 1
Versus Accumulated Mileage

Figure 8 - HC Emissions of Hot-Start Bag 2
Versus Accumulated Mileage
Figure 9 - NO$_2$ Emissions of Cold-Start Bag 1 
Versus Accumulated Mileage

Figure 10 - NO$_2$ Emissions of Cold-Start Bag 2 
Versus Accumulated Mileage
Figure 11 - NO$_2$ Emissions of Hot-Start Bag 1
Versus Accumulated Mileage

Figure 12 - NO$_2$ Emissions of Hot-Start Bag 2
Versus Accumulated Mileage
Figure 13 - CO₂ Emissions of Cold-Start Bag 1 Versus Accumulated Mileage
Figure 14 - Mean and Standard Deviation of HC

- 54 Fleet Cars
- Jeep with FCP Engine (EPA)
Figure 15 - Mean and Standard Deviation of CO

- 54 Fleet Cars
- Jeep with FCP Engine (EPA)
  (10 times enlarged)
Figure 16 - Mean and Standard Deviation of NO\textsubscript{x} for 54 Fleet Cars and Jeep with FCP Engine (EPA)
Figure 17 - Mean and Standard Deviation of CO₂

[Diagram showing comparisons between different bags and conditions]

- 54 Fleet Cars
- Jeep with FCP Engine (EPA)