DISCUSSION

D. T. Wade[1] (*written discussion*)—The author has done a good job of providing a general over view of four complex American Petroleum Institute (API) programs on fuel effects. I would like to expand his comments in the area of evaporative emissions to cover two additional studies. One of these studies commonly referred to as the Joint Committee Study involved the California Air Resources Board, the Western Oil and Gas Association (WOGA), the Los Angeles Air Pollution Control District (LAPCD) and the API. It was designed to estimate the effect of reducing fuel volatility on emissions to the Los Angeles atmosphere. The second study has been sponsored by the API and is designed to develop a method of characterizing the evaporative emissions tendency of a fuel.

In commenting on the API-Bureau of Mines (API-BOM) volatility study, the author pointed out that simple arithmetic averages of the Bureau's data were not sufficient to estimate volatility effects in a specific geographical area. The Joint Committee study is a good example of the kinds of techniques that must be followed to make such an estimate, and I would like to spend the next few minutes discussing that study in order to illustrate those techniques.

In the Joint Committee study the area studies was the Los Angeles basin, and the data relating fuel volatility effects to mass emissions was wholly derived from the API-BOM program.

The fuels used by the Joint Committee were supplied by eight individual member companies of WOGA. The fuels from the eight companies were blended by Saybolt in proportion to the sales volume of the eight companies, and the composite blends were used by the Joint Committee to estimate fuel properties. The two principal fuels in the study were a composite of the fuel produced by the eight companies in July 1968, and a composite of a prototype 6.0 RVP fuel. The Joint Committee was interested in evaporative emissions for a typical day in Los Angeles. Therefore, a transformation of the API-BOM data was necessary. This was accomplished by using the downtown traffic count and an assumed diurnal temperature cycle to estimate the number of cars operating at a given temperature. They then interpolated the API-BOM data to calculate the evaporative emissions for

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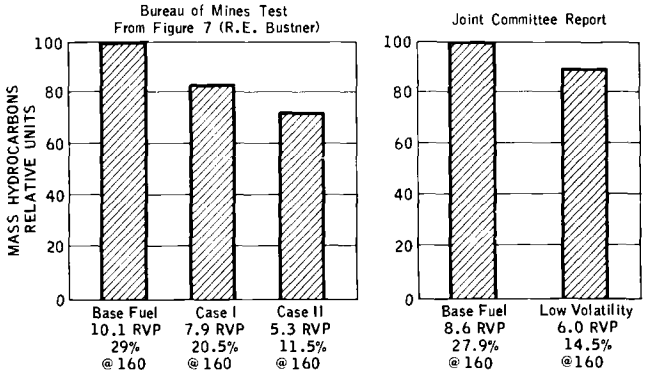

FIG. 20—*Comparison of Joint Committee report with simple averages from Bureau of Mines test.*

that fraction of the car population operating at a given temperature and finally summed those emissions over the entire day.

In studying fuel effects the Committee assumed that the fuels chosen for study were related to the API-BOM fuels as a function of their RVP levels. As it turned out this was not a bad assumption for the fuels involved as we will see when I discuss the API program on emissions characterization.

In effect then the Joint Committee took the results of the API-BOM volatility experiments and translated them to Los Angeles by considering the factors which were unique to that specific area, that is, car population, driving patterns, ambient temperatures, and fuel volatilities.

As you see from Fig. 20 the results of the Joint Committee report are considerably different than what might have been expected by simple inspection of the author's Fig. 7. In the Los Angeles case going from the base fuel to the 6.0 RVP fuel reduced the mass evaporative emissions by about 9 percent on a typical 85 F day—while going from the base fuel to the lowest volatility fuel in the API-BOM study reduced the mass evaporative emissions by about 26 percent if you average the 70 and 95 F results as the author did in his Fig. 7. This, of course, does not mean that either one of the two results is anomalous. But it does emphasize the importance of considering the realities of a specific situation rather than drawing broad conclusions from a general study.

In the remainder of my comments I would like to present a brief status report on some work that is currently being performed by Scott Research Corporation for API which has relevance to this general topic. In that program, Scott is trying to develop a way of characterizing fuels with respect to their evaporative emissions tendency.

The desire for this type of program arose as a result of the Joint Committee study. As you will recall the Joint Committee correlated fuels by their RVP. For example, their evaporative emissions correlation is shown

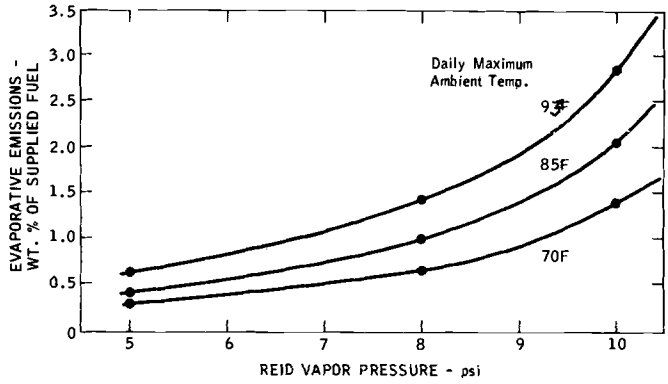

FIG. 21—*Evaporative losses from motor vehicles in Los Angeles County (emissions versus Reid vapor pressure, for typical days).*

in Fig. 21. There are two implicit assumptions in this correlation: first, it is assumed that a fuel's evaporative emissions tendency is only a function of its RVP and, second, it is assumed that the API-BOM study properly developed that functionality. In fact, since there were only three fuels of different volatility in the API-BOM study, it was not possible to address directly the question of what fuel factors were most relevant with respect to evaporative emissions. Instead, the API-BOM fuels were designed to be representative of the average fuels which might be produced at a given volatility level. And as a working assumption the volatility levels were specified in terms of RVP and the percent distilled at 160 F, as measured by the ASTM D 86 procedure. These characteristics are shown in Fig. 22 for the API-BOM fuels and for the two Joint Committee fuels. As you can see the two Joint Committee fuels fall close enough to the straight line between the API-BOM fuels so that an interpolation of evaporative emis-

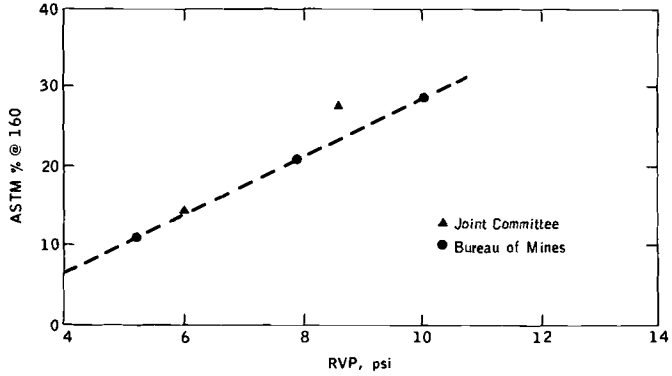

FIG. 22—*Characteristics, Bureau of Mines and Joint Committee fuels.*

sion effects seemed valid. This plot also indicates that insofar as southern California refiners are concerned the API-BOM fuels were well chosen, that is, with respect to RVP and percent 160 they can be interpolated to fit the average case.

However, the individual fuels which went into these averages scattered broadly over a plot of this type. And there was a real question about how a line of constant evaporative emissions should be drawn. The API project at Scott then has been directed toward answering this question, and I would like to briefly indicate the course and status of that project.

The basic problem in answering this question was to obtain data on carburetor and fuel tank emissions from a large number of fuels on a large number of cars under widely varying conditions of temperature and vehicle use. Those of us who participated in the Coordinating Research Council (CRC) evaporative emissions measurement program quavered at the thought of generating this massive amount of data experimentally. Furthermore, given the accuracy of the measurement techniques available we had considerable trepidation about the degree of uncertainty which would exist in the results. And it was in the face of these two very large obstacles, that is, cost, and accuracy, that we decided to perform a modeling study rather than undertake an actual experimental program.

In order to perform this study we needed models of the carburetors and fuel tanks of vehicles which would allow us to plug in fuel characteristic and temperatures for the fuel systems and thereby predict evaporative emissions. Fortunately, candidate models existed in the literature. Also, fortunately, Air Pollution Research Advisory Committee (APRAC) had completed recently an 80 car survey of fuel system temperatures under different driving conditions in the Los Angeles basin. The final steps to obtain the raw data then were to blend up a set of fuels to cover a large part of the commercial range, and to calculate evaporative emissions for each car with each fuel as it went through several different driving patterns

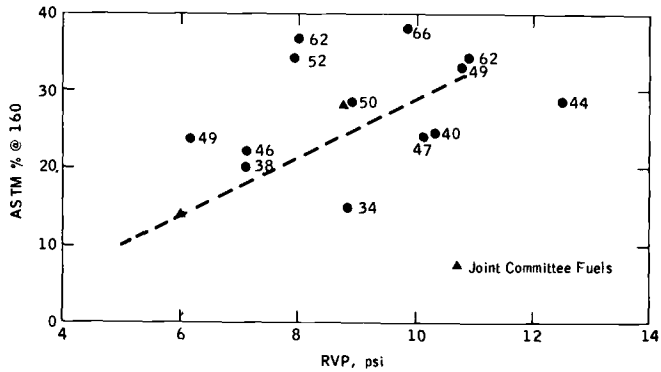

FIG. 23—*Test fuels for EF-3 program.*

EQUATION	CORRELATION COEFFICIENT	STANDARD ERROR OF MEASUREMENT
E = 2.51(RVP) - 128	0.906	22.1
E = 28.0(RVP) - 20.3(AS) - 105	0.959	15.6
E = 6.22(V120) + 0.852(V160) + 27.7	0.975	12.2
E = 25.1(MRVP) - 212	0.981	10.8
E = 2.42(SP) + 2.52(A160) - 18.6	0.996	5.2
E = 2.24(SP) + 2.86(S160) - 9.19	0.998	3.1
E = 2.50(SP) + 2.98(S160) - 5.44(S120) + 6.28	0.999	2.5

Symbol	Explanation
RVP	Reid vapor pressure
AS	slope of ASTM D 86 at 10% distilled
V120, V160	vapor liquid ratio at indicated temperature in deg F
MRVP	modified Reid vapor pressure
SP	$\left[\frac{RVP^2}{14.7 - 1.01\,RVP}\right]$
A160	percent distilled from ASTM D 86 at 160 F
S160, S120	percent distilled from single plate equilibrium distillation at temperature indicated deg F

FIG. 24—*Selected regression equations for total evaporative emissions.*

on an 85 F day in Los Angeles. After generating the raw data in this manner the remainder of the program was devoted to looking for fuel inspection parameters or combinations thereof which generally would predict evaporative emissions of the fuels over the range of variables employed.

The range of fuel properties studied is shown in Fig. 23, on a plot of RVP versus ASTM percent at 160. The numbers beside the dots indicate the percent distilled at 210 F. These 13 fuels are orthogonal with respect to RVP and percent at 160 and represent a partial replicate of an orthogonal design at percent 210 F. For reference, I have shown the Joint Committee fuels on this plot and also the straight line which went through the three API-BOM fuels. In general, you can see that both the Joint Committee and API-BOM fuels lie in the middle of the field.

Some of the factors considered for correlating fuel emissions are shown in Fig. 24, along with the correlation coefficients and standard errors of estimate of the equations involving them. The most promising equation involving only ASTM parameters was nonlinear equation using RVP and ASTM percent 160. A slightly better equation is obtained substituting points from the single plate distillation curve for the ASTM distillation points.

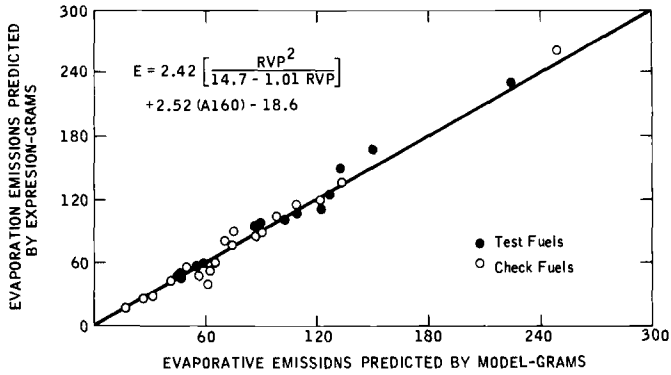

FIG. 25—*Predictive ability of nonlinear equations using ASTM parameters.*

Because of the historical wealth of data on fuels tested via the ASTM methods we have tended to concentrate on the best equation involving only ASTM parameters, and I will now discuss that equation and its potential use in more detail.

The predictive ability of this equation is illustrated graphically in Fig. 25 by comparing evaporative emissions predicted by the equation with evaporative emissions predicted by the models. The dark circles indicate the orthogonal array from which the correlation was derived. The open circles represent a wide variety of other fuels which we used as check fuels to look for uncontrolled variables in the fuel design. As you can see, the equation does a good job over a range of fuel volatilities where predicted evaporative losses go from 15 g per day to nearly 300 g per day. These results demonstrate that under a specific set of relatively restrictive conditions a moderately complex equation involving RVP and ASTM percent

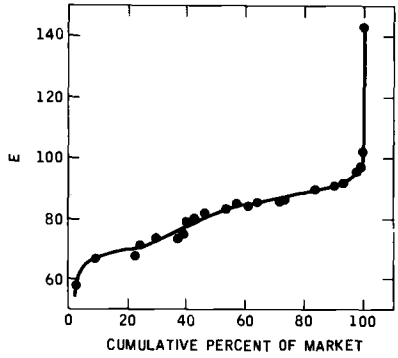

FIG. 26—*Sales weighted* E *values Los Angeles summer 1968, Bureau of Mines.*

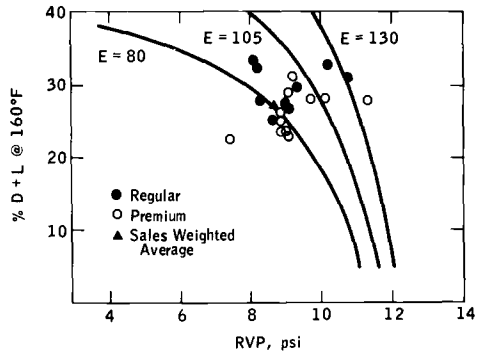

FIG. 27—E *for Los Angeles summer fuels 1969 Bureau of Mines survey.*

at 160 F will predict accurately the evaporative emissions tendency of a fuel.

We would envision that this equation could serve the same function for evaporative emissions; as, for example, $T - V/L$ does for vapor lock or perhaps a more apt analogy as some of the correlations which have been developed for $T - V/L$ do for vapor lock.

You could, for example, look at the fuels sold in a given area with respect to their E values and percent of sales as the Bureau of Mines was kind enough to do for us based on their 1968 summer survey (Fig. 26). Or alternatively, you could go back to our plot of RVP versus ASTM percent 160 and draw lines of constant evaporative emissions as shown in Fig. 27. As a reference I have plotted also on Fig. 27 regular and premium fuels reported in the 1969 Bureau of Mines summer survey for Los Angeles.

To summarize then, although the work that we have done so far indicates considerable promise, there are some problems which remain that prevent its general use. First, it has only been tested for an 85 F day, using Los Angeles driving patterns, and the Los Angeles vehicle population. And second, as presently constituted the equation would have different coefficients at different temperature levels even if the driving patterns and vehicle populations turned out to be insignificant variables. Therefore, we have extended the program to cover other temperatures in Los Angeles and to cover several other cities, for example, Chicago, Houston, and New York. When this work is completed, we will have a much better feel for the general utility of correlations of this type. We presently hope to have these additional parts of the program completed by the end of 1970.