891116

Oxygenated Fuels, A Remote Sensing Evaluation

Gary A. Bishop and Donald H. Stedman

University of Denver

ABSTRACT

Remote sensing, a new way to investigate automobile emissions, has been used to study the effect of oxygenated fuels on carbon monoxide emissions from in-use vehicles. During the 1988 State of Colorado Oxygenated Fuels Program more than 60,000 vehicle emissions were measured at a local freeway on-ramp for periods before, during and after the mandated oxygenated fuel usage. The results show a small but significant decrease in average carbon monoxide emissions of 6 ± 2.5%. The distribution of emissions shows that 50% of the carbon monoxide was emitted by 7.2% of the vehicles.

THE CLEAN AIR ACT of 1970 and subsequent amendments resulted in the Environmental Protection Agency establishing ambient air quality standards for several chemical species including carbon monoxide (CO) (1, 2)*. Many major metropolitan areas experience high wintertime levels of CO, mostly generated by automobiles (3). In its ongoing attempts to reduce wintertime CO levels the State of Colorado was the first to impose the use of oxygenated fuels by enactment of Regulation No. 13 by the Colorado Air Quality Control Commission (4). All gasoline sold during January and February 1988 had to have a minimum of 1.5% oxygen by weight. In Denver 94% of the market used an 8% methyl-tert-butyl ether (MTBE) blend and the remainder a blend of gasoline and 10% ethyl alcohol (4).

At the University of Denver we have designed and constructed a remote sensor that measures %CO emissions from passing vehicles by infra-red absorption using a gas filter correlation wheel to generate a reference signal (5, 6, 7, 8). The infra-red source is located on one side of a roadway across from the detector unit. Span, zero and data voltages are measured from each vehicle; Figure 1 shows a typical voltage versus time trace. Voltages are converted to CO and CO_2 values from calibration curves and a path independent ratio is determined (see Figure 2.). This ratio of CO/CO_2 is the only valid measurement since the instrument cannot distinguish the magnitude nor

---

*Numbers in parentheses designate references at the end of the paper.

0148-7191/89/0502-1116$02.50

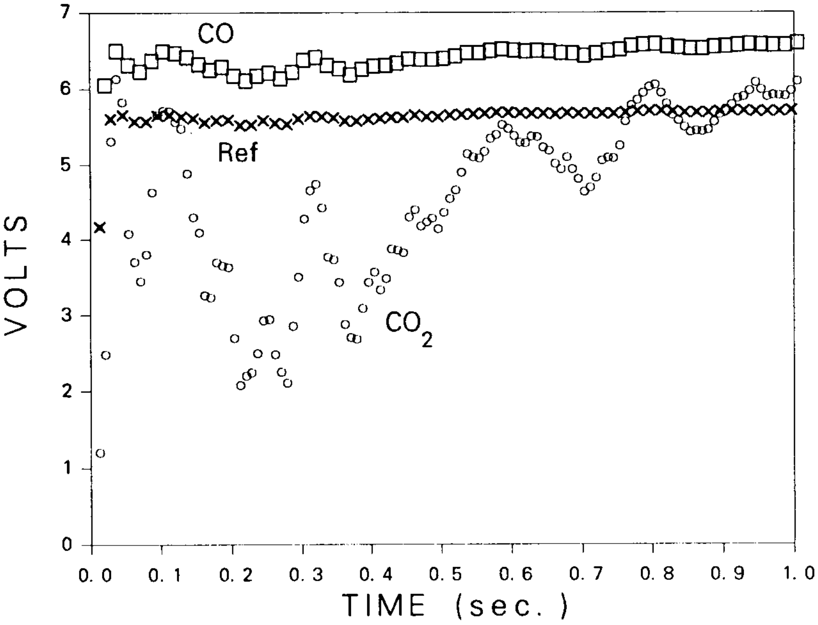

Figure 1. Data from the remote sensor for a 1983 Oldsmobile traveling at 20 mph.

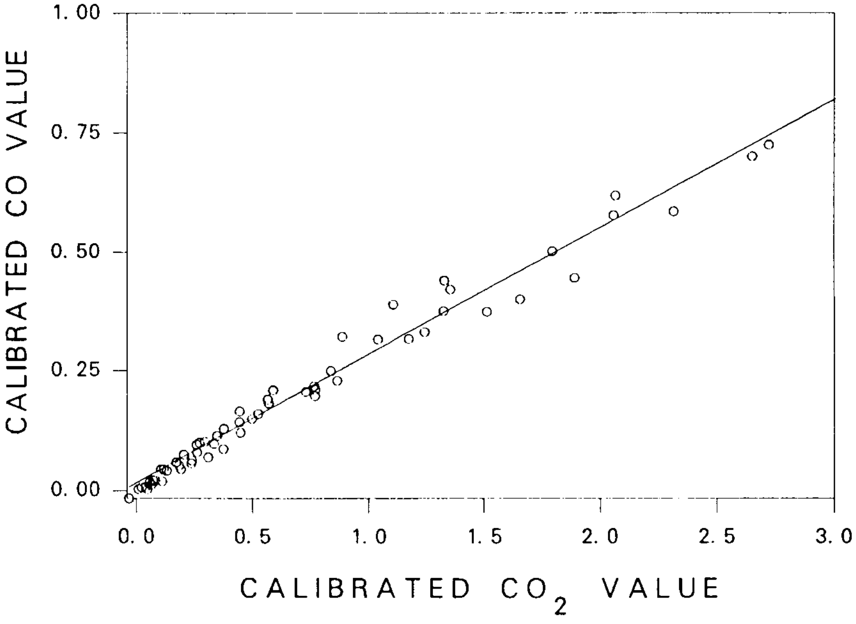

Figure 2. CO/CO_2 correlation graph of the data from Figure 1, used to obtain a single CO/CO_2 ratio from the unitless slope. Clean cars produce a horizontal correlation graph. The highest observed CO polluters produce almost vertical slopes.

position of the exhaust plume. The ratio is converted into an effective exhaust %CO through the standard combustion equation and an idealized engine map of CO and CO_2 emissions (9). In previous dynamometer, on-board monitoring and test-track testing the remote sensor has shown a precision and accuracy of better than ±1% CO with no temperature dependence (7).

IN-USE MEASUREMENTS

The remote sensor was placed at the on-ramp from south bound University Blvd. onto south bound Interstate 25 in south Denver. The gradient was about 2% uphill on a sharp curve. Traffic consisted mainly of automobiles and light trucks with an average flow of ~3,000 vehicles per week day. A variety of driving modes, light cruise, acceleration, deceleration and idle were noted. A random sample of 100 vehicles with a calibrated radar system produced an average vehicle speed of 25 mph. The remote sensing system made continuous automated measurements for a total of 27 days during the periods December 15 - 18; 21 - 22, 1987, February 17 - 20; 22 - 26; 29 and April 4 - 8; 11 - 15, 1988 in which emissions from 60,059 vehicles were recorded. In December an unknown fraction of the vehicles were already using oxygenated fuels which had been distributed in anticipation of the January 1 program start.

The instrument operated unattended except for 3 to 4 service visits per day. Service included alignment checks, detector liquid nitrogen replenishment and gas calibrations from three certified gas cylinders with CO/CO_2 ratios of 1:12.1, 1:1 and 4.96:1. The device operated with a total path length of 43 feet. The results from the calibration gases were fit to a second order polynomial equation which was used to correct for the non-linearity of the optical density of CO_2. Measurements were made in dry weather conditions with temperatures ranging from low teens to upper seventies (°F).

RESULTS

The data from each day were divided into five measurement periods, morning 6:00 - 9:59, midday 10:00 - 13:59, afternoon 14:00 - 17:59, evening 18:00 - 21:59 and midnight 22:00 - 5:59. The last period was lengthened because of low traffic volume. Figure 3 is a graph from the

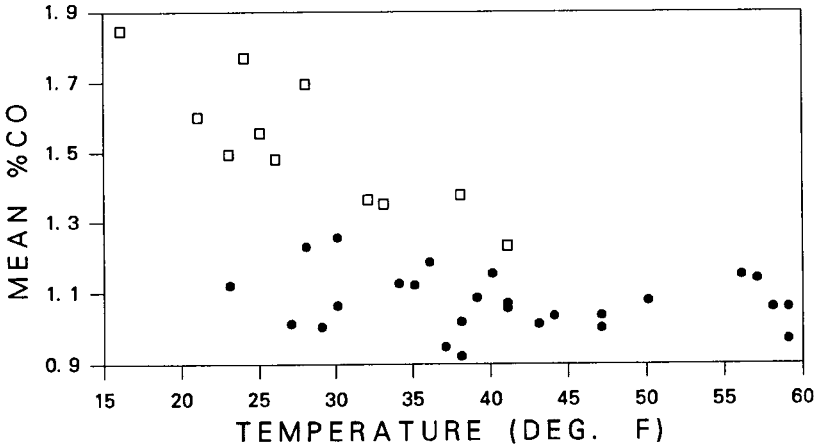

Figure 3. February mean %CO values versus temperature. 10:00 - 22:00 measurements (•), 22:00 - 10:00 measurements (□).

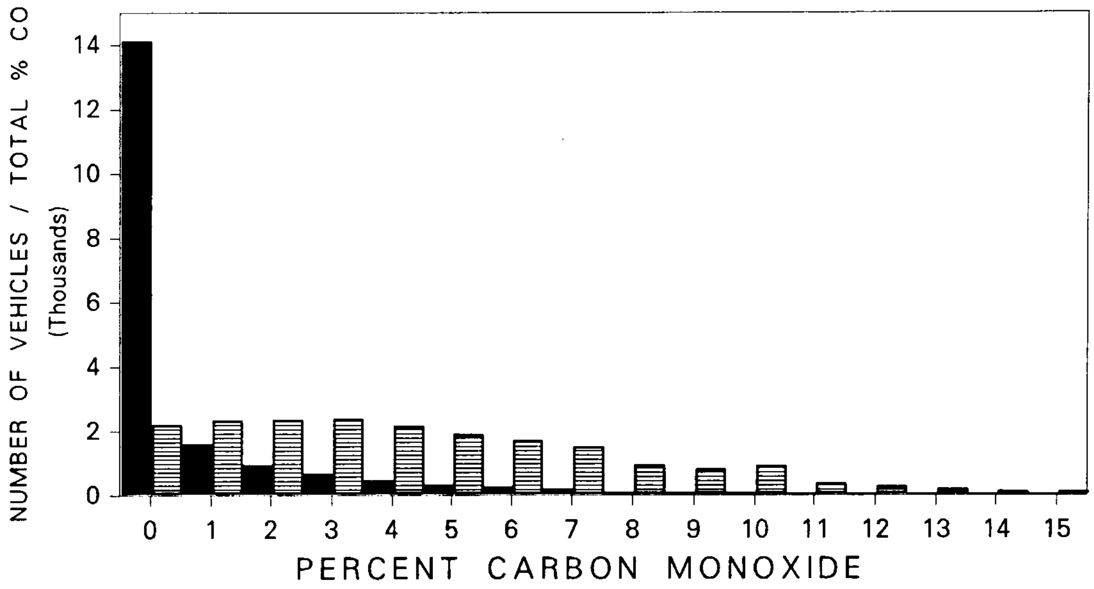

Figure 4. Observed February histograms for the number of vehicles and their CO contribution as a function of %CO. The solid bars represent the number of vehicles in the category between the indicated %CO and the next highest %CO. The hatched bars represent the sum of the %CO from these vehicles.

February measurements of data taken during the above time intervals versus ambient air temperature, provided the intervals included at least one hundred vehicles (missing data is due to instrument malfunction or maintenance). Between 10:00 and 22:00, the average emissions are independent of temperature. For the midnight and morning data (22:00 - 10:00) the points are scattered, and show a weak temperature dependence. The data for December (11°F - 45°F) show the same results while April (36°F - 79°F) showed no evidence of any temperature dependence. One possible explanation is that the morning observations include vehicles which have been driven short distances from local residences. At the lower ambient temperatures of the colder months a larger percentage of these vehicles would be expected to be in a cold-start mode (i.e. choke still closed and or catalytic converter not yet functioning, thus generating higher levels of CO). Later in the day, almost all the observed vehicles have been driven greater distances allowing the vehicles to fully warm up, providing observations of fleet mean %CO values independent of ambient air temperature.

To avoid introducing errors due to temperature effects into the fuel use comparison, only the data collected between the hours of 10:00 - 22:00 was used (49,059 vehicles). Figure 4 is a histogram of the February data showing that 50% of the carbon monoxide is contributed by 7.2% of the vehicles, and that 74% of the vehicles were measured with values less than 1% CO. Each 10:00 - 22:00 day is a sample of approximately the same fleet of

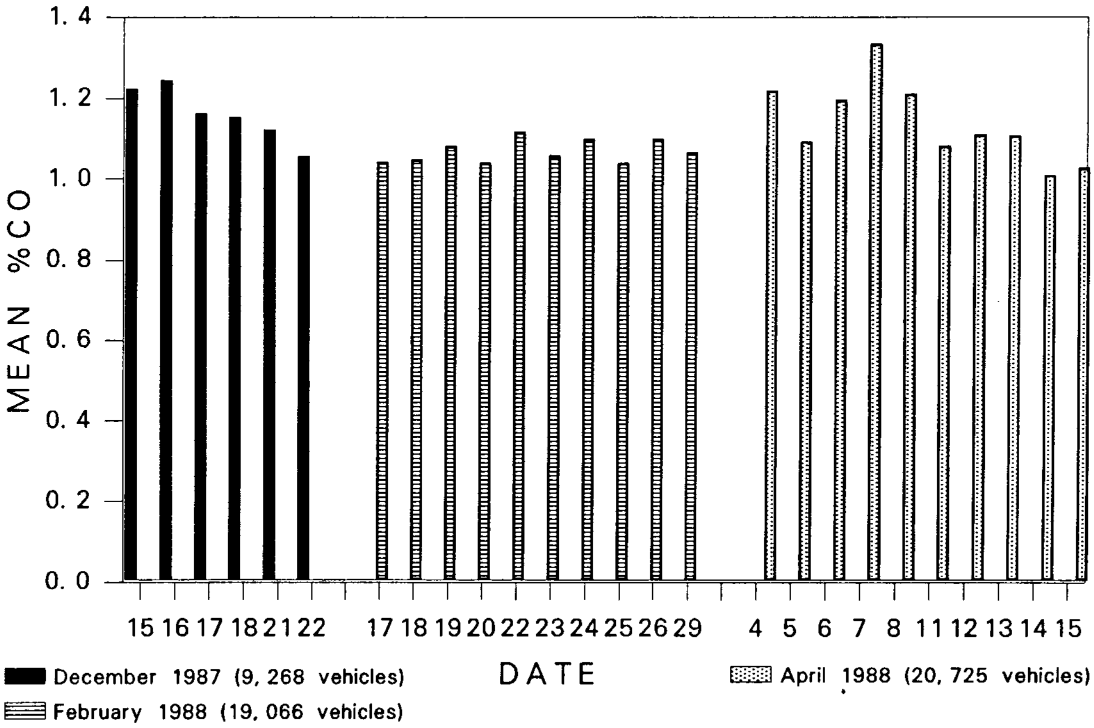

Figure 5. Daily averaged 10:00 to 22:00 remotely determined mean %CO for the three data sets, composed of a total of more than 49,000 vehicle emission measurements.

commuting vehicles. Treating each daily mean as an independent sample, the averaged daily mean %CO values with standard errors are 1.16 ± 0.03, 1.07 ± 0.01 and 1.14 ± 0.03 for December, February and April respectively, Figure 5 shows the data.

DISCUSSION

Qualitatively the results show the expected trend, i.e. the February data has a lower average than either December or April. The null hypothesis (H_0) $\overline{X}_{Dec} = \overline{X}_{Feb}$ and $\overline{X}_{Feb} = \overline{X}_{April}$ was tested using the Student's t distribution. For both comparisons H_0 is rejected at $\alpha < 0.01$ and therefore the differences are statistically significant. We do not consider further the December to February difference, because the oxygenated status of the fleet is unknown. Thus the 6% ± 2.5% decrease between April and February is a correct measure of the fleet-average CO emission reductions at our site if the average fuel economy did not change. Computer modelling using the EPA MOBILE3 model by the Colorado Department of Health resulted in a prediction of a basin wide fleet-average CO benefit of 11.7% ± 2.5% (4) which is significantly different than the measurements.

It is well known, but not well publicized that a minority of vehicles are responsible for a majority of CO emissions as observed. Support for this finding can be found in the 155 vehicle test fleet, chosen to partly simulate the on-road Denver fleet, studied for the Colorado Oxygenated Fuels Program. These vehicles were tested according to the Federal Test Procedure between 1978 and 1987 (4). For the non-oxygenated data set 50% of the CO was contributed by 14.2% of the vehicles. In 1987 we conducted a remote sensing study of 619 volunteer vehicles on arrival at their employers parking lots. In this case 50% of the CO came from 16.9% of the vehicles. These "gross polluters" were 13% of the 1980's vehicles, 24% of the 1970's and 42% of 1960's, however because of the relative populations of the three age groups the majority of the gross polluters were 1980's vehicles. The fact that the in-use percentage of gross CO emitters is smaller than volunteered fleets is not surprising when considering that knowingly tampered vehicles are likely to be underrepresented in volunteered fleets.

Remote sensing measurements of %CO can be directly converted to grams of CO per gallon of fuel (7), thus our fleet-average reductions in %CO are the same as the fleet-average reductions in grams of CO per gallon of fuel. If the fleet-average fuel economy decreased because of the use of the oxygenated fuels in February, as compared with April, then our observed CO improvements would have to be decreased accordingly.

Fuel economy testing by the Colorado Department of Health (4) reported the following changes for the MTBE blend: (a) Non-catalyst equipped vehicles: no change, (b) Catalyst equipped but open-loop control showed a 1.3% fuel use improvement and (c) Closed-loop computer controlled vehicles showed a 4.3% decline. There currently are no accurate estimates of vehicle numbers for each emission technology category for Denver and so only a rough overall estimate of a less than 2% decline in fuel economy between gasoline and the MTBE blend is possible. A companion analysis of state wide gasoline sales tax statistics for the last five years (10) show an unexplained rise in fuel sales for December 1987 (stockpiling?), otherwise only the normal decrease in gasoline consumption during the winter driving season for February 1988. Because of the uncertainties in the effect of oxygenation on fuel economy, no corrections are reported herein.

Neither the driving mode sampled, nor the vehicle fleet observed are presented here as being representative of the Denver basin as a whole, however we believe that our studies are relevant to basin wide emissions. Using fuel sales information (10) and assuming that half of the fuel burned in the State of Colorado is burned in the Denver basin and that all vehicles behaved exactly as our measured average (1.14% ≅ 660 grams of CO per gallon) at all times during their driving, they would emit approximately 1400 tons per day of CO. The computer model currently used by the Colorado Department of Health predicts a mobile source emission of 1563 tons per day of CO (11). This comparison suggests that the particular set of vehicles and driving modes observed at our site is not unrepresentative of typical Denver driving patterns.

SUMMARY

The remote sensing system observed a small but quantifiable decrease in carbon monoxide emissions at a single location of 6 ± 2.5%, presumably attributable to the mandated use of oxygenated fuels during February 1988. The remote sensor easily identifies the 10% of vehicles responsible for more than half the CO pollution, which has implications for future emission control programs (12). Costs of oxygenated fuel programs are not negligible (4), and benefits are currently based on uncertain computer modelling of very small vehicle fleets (4, 13). Adequate measurements of the benefits of future oxygenated fuels programs can be provided by remote sensing techniques.

ACKNOWLEDGEMENTS

The authors thank the Colorado Department of Energy Conservation, Kenneth J. Barr and the American Petroleum Institute for funding and the Colorado Department of Highways, the Public Service Co. of Colorado, the City of Denver, Solomon Bairai and Jane Wilken for technical assistance and Drs. Arnold Miller and Hazel Stedman for helpful suggestions.

REFERENCES

1. Clean Air Act as Amended, 42. U.S.C. Sec. 7401 et. seq. (1970).

2. Clean Air Act as Amended, Serial No. 95-11 U.S. Gov. Printing Office, Washington, D.C. (1977).

3. Colorado Department of Health, "Colorado Air Quality Data Report" (1986).

4. Colorado Department of Health, Report to the Colorado Air Quality Control Commission, "1988 Oxygenated Fuel Program" Vol. I & II, (1988).

5. Hiroshi, H., Lockheed Missiles and Space Corp. report to California Air Res. Board, #081903, (1971).

6. L. W. Chaney, J. Air Poll. Control Assoc. 33, 220 (1983).

7. G.A. Bishop, J.R. Starkey, A. Ihlenfeldt, W. J. Williams and D.H. Stedman, Anal. Chem., In press, scheduled for publication in May 1989.

8. R. H. Weins & H. H. Zwick, "Trace Gas Detection by Correlation Spectroscopy", *Infrared, Correlation & Fourier Transform Spectroscopy*, J. S. Mattson, H. B. Mark Jr. & H. C. MacDonald Jr., Eds. (Marcel Dekker, N.Y., 1977) pp. 119 - 190.

9. T. R. Wildeman, J. Chem. Ed. 51, 290 (1974).

10. Colorado Department of Revenue, Monthly State Motor Fuel Tax and Special Fuel Tax Refund Data (1982-1988).

11. Colorado Department of Health, "Staff Statement to the Air Quality Control Commission Concerning Proposed Regulation 13", (1987).

12. D. H. Stedman, Environ. Sci. Technol. 23, 147 (1989).

13. M. W. Hlavinka & J. A. Bullin, J. Air Poll. Control Assoc. 38, 1035 (1988).