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Comparison of auto emission measurement techniques

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Abstract

The Clark and Washoe Remote Sensing Study (CAWRSS) field season took place in September 1994. The study was designed to characterize the exhaust emissions of the on-road vehicle fleet in the two major urban centers of the State of Nevada. The air quality in Las Vegas (Clark County) and Reno (Washoe County) is significantly worse than the surrounding rural areas and vehicle emissions have been identified as one of the primary sources of the pollution. Inspection and maintenance programs, mandated by the federal government, have been implemented in both urban areas. The study compared the State-approved test, a no-load, two-speed idle test, to two other measurement techniques: remote sensing devices (RSDs) and the IM240 test, a loaded-mode test run on a dynamometer. Results were viewed from two different perspectives. Fleet-wide characteristics showed that concentrations of CO (%) measured with RSDs were higher than those obtained with the no-load idle tests. Characteristics of pollution distributions derived from the two techniques were similar in range and shape. Observations for individual vehicles were then compared. CAWRSS is in agreement with earlier studies in that high emitters in the idle test are also high emitters on-road.

Keywords: Auto emissions; Air quality; Measurement techniques

1. Introduction

Field work for the Clark and Washoe Remote Sensing Study (CAWRSS) took place during the month of September 1994. The project was designed to characterize the exhaust emissions of the on-road vehicle fleet in the two major urban centers of the State of Nevada. The Desert Research Institute working in cooperation with the US Environmental Protection Agency (US EPA), the University of Denver, General Motors Research and Development and numerous state agencies used three different methods to observe the exhaust carbon monoxide and hydrocarbon emissions from in-use vehicles.

The study compared results obtained from a no-load, two speed idle test with data collected with remote sensing devices (RSDs) and the IM240 test, a loaded-mode test run on a dy-

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namometer. The two-speed idle test is the standard test used in the current inspection and maintenance (I/M) program in Clark and Washoe Counties. The IM240 test, which is considered by the federal government to be representative of on-road driving conditions, has been designated as the standard test for new 'enhanced' I/M programs. RSDs, which use infrared long-path photometry to probe the exhaust of vehicles passing the instrument [1], sample faster than either of the other two tests and have the advantage that the observation does not disturb the motorists.

2. Experiment design

Three roadside pullover sites were used during CAWRSS, one in Washoe County and two in Clark County. The design of the roadside pullover sites was similar to that used in the 1989 Lynwood Study [2]. Site selection criteria included traffic density, roadway access, safety issues and demographics. All sampling was confined to a single direction of the roadway and two lanes of traffic were restricted to a single lane. Vehicles passed the remote sensing devices at speeds ranging from 15–50 mph (25–80 kph). RSDs were located approximately 5 m apart. Two sensors were used at each site, one from the University of Denver (DU) and one from the U.S. EPA (EPA). At one site (Washoe) a third sensor was used for two days. Data for the third sensor will not be included in this discussion. Data for the individual sensors were stored in separate data sets on magnetic media in a nearby van. Concurrent with each data record, a freeze-frame video image of the rear license plate was recorded. Post-season analysis included review of the video tapes and the transfer of the license plate information to the computer-compatible data set.

RSD operators monitored the instruments from the van. Special interest was given to 'gross polluters' which were defined as those vehicles with RSD readings exceeding 4.0% CO and/or 0.3% HC. A second computerized data set containing only vehicles which exceeded those criteria was created by each RSD. Vehicles were selected for the roadside two-speed idle test based on the RSD readings. RSD operators radioed ahead to a uniformed Nevada Highway Patrol Officer who stopped the vehicle of interest and directed the motorist to one of two test positions. All participation in the study by motorists from this stage on was voluntary. To encourage motorists with gross-polluting vehicles to participate in the study, all results and findings were exempt from law enforcement.

The roadside two-speed idle tests were performed by state certified Department of Motor Vehicle (DMV) inspectors. Due to the time required to perform a two-speed idle test less than one out of 100 vehicles passing the RSDs were requested to stop for the roadside pullover portion of the study. Two teams of inspectors used two BAR84 analyzers to perform the state approved two-speed, no-load idle test [3].

The third type of instrumentation used during the project was a transportable dynamometer supplied by the US EPA National Exposure Research Laboratory (NERL). The dynamometer, a treadmill for vehicles, was used to run IM240 tests, considered to represent on-road driving conditions by the U.S. EPA [4]. Vehicles for the IM240 test were selected from those undergoing the no-load idle test. Due to stress on vehicles during the IM240 and in the interest of safety, only mechanically sound vehicles were selected for testing. While on the dynamometer, the exhaust of an even smaller subset of vehicles was sampled for particulate and organic compounds under a contract with the General Motors Research Laboratory. The results of those studies are not included in the current work but may be found in work by Sagebiel et al. [5].

3. Results

During the CAWRSS field season the DMV teams performed 368 roadside idle tests. Of that number 275 tests were valid, that is, the test resulted in either a 'pass' or 'fail' conclusion. Incomplete or aborted tests were discarded. We were able to identify 234 of the valid tests in the State of Nevada registration database. Some of the unidentified vehicles were from out-of-state,

Table 1
Comparison of the characteristics of the CO (%) distributions for combined RSD and DMV roadside idle tests

	Variable name							
	DU RSD results				EPA RSD results			
	RSDCO	HiCO	LoCO	HiLoCO	RSDCO	HiCO	LoCO	HiLoCO
Mean	5.09	2.23	2.62	2.42	3.50	2.09	2.61	2.35
Median	5.38	0.68	0.82	1.58	3.69	0.73	0.60	1.39
Mode	0	0	0	0	0	0	0	0
Standard deviation (σ)	2.72	2.95	3.14	2.67	2.81	2.75	3.17	2.58
Minimum	0	0	0	0	0	0	0	0
Maximum	11	10	10	10	10	10	10	10
Count	143	143	143	143	142	142	142	142
Confidence level (95%)	0.45	0.48	0.51	0.44	0.46	0.45	0.52	0.42

some were new and had not completed the registration process and others remain a mystery.

The DU and EPA RSD 'gross polluter' data sets, with the license plate information appended, were merged, by license plate, with the DMV idle test data. The results showed the EPA captured 142 vehicles and the DU RSD observed 143 'gross-polluter' vehicles. Each combined data set contained four CO (%) values: RSD CO (%), a high and low idle speed CO (%) and an average of the high and low observations. The results are shown in Table 1. The mean and median for each of the distributions indicate that both RSDs report higher values of CO when compared to the roadside idle test but the range and standard deviations of the distributions obtained by both types of instruments are similar. This could be attributed, in part, to the difference between the emissions generated by vehicles operating under load as they are sampled by the RSDs and emissions of a vehicle during idle speed operation. CO emissions under load tend to be higher than no-load conditions.

Fig. 1a shows a scatter plot of the EPA RSD against an average of the high and low speed idle measurements obtained by the DMV idle test. Data are scattered on both sides of the 1:1 line. Fig. 1b is the corresponding plot for the DU RSD. In both plots, the data are essentially bounded at the lower end by the 1:1 line showing that the RSDs tend to record higher values of CO(%) than the levels observed during idle tests. Since changes in travel speed (acceleration/deceleration) and traffic speed can affect vehicle emissions, results of the two RSD sensors were averaged in an attempt to compensate. Fig. 1c shows the results of a comparison between the averaged RSD readings and the averaged idle test values. The correlation is slightly better than those obtained with the individual comparisons. These results are in reasonably good agreement with the results of the Lynwood Study [2].

The comparison of full fleet values for CO shows that RSDs, on average, accurately measure emissions from vehicles in a fraction of the time required for a no-load, idle test. For inspection and maintenance programs the real test comes when comparing results from the various instruments for each individual vehicle.

Emission measurements for individual vehicles were compared at each of the roadside pullover sites. DMV inspectors performed about 25–30 inspections per day. Results of the no-load idle tests were matched to the RSD record by license plate. Some of the vehicles in the merged data set were represented by two or more RSD readings and will be discussed later. The high and low idle values from the DMV no-load idle test were averaged for each match.

Full fleet RSD data showed little variation in fleet characteristics (model year, mean and median of pollutant concentrations) at the multi-day

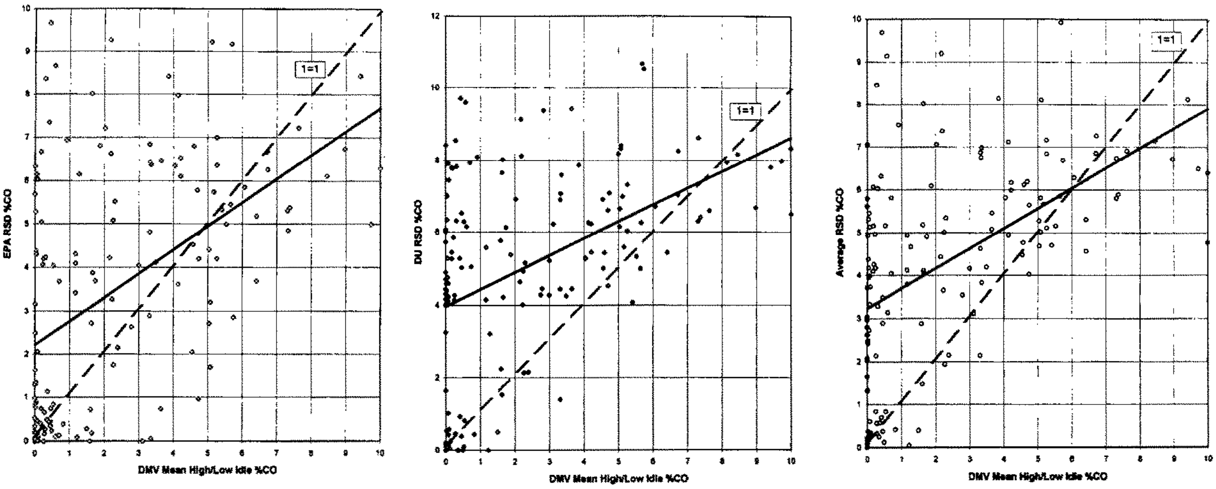

Fig. 1. Comparison of the CO concentration from moving vehicles measured with RSDs with the average of high and low speed idle CO measured during the DMV roadside test. The regression line for each data set is plotted as a solid line. 1:1 correspondence is shown in each panel as a dashed line. (a) EPA RSD versus DMV regression line: (EPA CO) = 0.54(DMV AvgCO) + 2.22, $r = 0.50$; (b) DU RSD versus DMV regression line (DU CO) = 0.47(DMV AvgCO) + 3.96, $r = 0.46$; (c) average RSD versus DMV regression line (RSD CO) = 0.47(DMV AvgCO) + 3.23, $r = 0.52$.

sites. Intra-site variation was much smaller than inter-site differences. The coefficient of correlation between the calculated average DMV CO (%) and the observed RSD CO (%) was $r = 0.50$ for the full fleet. The relationship between the two distributions was quite different above and below the arbitrary 4.0% cutoff used to identify gross polluters in the RSD data set. For the 115 points with an RSD reading of less than 4.0% CO, $r = 0.57$. For RSD readings greater than or equal to 4.0% CO, $r = 0.29$ for the 131 points. Note that the number of vehicles above the cutoff point is approximately the same as below. This pattern for CO was repeated at each of the roadside pullover sites. Table 2 summarizes the coefficients of correlation for the entire study.

Fig. 2 shows the comparison of vehicles for one day at the Washoe County roadside pullover site. Thirty-two matched records were found and the results were ranked from cleanest to dirtiest by RSD reading. Correlation coefficients below and above the cutoff point agree with the Kietzke site values listed in Table 2. Vehicles with RSD readings of less than 4% had $r = 0.68$ while those with RSD readings above 4% CO had the much lower value of $r = 0.18$ (not significant at the 5% level). The lower correlation coefficient above the 4.0% cutoff point may be due to differences in operating conditions including heavy acceleration or deceleration or 'cold start' operation. Higher emitting vehicles are also likely to lack maintenance and have much more variable engine response. Three vehicles were observed twice by the RSDs and are compared to the common roadside idle test. Record numbers 2 and 3 are related as are records 6 and 8. In both cases, 'clean' vehicles appeared 'clean'. Record numbers 11 and 28 correspond to the third vehicle. Information obtained during the roadside pullover portion of the test indicated that the first RSD reading (record number 28) was obtained when the vehicle was operating in the 'cold start' mode. Good agreement between the DMV idle test and the RSD was obtained when the vehicle passed through the RSD sensors again later in the day (record number 11). When available, results of IM240 tests are shown on the figure. With the exception of record number 10, the results of the IM240 test agree with the other two measurement methods.

A comparison of measurements from one day at the Hadland Park roadside pullover site in Las Vegas is shown in Fig. 3. The site was located in a school zone with a maximum speed limit of 15 mph. Traffic flow at the site was not smooth, the

Table 2
Summary of the coefficient of correlation (r) for CO and HC comparisons

Site	Full range CO		RSD CO <4.0%		RSD CO > =4.0%	
	Count	r	Count	r	Count	r
Total study	246	0.50	115	0.57	131	0.29
Kietzke (Reno)	110	0.50	57	0.62	53	0.23*
Sunset Park (Las Vegas)	38	0.41	16	0.92	22	0.37*
Hadland Park (Las Vegas)	98	0.54	42	0.46	56	0.31
	Full range HC		RSD HC <0.3%		RSD HC > =0.3%	
	Count	r	Count	r	Count	r
Total study	226	0.38	198	0.34	28	0.09*
Kietzke (Reno)	97	0.06*	91	0.52	6	0.19*
Sunset Park (Las Vegas)	35	0.56	28	0.37*	6	0.63*
Hadland Park (Las Vegas)	94	0.45	78	0.14*	16	0.43*

Values marked with an asterisk (*) represent regressions not significant at the 5% level using the F-test.

stop-and-go pattern and the low speed appear to have affected the results. Idle test CO values for vehicles with RSD readings less than the 4.0% CO cutoff point were higher and much more variable than those seen at the other sampling sites. There was little difference in the coefficient of correlation below ($r = 0.53$) and above ($r = 0.52$) the 4.0% cutpoint. Again the results of the IM240 tests are shown when available. In most cases the IM240 agrees with the other measurement techniques. The one exception is record number 13. For that vehicle, a 1989 Yugo, both loaded-mode measurements were much higher than the no-load idle test results suggesting that the engine emissions characteristics are highly correlated to engine load.

A similar analysis of hydrocarbon (HC) measurements was performed. As shown in Table 2, HC measurements were much more variable and

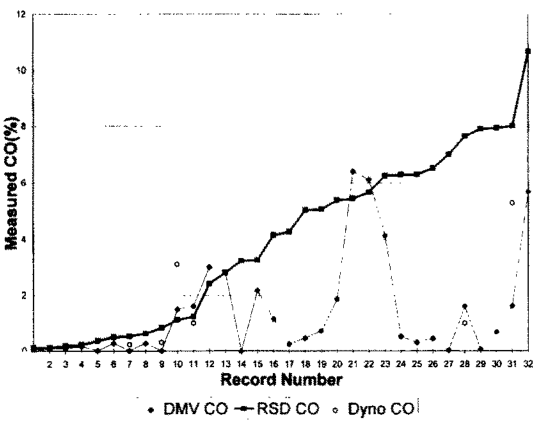

Fig. 2. Comparison of all three measurement techniques by individual vehicles for one day at the Kietzke Lane roadside pullover site in Reno. Data are rank-ordered by the DU RSD CO (%). Gross-polluter cutoff was 4.0% CO. Measurements are coded as follows: RSD CO (DU RSD %CO), DMV CO (Average of the DMV high and low idle speed %CO) and Dyno CO (US EPA IM240%CO).

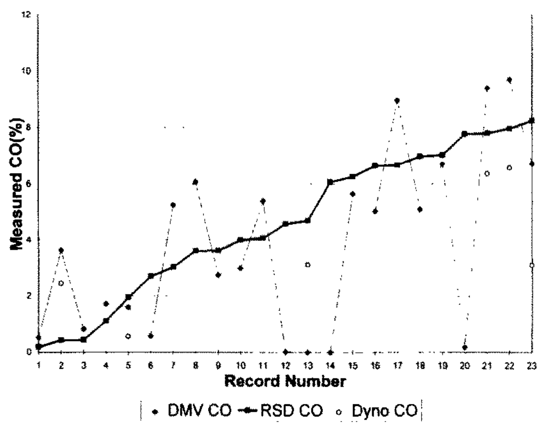

Fig. 3. Comparison of all three measurement techniques by individual vehicles for one day at the Hadland Park roadside pullover site in Las Vegas. See Fig. 2 caption for details.

less predictable than CO measurements. Although fewer vehicles were classified as HC gross-polluters (greater than 0.3% HC), the cutoff point did accurately identify a discontinuity in the distribution of HC emissions. Partitioning of the fleets resulted in a 90% 'clean'/10% 'dirty' split with the 'dirty' fraction accounting for over 50% of the total observed HC.

4. Conclusions

CAWRSS collected emissions data from the on-road fleet with three different measurement techniques. The results show that there is good agreement between the various methods but that care must be taken in the interpretation of RSD readings when the sampling conditions are not well defined. RSD data were divided into two mutually exclusive populations. Vehicles with RSD readings below a pollutant-specific cutoff point consistently tested clean regardless of testing method. Above that 'gross-polluter' cutoff point discrepancies between the various instruments may be due to high emissions or caused by other operational or environmental factors. Careful site selection and the addition of auxiliary data, including acceleration and deceleration and a measure of engine temperature, could minimize false high-emitter identification. Selection of the appropriate cutoff point for a given on-road fleet is crucial to accurate analysis of RSD data.

RSDs have two advantages over the other instruments: (1) emissions data can be obtained without interfering with the motorist's schedule; and (2) many more vehicles can be sampled in a limited time period than by any other method. The larger data sets provide better characterization of the on-road fleet.

Acknowledgements

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References

[1] G.A. Bishop, J.R. Starkey, A. Ihlenfeldt, W.J. Williams, D.H. Stedman, IR Long-path Photometry: A Remote Sensing Tool for Automobile Emissions. Anal. Chem., 61, 671A (1989).

[2] D.R. Lawson, P.J. Groblicki, D.H. Stedman, G.A. Bishop and R.L. Guenther, Emissions from In-use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program. J. Air Waste Manage. Assoc., 40, No. 8, 1096–1105 (1990).

[3] State of Nevada, Department of Motor Vehicles and Public Safety, Vehicle Inspection and Maintenance Program Regulations, August 1990.

[4] US EPA, Office of Air and Radiation, EPA I/M Briefing Book - Everything You Ever Wanted to Know About Inspection and Maintenance, EPA-AA-EPSD-IM-94-1226, February 1995.

[5] J. Sagebiel, B. Zielinska, P. Walsh, J. Chow, S. Cadle, P. Mulawa, K. Knapp, R. Zweidinger and R. Snow, PM-10 Dynamometer Exhaust Samples Collected from In-Service Vehicles in Nevada, presented at the 5th CRC On-Road Vehicle Emission Workshop, San Diego, CA, 3–5 April 1995.