Reprinted from Journal of the Air & Waste Management Association, Vol. 42, No. 5, May 1992

Infrared Emission and Remote Sensing

Gary A. Bishop and Donald H. Stedman
University of Denver
Denver, Colorado

Tad Jessop
Cherry Creek High School
Denver, Colorado

With initial support from the Colorado Office of Energy Conservation in 1987, the University of Denver (DU) developed an infra-red (IR) remote monitoring system. In less than a second the instrument measures the carbon monoxide to carbon dioxide ratio (CO/CO_2) in the exhaust of most vehicles passing through the IR light beam.[1,2] It has been shown to give accurate readings for CO by double-blind studies of vehicles both on the road and on dynamometers.[3,4] Recent improvements include the capability to monitor hydrocarbon exhaust levels, also using IR absorption. These readings have also been validated by the California Air Resources Board.[5]

Researchers from General Motors were the first to raise the question of IR emission interferences. Potential inaccuracies can occur if IR emission occurs in sufficient magnitude during absorption data collection. The GM researchers observed IR emission especially from trucks and vans.[6,7] Uncertainty exists about its effect on the absorption data. This investigation shows that under normal operating conditions IR emission is not a problem for the DU remote sensing instruments.

Experimental

The DU remote sensor was set up at the interchange ramp from southbound University Boulevard to southbound I-25 about six miles south of downtown Denver, Colorado.[1,2] After alignment the IR source was turned off, but left in place to provide a visual reference point. A video camera was positioned directly behind the detector unit and along the line of sight of the IR source so as to record the measurement sequences. A computer-controlled light was attached to the side of the detector unit and positioned so as to be visible in the lower right corner of the video screen. Data were recorded by the computer upon manual command prior to, along the entire length of, and for approximately 1 second after, each vehicle, using a total analysis time of two seconds. Average voltages (8.33 msec averages) were collected from each of three channels CO, CO_2, and reference over the two second time span. The video camera records 60 frames per second (about one frame for every 9" of vehicle travel). The light was triggered by the computer to be on for a half second, off for a half second, then on for the next half second and finally off. The on and off of the light provided visual half-second markers to position the computer-acquired IR emission data within the 120 video frames.

The data were examined for IR emission. If found, the type of emission was noted and the video tape was reviewed frame by frame to identify the source. This procedure enables the source of the observed signal to be pinpointed on the vehicle to within ± 9". Black body emission, tested previously in the laboratory, showed approximately equal signals on all channels. Gaseous IR emission would be implied if one or both gas channels showed an increased signal relative to the reference channel.

Results

An hour of afternoon traffic (438 total vehicles passed during the hour) was sampled. Data from 95 vehicles and 9 blanks (no vehicles present) were recorded. All the trucks and vans (this included medium-duty gas/diesel trucks, 4 × 4s and any type of van) were monitored for (a total of 42) because of GM's suggestion that such vehicles are likely candidates for IR emission. Random sampling accounted for 52 samples of passenger automobiles and one motorcycle. The nine blanks showed no emission, and fifty-five (58 percent) of the samples showed no signs of any IR emission. Thirty-two (34 percent) had positively identified black body emission while 8 (8 percent) had confirmed gaseous IR emission (6 trucks/vans and 2 passenger cars).

Twenty-two of the black body emission measurements were from trucks/vans with the remaining ten from passenger cars. In all instances the sources of the black body emission were hot engine/exhaust system components. These included engines, oil pans, transfer cases, catalysts, mufflers and tailpipes. We saw no emissions from "cold" vehicle parts, i.e., hub caps, frames, etc., or from visible black smoke behind one vehicle.

The remaining eight vehicles were distributed with five showing gaseous emission in only the CO_2 channel and three in both the CO and CO_2 channels. This distribution agrees with previous absorption measurements made at this ramp showing that 70 percent of the fleet are low CO emitting vehicles. Figure 1 gives the voltage traces for two of the vehicles found to exhibit IR emission [a Jeep Wagoneer (upper set) and an unidentified truck (lower set)]. The Wagoneer appears to have a leaky muffler. Voltages average 5 volts on all absorption channels, 8 volts when the system is used with its normal light source in an absorption mode.

Exhaust CO_2 typically lowers this voltage to 2–3 volts at the peak of the plume. A high CO car lowers the CO channel voltage by about one volt. The plume peaks are often 100 ms (~10 points) wide. Gaseous or black body signals never exceeded 0.25 volts.

Discussion

A description of the mechanics of an actual absorption measurement is given to provide a framework for discussing IR emission interferences.[2,4] The DU remote sensor measurement sequence is started with the blockage of the IR source. A valid block requires that the reference channel voltage drop below a preset threshold value for two consecutive readings. Voltage data collected prior to the blockage are stored in memory. During the blockage minimum voltage values are acquired for each channel. Any event that causes increased voltage during a beam blockage is ignored.

As the vehicle exits the beam, two consecutive readings above a preset threshold voltage are required to qualify as a valid unblock. The instrument ignores the next two data points collected and only on the fifth point (two to unblock and two skipped) does the half-second of absorption data collection begin. Thus while the vehicle is physically blocking the IR source plus an additional 40 msec. delay the remote sensor will not respond to any external event. The delay was added to eliminate interferences produced by partial blockage of the beam by vehicle parts at the rear of the vehicle, for example step bumpers. This eliminates the influence of IR emission/partial blockage events encountered between the front and rear wheels of high ground clearance vehicles. During the half-second (fifty, ten millisecond averages) of data collection if the IR source is blocked (by the next vehicle or rear wheels of a high ground clearance vehicle) the data collection is interrupted and a new delay and fifty point measurement sequence is started.

The most frequently observed IR emission is black body emission. This is illustrated in Figure 1. Many light-duty and medium-duty trucks have higher ground clearances, therefore the catalyst and mufflers are easier for the system to "see." We only observed black body emissions from mufflers and tail pipes on passenger cars. Because these emissions are associated with vehicle parts, they do not interfere with the collection of absorption data.

An attempt was made to observe IR emission from black smoke. One author owns a 1973 Ford Bronco with a manual choke. Operation of the vehicle when warmed up with the choke closed produces black smoke. We successfully identified black body emission from the muffler and tail pipe but saw no evidence of emission from the visible particles.

Hot gaseous emissions were detected in only eight vehicles (two passenger cars and six trucks or vans). All of the IR emissions lasted less than 30 msec. and were found only near the tail pipe. Two of the trucks had exhaust that exited the vehicle between the front and rear wheels, making these emissions irrelevant because of the restart parameters previously mentioned. The remaining six occurrences all took place behind the vehicle but during the 40 msec delay period prior to the onset of absorption data collection. These observations would not produce any interferences. These short lifetimes are in sharp contrast to the data collected by the GM researchers.[7]

Vehicle speeds at this location have been measured between 18 and 30 mph.[2] At speeds below 15 mph IR emission could occur during the absorption data collection. Could they significantly alter a measurement? Emission from CO_2 cannot change a measurement. This is because the CO/CO_2 ratio for a clean vehicle is zero, and only changes in observed CO levels can alter the ratio. This will remove most of the occurrences from consideration. The remaining three measurements from a total of 438 vehicles, which involved CO and CO_2 emissions, might significantly influence one or at most two data points out of the 50 used in the correlation. The question then becomes how influential two slightly lowered data points will be in a 50 point least squares fit? It would appear that mistaking a high CO car for a low CO car at very low speeds due to IR emission is improbable. Mistaking a low CO car for a high CO one is impossible.

Conclusions

Infrared emission have been detected by the DU remote sensor in a minority of the fleet. The most common source is black body radiation from hot vehicle components. The few vehicles that do exhibit gaseous IR emission do so for very short time periods and only immediately behind the tail pipe. In all the cases presented here, minimal or insignificant interferences to absorption measurements

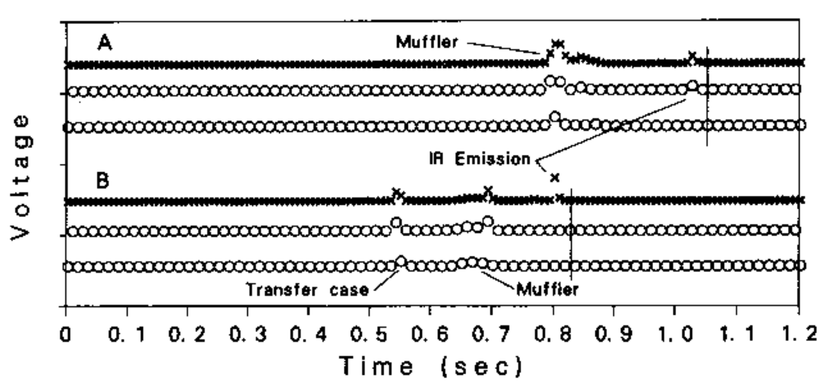

Figure 1. Voltage vs. time traces for two vehicles with observed black body and gaseous IR emission. Upper trace (A) Jeep Wagoneer, lower trace (B) unidentified pickup. For each set the upper trace (x) is CO_2 (4.3 μ), the middle trace (o) is CO (4.6 μ), the lowest trace is the reference channel (4.6 μ, but with a CO gas filter). Signal voltages are offset from zero for clarity. Tick marks on the vertical axis represent 0.5 volt divisions. The short vertical bars on each vehicle trace show the time at which absorption measurements would commence if the system were operating in the absorption mode.

would occur. This is the result of a combination of vehicle design, vehicle speed and software design. The possibility exists that at slower speeds (< 15 mph) gaseous IR emission could effect absorption measurements. Yet, the size and magnitude of these emissions would not be expected to change the measurements significantly.

Acknowledgments

The authors gratefully acknowledge the support provided by the Coordinating Research Council, the American Petroleum Institute and the Environmental Protection Agency. The authors also would like to thank Robert D. Stephens for his helpful discussions and interest in this area.

References

1. Bishop, G. A.; Stedman, D. H. "On-road carbon monoxide emission measurement comparisons for the 1988–1989 Colorado oxy-fuels program," *Environ. Sci. Tech.* **24:** 843 (1990).
2. Bishop, G. A.; Starkey, J. R.; Ihlenfeldt, A.; Williams, W. J.; Stedman, D. H. "IR long-path photometry, a remote sensing tool for automobile emissions," *Anal. Chem.* **61:** 671A (1989).
3. Lawson, D. R.; Groblicki, P. J.; Stedman, D. H.; Bishop, G. A.; Guenther, P. L. "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:** 8 (1990).
4. Stedman, D. H.; Bishop, G. A. "Remote sensing for mobile source CO emission reduction," EPA Report #600/4-90/032 (1991).
5. Ashbaugh, L. L.; Lawson, D. R.; Bishop, G. A.; Guenther, P. L.; Stedman, D. H.; Stephens, R. D.; Groblicki, P. J.; Johnson, B. J.; Huang, S. C. "On-road remote sensing of carbon monoxide and hydrocarbon emissions during several vehicle operating conditions," presented at A&WMA International Specialty Conference, Phoenix, AZ (1992).
6. Stephens, R. D.; Cadle, S. H. "Remote sensing measurements of carbon monoxide emissions from on-road vehicles," *J. Air Waste Manage. Assoc.* **41:** 39 (1991).
7. Stephens, R. D.; Cadle, S. H. "Remote sensing measurements of carbon monoxide emissions from on-road vehicles,"GM Research Publication #GMR-7030 (1990).

G. A. Bishop and D. H. Stedman are with the Department of Chemistry, University of Denver, Denver, CO 80208. T. Jessop is with the Cherry Creek High School, Denver, CO. This note manuscript was peer reviewed.