Abridgment

Remote Sensing of Atmospheric Pollutants to Assess Environmental Impact of Highway Projects

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Remote sensing techniques provide a powerful and effective tool for monitoring atmospheric pollutants to assess their environmental impact. Because of the mounting concern for the health hazards involved in living close to highways, environmental studies have become an increasingly important aspect in highway planning.

Conventional pollution monitoring devices use point sampling techniques to sense the presence of pollutants in ambient air. This method is costly because of the large number of units required, and it does not provide the continuum of data that can be obtained by remote sensing of an area from an airplane or from a moving vehicle. Remote measurements can include not only the nature and concentrations of the pollutant gases, but also the mass flow and mass transport of pollutants from one area to the next.

The majority of gaseous pollutants exhibit characteristic absorption bands in the ultraviolet, visible, or infrared regions of the spectrum. Radiation passing through an atmosphere containing these gases will have the characteristic absorption fingerprint of these vapors superimposed on it. Analysis of this radiation allows identification and concentration path length product measurements to be made of environmental pollutants associated with industrial activity, urban developments, and transportation. Both dispersive and nondispersive correlation sensors can be used for these measurements.

CORRELATION SPECTROSCOPY

A simple technique to measure gas correlation compares the absorption obtained at one wavelength corresponding to a strong absorption band in the gas with an absorption at an adjacent wavelength where the gas does not absorb. Although absorption bands are unique, interference problems occur from other gases present whose absorption bands overlap in one of the chosen spectral areas of measurement. This interference can be effectively resolved by correlating a substantial portion of the absorption spectrum of a gas being measured against a stored replica or mask of the spectrum. This technique has been named correlation spectroscopy and the method and applications are summarized in several publications (1, 2, 3).

COSPEC

In the Barringer Cospec group of instruments, the stored masks are a series of exit slits concentrically inscribed on a circular disk rotating in the exit plane of a conventional folded Ebert spectrometer. The mask line positions match the peak and trough absorption bands of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2); the spectrum is shown in Figure 1. The rotational position of the masks is monitored by logic diodes, and a photomultiplier (PM) tube is used for signal detection. Calibration references are provided by positioning internal calibration cells containing sealed known amounts of SO_2 gas in front of the PM tubes. This single gas instrument is known as the Cospec IV. The Cospec IV provides increased sensitivity for single gas monitoring by fully using a single grating for one gas without any time shared multiplexing. For dual gas operation, a Cospec II instrument has been developed in which half the grating is used for SO_2, the other half is used for NO_2, and the rotating disk is divided into two halves—one for each gas. This instrument has enjoyed worldwide use for high-sensitivity measurements of SO_2 and, more recently, NO_2. Figure 2 shows an overview of the Cospec optical layout.

Cospec has been frequently used to remotely sense the total vertical burden of pollution, that is, the amount of gas in a column above a unit area of ground, usually expressed in milligrams of gas per meter^2. Mobile vertical burdens can be measured by using ground mobile and low-flying airborne platforms looking vertically upward where Rayleigh backscattered daylight from the overhead hemisphere is used. Mobile vertical burdens can also be measured from an airborne, vertical, downward-looking mode where sunlight reflected upward from the earth is used. A third application is the airborne closed path mode where the Cospec views horizontally along an optical path beamed around the aircraft

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from an active light source. Optical paths of 20 to 30 m can be practically achieved by employing wing-tip and tail-stabilizer retroreflectors. Of these platforms, the ground mobile method is most widely used. Mass transportation of a pollutant can be estimated from the vertical burden measurements along a traverse line. When this is coupled with wind velocity and direction information, the mass of gas transported across the traverse line can be estimated in terms of mass per linear distance of traverse line. This concept can be used on both large and small scales and clearly provides a picture of the resulting diffusion of pollutants from smoke plumes, an entire industrial complex, or highway. Figure 3 shows the current single-gas Cospec IV high-sensitivity SO_2 instrument.

Figure 1. SO_2 absorbance versus wavelength.

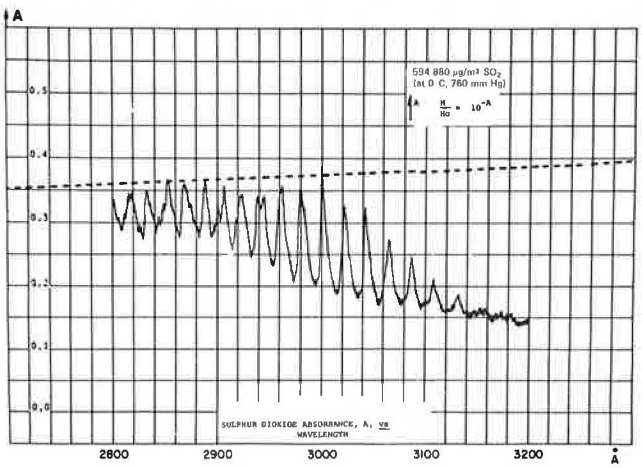


Figure 2. Cospec optical layout.

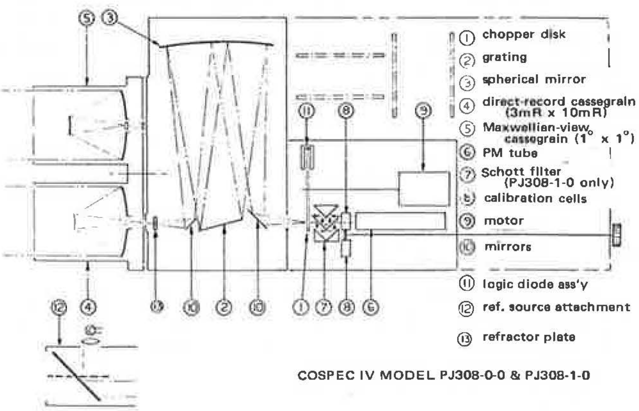


Figure 3. Cospec IV high-sensitivity SO_2 layout.

GASPEC

The Barringer Gaspec, or gas filter correlation spectrometer, operates by employing the differential measurement of characteristic absorption of the gas of interest by using the gas itself as a very selective filter as shown in Figure 4. A pair of gas cells are employed. A reference cell contains a spectrally inactive gas, and the filter gas cell contains the target gas to be sensed in a quantity such that the optical depth of the gas is optimized for a maximum product of the modulation of target gas energy and high average transmission. Incoming radiation characteristic of the target gas is selectively filtered by being absorbed in the sample cell but is readily transmitted through the reference cell. Thus

Figure 4. Gaspec optical layout.

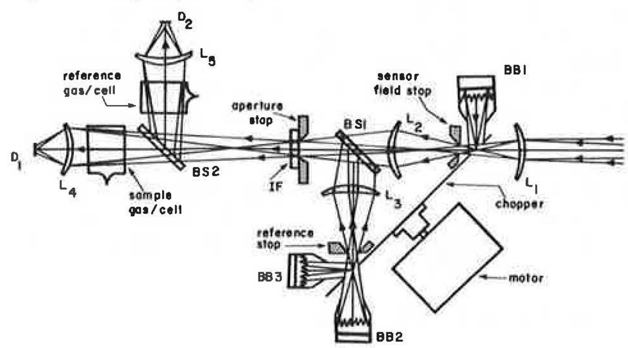
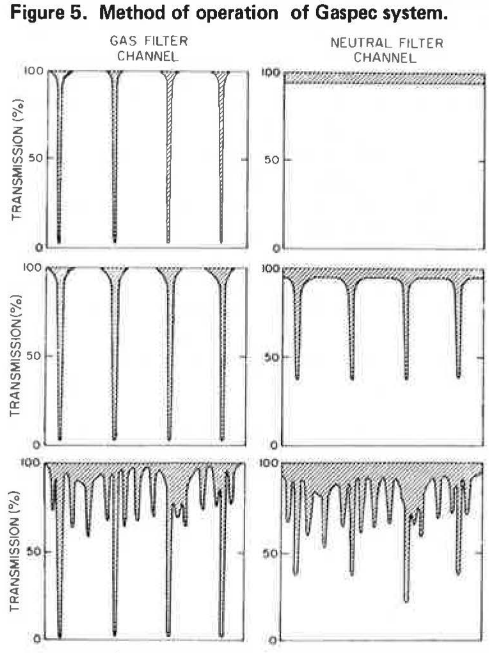


Figure 5. Method of operation of Gaspec system.



the transmitted radiance through the sample cell is largely independent of the target gas signatures, and the transmitted radiance of the reference cell is strongly dependent on the presence of target gas. The differential spectral transmittance between the cells provides a sensitive indicator for the amount of target gas present in the incoming radiation.

The principle of operation of this system is best described by the consideration of two channels as shown in Figure 5. In one, the absorption line spectrum of the target gas is present with almost zero transmission occuring at these band positions while the other channel contains a neutral filter adjusted to yield the same total absorption as in the first channel. Thus, as the detection system alternates between the two channels, it sees constant intensity. When matching spectral lines characteristic of the target gas appear in the incident radiation, the transmission in the first channel will not change appreciably because it is already at almost full absorption; however, a decreased intensity is transmitted through the second channel and the detection system now sees unequal intensities appearing at the channel switching frequency. If an interfering gas is also present, the transmitted light will be reduced equally in both channels, and, because the alternating signal is not changed, the interfering gas will be observed by the instrument.

To overcome the problems of spatial responsiveness difference at the detector that is produced by chopper changes and to avoid scene radiance changes as the sensor footprint moves, a two-detector system was developed. The detectors receive amplitude-shared source signals at the source chopping frequency. Another feature of the Gaspec design is a further adjustable reference blackbody that may be adjusted to have comparable radiance to the source and thereby facilitate electronic signal processing by minimizing the chopped radiance. Gaspec is further described elsewhere (4, 5). The most recently built Gaspec is now capable of sensing two different gases simultaneously.

METHODOLOGY AND MODELS

The application of these remote sensing instruments to highway and transportation environmental problems and studies is now possible. Pioneering work in these applications has already taken place, and further developments are envisaged.

One initial application is to the validation and verification of mathematical computer models of local and regional pollution and air-shed movements. There are of course in the generalized area of environmental input studies two major sources, fixed and mobile. Essentially the moving automotive sources provide the carbon monoxide (CO) oxidents, oxides of nitrogen, and hydrocarbon pollutants. The fixed sources, such as industrial plants, petrochemical complexes, and power stations, chiefly provide particulates, oxides of sulfur, and oxides of nitrogen. Selection of the appropriate mathematical model then depends on short- and long-term reaction rates and time-distance domain requirements.

For modeling transportation sources in urban areas, almost all CO is emitted from mobile sources. Thus, in Washington, D.C., 98 percent of all CO emissions are from transportation sources. Several types of models are possible, including synoptic, climatological, and grid-point models.

1. The synoptic model computes hourly concentrations as a function of time for operational applications.
2. The climatological model computes the frequency distribution of concentrations for statistical predictions of specified high concentrations for planning needs.
3. The grid-point model computes concentrations at different locations in a geographical grid for horizontal isopleth patterns for both operational and planning needs. Such a model assumes all emissions to be at ground level because they are from transportation sources.

In considering the running of a grid-point model, emission data are inputted from (a) emissions from vehicles traveling the major thoroughfares, streets, and freeways and (b) secondary background emissions from vehicles on less densely traveled local and feeder streets and roads. This model also requires essential traffic data such as

1. Coordinates of ground-level ambient receptors;
2. Gasoline consumption rates;
3. Vehicle speeds for the various types of roads;
4. Daily traffic fraction within each 24-h period by type of road and day of week for workdays versus weekends;
5. Day and hour to be modeled;
6. Associated projected air temperature and air pressure for the day and hour;
7. Associated hourly surface data such as type of cloud cover, temperature, wind speed, and direction.

A similar methodology allows the development of a fixed-source SO_2 model by using point and area source inputs such as geographical location of source, stack height, stack diameter, stack gas exit velocity and temperature, and source emission rate. The SO_2 model also requires, in addition to the above point and source inputs, the following:

1. Mean morning and afternoon mixing height;
2. SO_2 decay constant;
3. Day and hour to be modeled;
4. Meteorological inputs for wind field profiles for stable, neutral, or unstable atmospheres;
5. Background level concentrations;
6. Surface data for ceiling heights, sky conditions, air temperature, wind speed and direction, and the like;
7. Coordinates of ground-level ambient receptors.

CO MODEL

The models previously described have been run for assessing the CO emissions from transportable sources. For example, they have been used in Washington, D.C., where the basis for CO emission was a network of 737 road segments or links each assigned a daily traffic volume generated from historical, current, or projected data obtained from U.S. Department of Transportation sources. Growth factors have to be extrapolated into the model conditions. The CO model can generate the ground-level ambient CO for 625 chosen receptor points. From these projected readouts, projected isopleths can be plotted. Because the minimum detectable sensitivity for continuous CO ambient monitors is 0.565 mg/m^3 (0.5 ppm), this is the lower bound for the isopleths. However many assumptions are made with regard to the input data when such models are generated. Errors in assumption relate to both the pollution source data and the associated meteorology. The net result is a model prediction that needs validation. The remote sensing Gaspec and Cospec technology then becomes most valuable in the validation of these models. The Cospec-Gaspec technique takes total vertical burden measurements through the atmosphere and in effect sounds the isopleth. These rapid, mobile Cospec-Gaspec surveys enable a complete verification of the model to be undertaken and the model to be adjusted through iterative fine tuning.

REFERENCES

1. A. R. Barringer. Chemical Analysis by Remote Sensing. Paper presented at 23rd Annual Instrument Automation Conference, Instrument Society of America, Oct. 1968.
2. A. R. Barringer and J. H. Davies. Applications of Correlation Interferometry and Spectroscopy to Aerospace Monitoring of Earth Resources and Pollution. Paper presented at 7th International Aerospace Instrumentation Symposium, Cranfield, U.K., March 1972.
3. A. R. Barringer, J. H. Davies, and A. J. Moffatt. The Problems and Potential in Monitoring Pollution From Satellites. American Institute of Aeronautics and Astronautics, New York, Paper 70-305, March 1970.
4. J. H. Davies, T. V. Ward, and H. H. Zwick. Latest Developments With an Airborne Gas Filter Correlation Spectrometer. Canadian Journal of Remote Sensing, Nov. 1975.
5. T. V. Ward and H. H. Zwick. Gas Cell Correlation Spectrometer—Gaspec. Applied Optics, Vol. 14, No. 12, Dec. 1975.