Air quality investigation by means of remote sensing, with application to CO thermodynamic measurements in the city of Timisoara

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SUMMARY
Instruments based upon Remote Optical Measurement Techniques (ROMT) are becoming increasingly common in gas sensing applications due to advances in electro-optic detectors and system design. However the use of these for formal monitoring purposes is hampered by the lack of instrument performance standards against which products could be certified. The paper complies with the key objectives of determining the concentration of CO by means of remote sensing with a Siemens Hawk optical device and for comparison with the CO HORIBA APMA-350E classic monitor working ND in IR. The field measurement campaign has been fulfilled for a summer 2002 episode, at Timisoara. The results and the novelties of the comparison between the two ranges of values are very promising and indicate the possibility to apply optical remote sensing also in routine measurements for air quality.

1.1. Introduction and purpose of the study

Remote sensing devices offer a number of advantages over competing technologies such as electro-chemical sensors or closed path optical systems, including flexibility of deployment, and avoidance of extractive sampling. The value of ROMT instrumentation has already been proven in applications including transport, power generation, chemical processing and air quality monitoring, to monitor gaseous emissions for the protection of the environment, or the safety of citizens. However the use of these instruments for formal monitoring purposes, e.g. to comply with the requirements of European directives on air quality, is hampered by the lack of instrument performance standards against which products could be certified. Remote or open-path optical systems are explicitly excluded from current gas sensing and environmental monitoring standards. This is partly owing to the difficulties in defining performance requirements which take into account the environmental factors which affect the instruments use in the field [1], [5].

The paper complies with the key objectives of determining the concentration of CO by means of remote sensing with the Siemens Hawk optical device and for comparison with the CO HORIBA APMA-350E classic monitor working ND in IR, as applying an attested method by the EC [2]. It also indicates that concern about pollution control necessity has arisen also in East European countries, that are experienced unprecedented pressure as a result of the growth of road traffic, increasing by 50 % between 1970 and 1990 [3].

1.2. Theoretical introduction to the applied method

The Grottus-Draper law, or first law of photo-chemistry as it is sometimes called, states that only the light which is absorbed by a molecule can be effective in producing photochemical changes in the molecule,. Therefor to assess the potential of photochemically induced changes in a photochemical system such as the daytime troposphere, it is essential to know the absorption spectra of the reactants. Indeed, to fully characterise the reaction mechanism, one must also know the absorption spectra of the intermediates and reaction products [4], [6].

In addition to knowing the wave lengths of light absorbed by a molecule, it is important to know the strength of the absorption as a function of wavelength λ. For absorbing solutes, as customarily employed in spectrometric analysis, this is given by the well known Beer-Lamber law:

$$\ln\left(\frac{I_0}{I}\right) = eCl \qquad (1)$$

where: I_0 is the intensity of monochromatic light of wavelength λ incident on the front of a column of a single absorbing species, in quanta/sec;
I - intensity of light transmitted trough the path considered, in quanta/sec;
e - molar absorption (extinction) coefficient in cm^2/molecule;
C – concentration of the absorbing species, in number/cm^3;
l – path length, in cm.

Air pollutants are present in such small concentrations that the fraction of light absorbed is generally low at the path length of conventional lab spectrometers. Thus one increased the path length, either by modifying the distance between the source and the detector, or by using of a set of reflecting mirrors, or either end of a cell of fixed length and bounce the light beam back and forth many times, given an effective absorption path length for the pollutant, which is some multiple of the cell length.

The IR Hawk from Siemens Environmental Systems is an infrared DOAS (Differential Optical Absorption Spectroscopy) instrument which can be configured to detect any one species from CO, CH_4, C_2H_4, NO, HF, total hydrocarbons $<C_8$. The beam path can extend up to 400 m and the limit of detection is typically better than 50 ppb over such paths.

Open path techniques have an advantage over point source detectors in that the sampled volume is so much greater that the effect of non-uniformity of mixing in the sample is mitigated and a more representative value of the concentration of the compound to be measured is obtained. Under field conditions, the degree of mixing is affected by the local environment – primarily wind and thermal gradients. Where concentration gradients exist and mixing is limited there may be considerable variability in the concentrations detected according to the positioning of the instrument. Equally, the acquisition time and measurement intervals used may affect the values obtained [5], [7].

The principal components are given by Figure 1.

The field measurement campaign has been fulfilled for a 12 day episode, in summer 2002, at Timisoara, in a main cross road, thus depicting manly the influence of the traffic on the air quality. The beam path was 32 m and one concentrated only on the CO specie. Figure 2 gives details for the positioning of the instrument and data acquisition system. The site was located in one of the most polluted sector of the city, in correspondence to the simulation results accomplished with an Gaussian model [8].

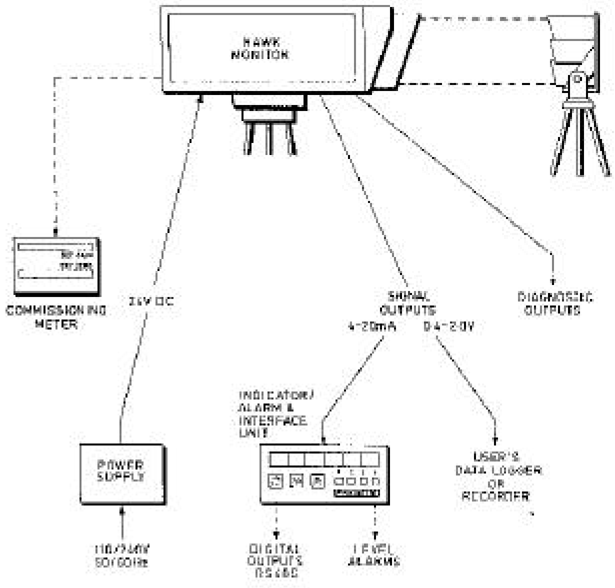

Figure 1: Schematic of the HAWK flow diagram.

Figure 2: Measurement campaign during the tests in July 2002, in the M. Viteazu - Parvan Cross Road.

For comparison a APMA-350E Ambient CO Monitor has been used, as internationally accepted. It is a field-proven cross-flow modulated NDIR (Non - disperse Infrared) analyser. The apparatus represents a new generation of ambient CO monitors designed to eliminate routine calibration cycles and to provide long-term stable measurements and unattended continuos operation, and having a newly developed cross-flow modulation (CFM) technique which results in remarkable improved zero drift performance and sensitivity. The basic design is shown in Figure 3.

The thermodynamic data from the field measurement have been accomplished in parallel to meteorological data. Special acquisition system has been used. Preliminary adequate calibration and alignment have been accomplished.

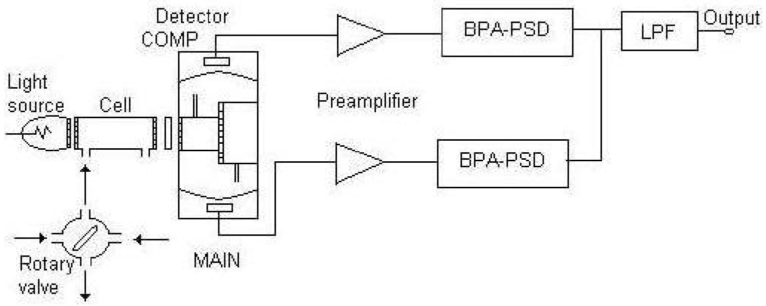

Figure 3: HORIBA APMA-350E ambient CO monitor operating principle.

1.3. Results

Figure 4 is showing the cluster of the histogram and Figure 5 the cluster.

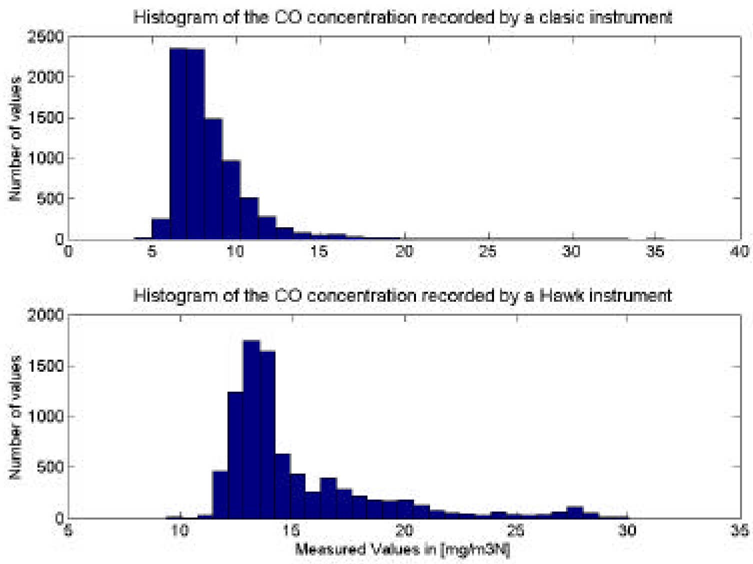

Figure 4: Histogram of CO concentration recorded by classic and Hawk instrument.

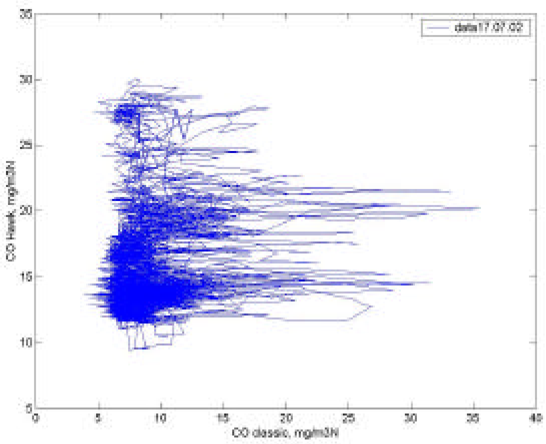

Figure 5: Cluster between the CO measured by classic and by the Hawk instrument.

1.4. Conclusions and future plans

Following conclusion have been drown:

- 48,811 data comparison data for CO have been recorded, using two systems,
- Polynomial approximation of the values (time series),
- Statistical analysis for one day is quite promising,
- The histograms indicate for the HORIBA values of 6 to 10 mg/m^3_N, and respectively 13 - 14 mg/m^3_N for the Hawk instrument, as most attempt,
- Mean value for the classical HORIBA is 8.4 mg/m^3_N, and respectively 13 - 14 mg/m^3_N for the HAWK,
- CO classic measurements with HORIBA indicate values approx. 70 from the indications of Hawk,
- The cluster indicates random position scattering of 2.4 for the classic system, and 3.5 for the HAWK,
- 10 - 20 mg/m^3_N for Hawk and 7 - 12 mg/m^3_N for Horiba,
- Correlation between both series is positive (0.1980), but week.

The results and the novelties of the comparison between the two ranges of values are still very promising and indicate the possibility to apply optical remote sensing also for routine measurements for air quality.

Remote optical measurement techniques (ROMT) have the great advantage over other more conventional techniques for measuring gaseous pollutants in that they can perform real time, in-situ gas analysis along an open path.

Future plans and experience gained from the first field trials are the followings:

- Elimination of the artefacts,
- Temperature recording in the tent (air conditioning),
- Texas Instruments acquisition system for the data,
- Localisation of the source for the classic apparatus in the middle of the open path,
- Correlation of the time series with the meteorological data,
- Variation of the measuring open path distances,
- Traffic monitoring,
- Obtaining of results from stationary series (smaller), when the standard abatement is stationary and the mean value is constant.

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