

# Remote sensing of atmospheric pollution by passive FTIR spectrometry

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## ABSTRACT

Passive remote sensing with a Fourier transform infrared (FTIR) spectrometer allows the detection and identification of pollutant clouds in the atmosphere. In this work, the measurement technique and a data analysis method that does not require a previously measured background spectrum are described. Recent experimental results obtained with a new high sensitive FTIR remote sensor are presented.

Many situations do not allow the measurement of a background spectrum prior to the measurement of pollutants in order to perform background removal. After a radiometric calibration of the FTIR spectrometer with IR reference sources the spectral radiance of the environment can be measured. With the inverse function of Planck's radiation law, the (spectrally resolved) brightness temperature is computed. The temperature spectrum has a constant baseline for many natural materials that serve as the background in field measurements (forest etc.) because their emittance  $\epsilon(\nu)$  is high and almost constant in the spectral range 800-1200  $\text{cm}^{-1}$ . The influence of environmental and instrumental parameters on the sensitivity of the method is discussed. Experimental results are presented to illustrate the enhancement of the signal to noise ratio that can be achieved by the alignment of the spectrometer to backgrounds with a high temperature difference to the environment.

Keywords: remote sensing, FTIR, passive

## 1. INTRODUCTION

The technique of Fourier transform-infrared (FTIR) remote sensing is increasingly used for the detection and identification of gas phase pollutants in open environments<sup>1-7</sup>. Compared to the traditional point sampling detection methods, remote sensing by FTIR spectroscopy has several advantages:

- universal for the detection of polyatomic molecules,
- fast analysis of multi-component mixtures,
- real-time monitoring of gaseous emissions over distance,
- large sampling area, no sample preparation and handling,
- no sensor contamination during measurement, and
- simple operation and little maintenance.

Due to this background, we have recently developed an automated infrared remote sensing system for the detection of atmospheric trace gas and air pollutants that can be used under outdoor conditions.

Open path measurement techniques can be divided into passive and active measurement techniques<sup>8</sup>. The active open path measurement technique is quite similar to the classical setup of a laboratory FTIR spectrometer and is often used for environmental air pollution studies, whereas passive FTIR remote sensing is not as well known in the community of analytic scientists. Due to the high sensitivity and mobility of modern FTIR spectrometers, the number of applications in field monitoring<sup>1,2,5,6</sup> and process control<sup>9,10</sup> is increasing.

## 1.1 ACTIVE REMOTE SENSING BY FT-IR SPECTROSCOPY

In an active remote sensing measurement the infrared light is emitted by a hot infrared source, and is received by the spectrometer optics. Thus, the emitted infrared light propagates in direction of an open optical path, which is defined by the distance and position of the IR-source and the spectrometer. The received infrared light is modulated by an interferometer, detected by an infrared detector, converted and subsequently stored as an interferogram by help of the spectrometer electronic and the connected data system. The infrared spectrum is then computed from the interferogram by a mathematical operation (Fourier-Transformation).

If there are IR-active molecules (i.e. molecules with a significant IR absorption cross section in the observed frequency range) in the optical path characteristically absorption features (lines or bands) will appear in the IR-spectrum. From the transmittance spectrum the composition and quantity of the species in the optical path can be evaluated (Lambert-Beer law) with high accuracy and reliability. The technique is commonly applied, if low detection limits are required.

Generally for a given concentration (partial pressure) of the target species the sensitivity of this detection technique increases with the

- optical throughput of the sensor,
- transmittance and modulation efficiency of the FTIR spectrometer,
- sensitivity of the IR-detector element,
- optical path length,
- absorption cross section of the target molecule i.e. absorption coefficient, and
- number of coadded spectra i.e. measurement time.

## 1.2 PASSIVE REMOTE SENSING BY FT-IR SPECTROSCOPY

Passive remote sensing works similar to the active setup described above. The only difference is that the ambient infrared radiation is detected instead of the light of the artificial IR source. This results in the advantage of mobile and fast operation (man-held system), remote sensing distance up to several kilometers, and easy handling.

Passive FT-IR spectroscopy is less sensitive than the active configuration, because the sensitivity decreases with the temperature difference between the background and the target compounds. In case of a small temperature contrast  $\Delta T$  the detection sensitivity is poor. For an effective temperature difference of 1 K we can estimate, that the sensitivity is about 1000 times smaller compared to the sensitivity of the active setup.

Typical applications of passive remote sensing are:

- reliable identification of industrial released hazardous gaseous compounds,
- observation of stack gas plumes<sup>1</sup>,
- civil defense and fire brigade operation purpose (chemical accidents, wildfires<sup>11</sup>),
- remote sensing of aircraft emissions<sup>12</sup>, and
- detection of warfare agents under battlefield conditions.

Passive remote sensing is the only detection method, which allows mobile, fast, man-held and standoff (wide range) detection of hazardous chemical agents.

## 2. THEORY

### 2.1 MODEL FOR PASSIVE IR REMOTE SENSING

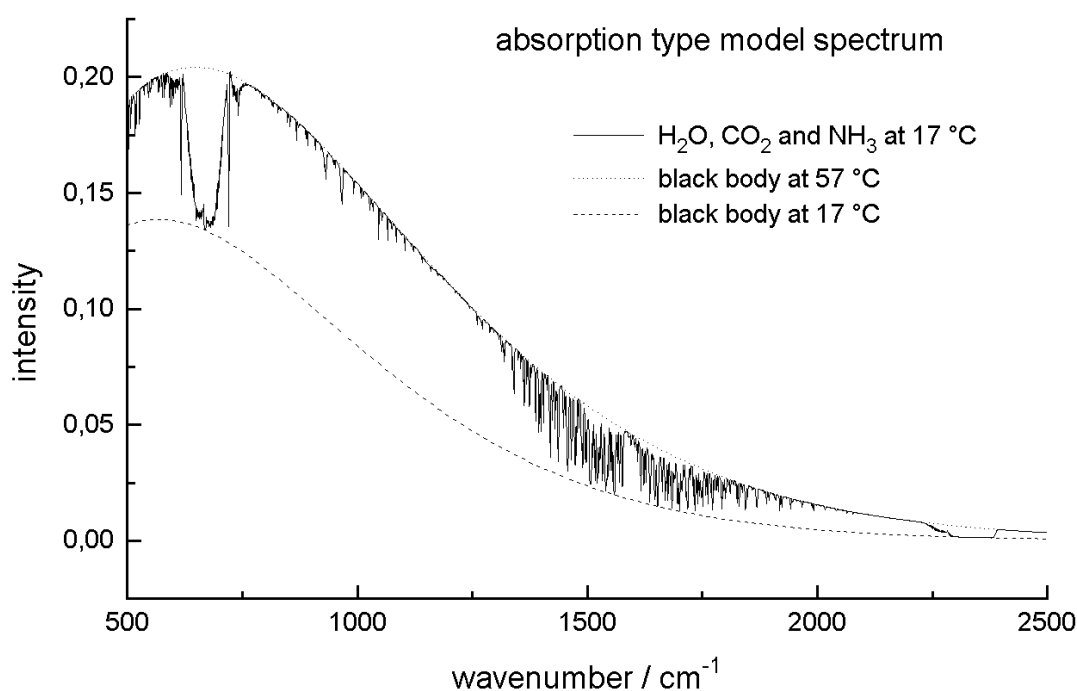
In order to understand the measured spectra, a model is applied. The atmosphere in front of the IR sensor is divided into multiple homogeneous layers. Every layer has an individual temperature and different partial pressures of IR-active gases. For this layer model, the equations of radiative transfer<sup>3</sup> must be solved.

In the simplest model, we may define an observation layer (O), and a background (B). If light scattering by aerosols and particles is disregarded as a first approximation, the observed radiance  $L$  is

$$L = B_O (1 - \tau_O) + B_B \tau_O \quad (1)$$

$B_O$ : radiance of a blackbody at the temperature of the observation layer;  $B_B$ : radiance of the background;  $\tau_O$ : transmittance of the observation layer. Equation (1) can be rearranged to

$$\tau_O = (L - B_O) / (B_B - B_O) \quad (2)$$



**Fig. 1** Spectral radiance (in  $W / m^2 sr cm^{-1}$ ) for a simple two layer model of passive remote sensing. The absorbance type radiation signatures are due to water, carbon dioxide, and ammonia gas, which is cooler (290 K) than the background (330 K). The upper (dotted) and lower (dashed) lines correspond to the radiation of a blackbody at temperatures of 330 K and 290 K.

Figure 1 gives a typical absorbance signature (two layer model), if the cloud has a temperature of 17 °C and the background 57 °C. The radiance signatures of the cloud components (carbon dioxide, water and ammonia) do not result in zero radiance, but in a radiance of an imaginary line which corresponds to the (17 °C) blackbody radiation envelope of the cloud. The

same arguments apply if we consider the case of an inverse temperature layer. The observed emission signatures will never rise above the theoretical curve of the radiance of a 57° C blackbody. This physical fact limits the dynamic range of spectral information from the target compound. If there is no temperature difference between the cloud and the background (e.g. a building), no information about the cloud composition can be obtained. This limitation cannot be overcome by any improvement of the sensor. However, the probability of such a singular point of identical atmospheric temperature conditions is infinitely low, but it may occur that there are only small temperature differences.

IR light absorption from atmospheric trace gases (e.g. water and carbon dioxide) overlaps with the characteristic "fingerprint" signatures (emission or absorption type) of the target species. In many cases it influences the result of the measurement and reduces the frequency range usable for remote sensing. Cross-sensitivities of the detected chemical agents with water and carbon dioxide reduce the selectivity and sensitivity (the same is valid for active remote sensing). Generally, one is forced to work in spectral regions, in which water and CO<sub>2</sub> do not absorb strongly (atmospheric windows: 750-1300 cm<sup>-1</sup>, 1900-2200 cm<sup>-1</sup>, and 2400-2900 cm<sup>-1</sup>).

In order to determine the transmittance  $\tau_0$  using Eq. (2), which contains the desired information about the chemical agent cloud) the background radiation  $B_B$  and the blackbody radiation  $B_O$  are needed. In principle  $B_O$  could be evaluated from the measured spectra if there are spectral regions with total IR light absorption in the observed layer ( $L = B_O$ , e.g. for water at wavenumbers from 1300-1900 cm<sup>-1</sup> at pathlengths > 100 m) or if well known hot band absorptions can be indicated. But in practice the determination of  $B_O$  is not reliable, because the layer model to be applied for the quantitative analysis of field measurements is much more complicated<sup>13</sup>. Prediction of passive IR spectra is possible if the temperature, pressure, and concentration distribution for all layers are included in the radiation layer model. Calculations can be done by several computer programs like FASCODE<sup>14</sup> and MODTRAN<sup>15</sup>. A certain atmospheric model can be confirmed (but not proved) by such calculations. The reverse procedure i.e. the evaluation of layer parameters from the open path spectra is not unambiguous, such that only semi quantitative results can be estimated.

## 2.2 SENSITIVITY AND DETECTION LIMITS FOR PASSIVE IR REMOTE SENSING

As obvious from the simple 2 layer model [Eq. (2)], the sensitivity of the passive IR remote detection technique is not a constant quantity, but depends on the relation of spectral noise  $DL$  to dynamic range  $|B_B - B_O|$ .

Higher values of  $|B_B - B_O| / DL$  increase the sensitivity for the chemical agent detection. For the evaluation of the detection limit from the transmittance  $\tau_0$  the Lambert law can be applied within a good approximation:

$$\tau_0 = (L - B_O) / (B_B - B_O) = \exp(-\epsilon c d) \quad , \quad (3)$$

with  $\epsilon$ : absorption coefficient,  $c$ : CA concentration, and  $d$ : optical pathlength. As expressed by Eq. (3), for a vanishing  $\epsilon$  or for a vanishing product of concentration and path lengths ( $c \cdot d$ ) the transmittance is near by 100% and no CA identification is possible.

For the analysis of the spectra it is convenient to transform the passive IR spectra into the radiance<sup>16</sup> and calculate the corresponding equivalent radiation temperature (brightness temperature)  $T(\nu)$  by Planck's Radiation Law<sup>17</sup>.

$$T(\mathbf{u}, L) = \frac{hc\mathbf{u}}{\ln \left[ \frac{L(\mathbf{u}) + 2hc^2\mathbf{u}^3}{L(\mathbf{u})} \right] k} \quad (4)$$

The spectral noise  $NE\Delta T$ <sup>17</sup> (root mean square deviation of  $T$ ) is the temperature difference, which can be resolved by the spectrometer.

Any infrared signature from a target compound will appear as a characteristic deviation  $D^2T(\nu) = T(\nu) - T_B(\nu)$  from the background temperature  $T_B$ . An identification is possible if

$$D^2T(\nu) \geq NE\Delta T \quad . \quad (5)$$

For small  $DT$  Eq. (3) can be rewritten in terms of the equivalent radiation temperatures as follows

$$D^2T \cong DT [1 - \exp(-\epsilon c d)] \quad (6)$$

For small values of  $\epsilon \times c \times d < 1$ , there is in good approximation a linear relation

$$D^2T \approx DT \epsilon c d \quad (7)$$

Fig. 2 illustrates this linear behavior by the example of methanol gas at  $c \times d$ -values of 30, 90, and 560 ppm m

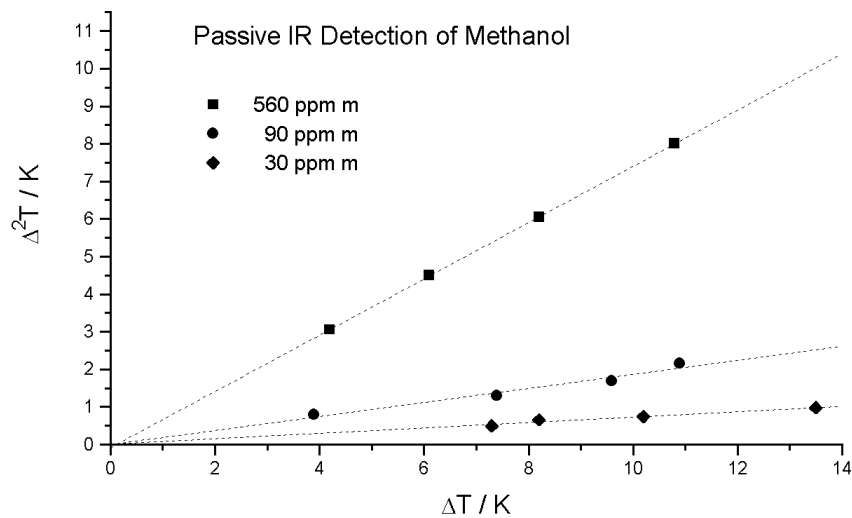
Eq. (7) can be transformed to

$$D^2T / \epsilon \approx DT c d \quad (8)$$

At the detection limit it is valid that  $D^2T = NEDT$  [Eq. (5)]. Due to this definition, we can calculate a detection limit,

$$G = (c d DT)_{\text{limit}} \approx NEDT / \epsilon \quad (9)$$

which includes the influence of  $DT$  within a good approximation. Thus the  $G$ -value gives an appropriate detection limit for the passive remote sensing technique, which can be calculated using the instrument parameter  $NEDT$  and the extinction coefficient  $\epsilon$  of the target compound.



**Fig. 2:** Maximum temperature deviation  $D^2T$  of the Q-branch of the methanol absorption band at  $1033.4 \text{ cm}^{-1}$ . The abscissa gives the temperature difference between the methanol vapor in a 1.5 m gas cell and the blackbody in the background.

**Tab. 1:** Detection limits [from Eq. (9)] for passive remote sensing of some target compounds: mass-ppm corresponds to mass parts per million and vol.-ppm to volume parts per million. In order to obtain reliable results, the detection limits defined by Eq. (9) should be multiplied by a field factor of approximately 10. The given values are determined from laboratory experiments at  $\Delta\nu = 1 \text{ cm}^{-1}$  and 1 minute measurement time.

Compound name	mol. weight g mol <sup>-1</sup>	vapor pressure at 20 °C in mbar	G-value	
			mass-ppm m K	vol.-ppm m K
Acrolein	56.1	293	84	43
Acrylo nitrile	53.1	116	48	26
Ammonia	17.0	8590	5	9
Hydrogen cyanide	27.2	810	4	4
Methanol	32.0	128	15	13
Phosgene	98.9	1550	10	3
Sulfur hexafluoride	146.1	21400	2	0.5
Tetrachloroethylene	165.8	19	35	6
1,1,1-trichloroethane	133.4	130	19	4
Vinyl chloride	62.5	3400	20	9

For example methanol has a maximum  $\epsilon \approx 2.4 \times 10^{-3} \text{ ppm}^{-1} \text{ m}^{-1}$  ( $\nu = 1033 \text{ cm}^{-1}$ , spectral resolution:  $\Delta\nu = 1 \text{ cm}^{-1}$  and total pressure 1 atm) and the RAPID has a *NETD* of 0.03 K per minute measurement time ( $\Delta\nu = 1 \text{ cm}^{-1}$ ). According to Eq. (9) the detection limit of methanol can be calculated to

$$G_{\text{methanol}} = 0.03 \text{ K} / 2.4 \times 10^{-3} \text{ ppm}^{-1} \text{ m}^{-1} \cong 13 \text{ ppm m K} .$$

For a number of 10 target compounds, the detection limits are determined as shown in Tab. 1.

From the values in Tab. 1 detection limits in terms of concentration  $\times$  pathlength values ( $c \times d$ -values) can be calculated by rewriting Eq. (6) and (7) as follows:

$$(c \times d)_{\text{limit}} \cong -1 / \epsilon \ln(1 - \text{NETD} / \text{DT}) , \quad \text{and} \quad (10)$$

$$(c \times d)_{\text{limit}} \cong (1 / \epsilon) (\text{NETD} / \text{DT}) = G / \text{DT} . \quad (11)$$

### 2.3 EVALUATION OF THE SPECTRA

For the evaluation of the spectral radiance  $L(\nu, T)$ , a linear calibration is applied<sup>16</sup>

$$S(\nu, T) = m(\nu) L(\nu, T) + b(\nu) , \quad (12)$$

where  $S(\nu, T)$  is the measured spectrum,  $m(\nu)$  the spectral response factor and  $b(\nu)$  the spectral offset. The instrumental response functions of Eq. (12) are determined from the calibration spectra  $B(\nu, T)$ , of a reference source (blackbody) at two different temperatures.

Eq. (12) is only valid as long as the values of the instrumental parameters  $m(\nu)$  and  $b(\nu)$  are within their uncertainties. Fluctuations of the properties of the spectrometer will change the response function of the spectrometer. The most important quantities that influence the response are the temperature of the instrument (offset radiation) and the temperature of the IR detector element. In order to achieve precise quantitative measurements of the spectral radiance and the equivalent radiation temperature, it is recommended to cover the spectrometer with an air conditioned casing and to do the calibration just before each measurement.

The identification of chemical compounds by their  $T(\nu)$ -signatures will not be strongly interfered by the stability of the calibration, because the main influence is a constant temperature offset.

### 3. EXPERIMENTAL

RAPID (Remote Air Pollution Infrared Detector) is an FTIR spectrometer which is optimized for the remote detection of chemical agents. The system consists of several components: sensor module, controller module (PC), power supply and tripod.

The FTIR sensor module consists of a base plate, which carries the spectrometer components. The optics of the spectrometer consist of an entrance window (ZnSe, diameter 50 mm), an autocalibration unit with two blackbodies at different temperatures, an interferometer block, a parabolic mirror and an infrared detector that is cooled by a closed cycle cryocooler. A metal casing protects the sensible spectrometer and keeps the inner nitrogen gas atmosphere of the instrument. A small telescope mounted outside of the spectrometer housing allows proper alignment of the field of view of the instrument. In the standard configuration the power supply unit contains a 24 V battery pack (input voltage: 12 - 36 V DC), which allows field operations up to 4 hours, before the batteries have to be charged.

For laboratory measurements we used a setup with a home built blackbody (active area: 25 cm × 25 cm, accuracy ± 0.5 °C@ 40 °C, stability ± 0.2 °C) as background and absorption path gas cells (10 cm and 150 cm with an inner diameter of 40 mm and 80 mm, respectively) with heating facilities as observation layer. The chemical compounds, thoroughly degassed by several freeze-pump-thaw cycles, are handled with a standard vacuum line, equipped with calibrated absolute pressure gauges (MKS BARATRON from MKS Instruments, accuracy better than 2%). After filling the cell with the measurement gas, dry nitrogen (800 - 1000 mbar) is added.

Field measurements have been carried out to acquire background spectra as well as spectra of vapors and gases in front of different background materials. Weather data, IR-, and video images were recorded to document the measurements. Since environmental parameters influence the diffusion of released gases, a setup that yields reproducible vapor concentrations and temperatures for remote measurements from a distance  $d > 100$  m is complicated to realize. That is the reason why the majority of field measurements were performed with a gas cell, which was mounted directly in front of the spectrometer entrance window. The gas cell consists of a PVC tube ( $l = 0.2$  m) with polyethylene foils as windows. With this setup, the concentration of the vapor is constant for all measurements and the temperature of the gas can be measured. To a first approximation (neglecting scattering), the observed spectra are independent of the position of a gas cloud along the optical path to the target if the vapor has the same temperature as the air along that path. Nevertheless, numerous experiments with vapors that were released into the atmosphere were carried out to test the automated identification software.

### 4. RESULTS AND DISCUSSION

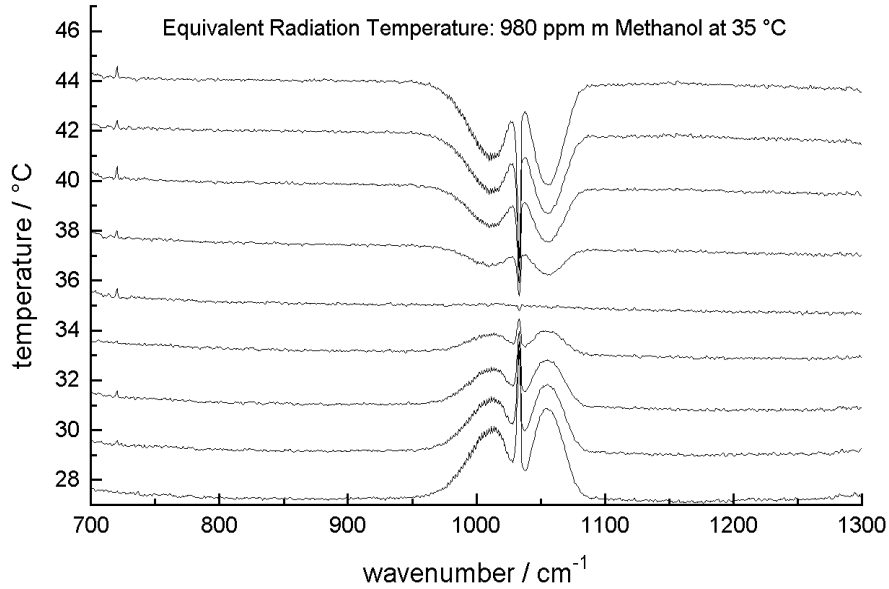
#### 4.1 LABORATORY MEASUREMENTS

Fig. 3 shows the spectral temperature signature of methanol with different background temperatures. Our experiments show that small spectral lines and broad absorption bands can be identified by the spectral interpretation of the equivalent radiation temperature. The dynamic range for the IR-signatures of the target compound is the difference between the baseline of the measured spectrum and the  $T(\nu)$ -spectrum of a background source (blackbody) at same temperature as the observation layer (37°C in figure 3). The characteristic IR-signatures increases with increasing temperature differences.

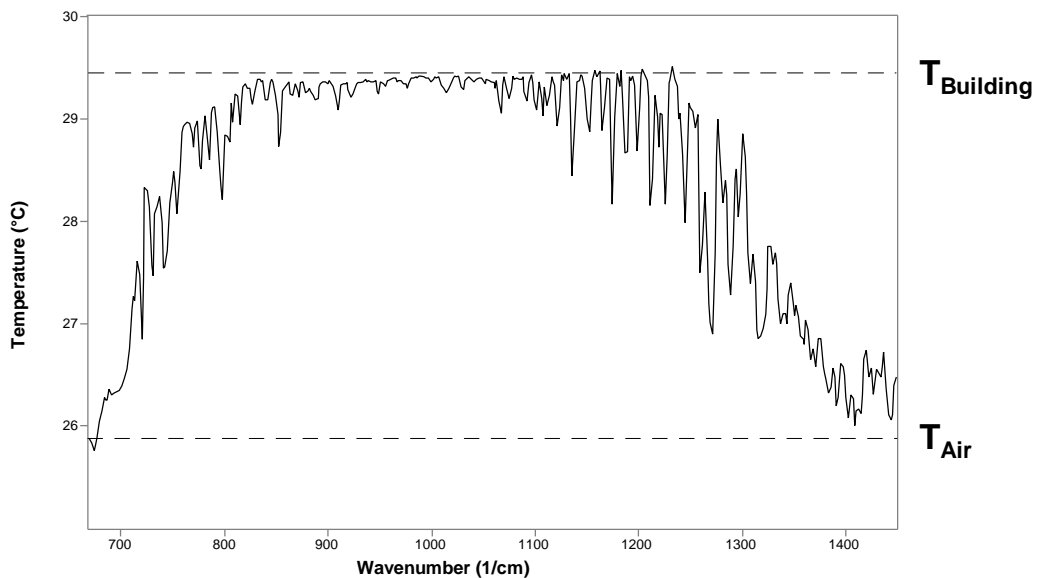
#### 4.2 FIELD MEASUREMENTS

To illustrate the interpretation of temperature spectra, a spectrum of a white painted building from a distance of  $d = 200$  m is shown in figure 4. The resolution of the measurement is  $\Delta\nu = 4$  cm<sup>-1</sup>. In the range 650-700 cm<sup>-1</sup> the transmittance of the atmosphere along a 200 m path is almost zero (CO<sub>2</sub> absorption). Thus the air exhibits properties of a blackbody at the temperature of the boundary layer of the atmosphere and the temperature spectrum yields this temperature. In the range 800-1200 cm<sup>-1</sup> the transmission lies in the range 0.75-0.98. An approximation of the temperature of the building, which has a high emissivity can be read off the temperature spectrum as the upper boundary in this spectral range. The absorption lines in the atmospheric window are caused by water vapor. At  $\nu > 1200$  cm<sup>-1</sup> the transmittance of the atmosphere decreases due to stronger absorption lines of water, methane and nitrous oxide. At  $\nu > 1400$  cm<sup>-1</sup>, the atmosphere is almost opaque due to a fundamental bending mode of the water molecule and the temperature spectrum yields the temperature of the air.

The spectrometer was aimed at nine different targets in numerous measurement campaigns. Examples of background spectra of five of these targets are displayed in figure 5.

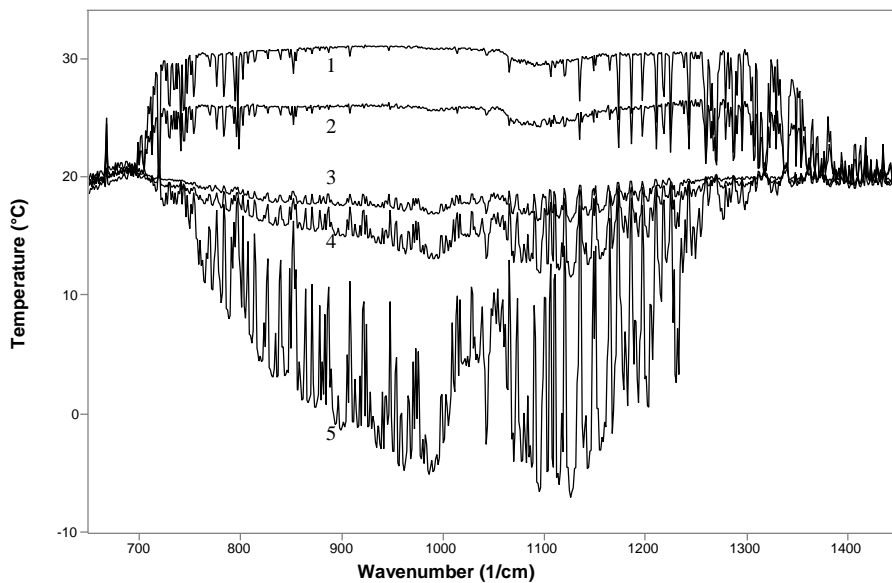


**Fig. 3** Equivalent radiation temperature of 980 ppm m methanol at 35 °C (1.5 m gas cell) and background temperatures of 27°C to 44°C. There is a straight baseline with emission type signatures (cold background) and absorption type signatures (hot background).



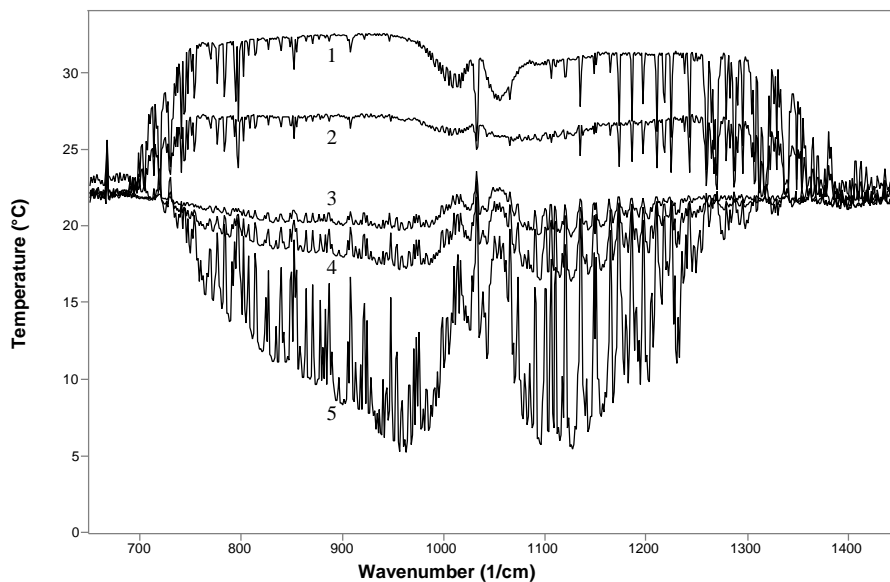
**Fig. 4:** Temperature spectrum of a painted building from a distance of 200 m.  $T_{\text{air}} = 26^{\circ}\text{C}$ , rel. humidity = 60%,  $\Delta\nu = 4 \text{ cm}^{-1}$ .





**Fig. 5:** Background temperature spectra of 5 different targets: 1: Brick wall facing south,  $d = 100$  m; 2: Brick wall facing west,  $d = 90$  m; 3: Forest,  $d = 1$  km; 4: Horizontal path (50% sky); 5: Sky at an angle of  $5^\circ$ . 1 scan,  $\Delta\nu = 0.5$   $\text{cm}^{-1}$ .

Due to the absorption of  $\text{CO}_2$  and water vapor all temperature spectra yield the temperature of the boundary layer of the atmosphere in the range  $650\text{-}700$   $\text{cm}^{-1}$  and at  $\nu > 1400$   $\text{cm}^{-1}$ . The emission peak at  $667$   $\text{cm}^{-1}$  is due to warm air at a small distance from the spectrometer. Besides the absorption and emission lines of water, an emission band caused by ozone can be observed ( $\nu = 1000\text{-}1070$   $\text{cm}^{-1}$ ).



**Fig. 6:** Temperature spectra of 1000 ppm m methanol in front of 5 different targets: 1: Brick wall facing south,  $d = 100$  m; 2: Brick wall facing west,  $d = 90$  m; 3: Forest,  $d = 1$  km; 4: Horizontal path (50% sky); 5: Sky at an angle of  $5^\circ$ . 1 scan,  $\Delta\nu = 0.5$   $\text{cm}^{-1}$ ,  $T_{\text{Mth}} = 24^\circ\text{C}$ .

As an example figure 6 shows spectra of 1000 ppm m methanol vapor at a temperature of  $T_{\text{Mth}} = 24^{\circ}\text{C}$ . The spectrometer was aimed at the same targets as in figure 5. An approximation of the temperature of the methanol vapor can be read off the spectra. It lies in the range of the temperature of the maximum absorption of the Q-branch at  $\nu = 1033 \text{ cm}^{-1}$  of spectrum 2 and the maximum emission of the same line of spectrum 3.

The best signal to noise ratio is obtained for the background with the highest temperature difference to the vapor. In the case of negative  $\Delta T$  (absorption), the brick wall facing south (spectrum 1 in fig. 5 and 6) which has been heated up by the sun yields the highest temperature difference. In the opposite case, the sky is the most suitable (spectrum 5 in fig. 5 and 6). The drawbacks of the sky as background for measurements are the presence of emission lines of water and ozone and the absence of a constant baseline. If topographical targets (spectra 1-3 in figures 5 and 6) are used as background for measurements, it is possible to analyze the spectra directly without a previously recorded background spectrum. The temperature spectrum has a constant baseline for these targets.

## 5. CONCLUSION AND SUMMARY

The signal to noise ratio of this chemical agent (CA) identification technique is a function of the following quantities:

- temperature difference  $DT$  between the CA cloud and the background
- mixing ratio of CA molecules in the field of view of the spectrometer
- noise equivalent radiation temperature  $NEDT$  of the spectrometer
- measurement time
- absorption coefficient  $\epsilon(\nu)$  of the CA molecules

While the number of molecules and their absorption coefficient are given by the specific application, the sensitivity can be improved by the other quantities. By optimizing the spectrometer, the  $NEDT$  can be decreased such that the sensitivity of the CA identification increases. The most important instrumental parameters, which determine the  $NEDT$  of an FTIR spectrometer, are the spectral resolution, the optical throughput (Etendue), the modulation efficiency of the interferometer, the transmittance of the optics and the detectivity of the IR detector.

For an individual measurement task, the sensitivity can be increased by the choice of the field of view of the spectrometer. The spectrometer can be aligned to targets which have a high temperature difference to the ambient air (e.g. a dark building warmed up by the radiation of the sun, a cold water surface of a pond or the cold background of the sky). By the adaption of a telescope the field of view can be decreased such that small objects which provide a high temperature contrast  $DT$  can be used to increase the signal to noise ratio.

If the (cold) sky is used as the background of the field of view the sensitivity is high, but the absorption path length for water and carbon dioxide increases. These compounds interfere with the identification of significant spectral features of the target compounds. Due to this fact it is advisable to use different fields of view in order to increase the probability of an automated identification.

By calculating the equivalent radiation temperature, a direct analysis of the measured spectra is possible. A previously measured background spectrum is not required. Quantification is possible in terms of the quantity concentration  $\times$  path length  $\times$  temperature difference ( $c d DT$ -value) if the transmittance is high. The quantity concentration  $\times$  path length, which is used to assess the risk in case of the release of a chemical agent, cannot be measured directly. However, it is possible to calculate a maximum concentration  $\times$  path length value if the equivalent temperature of the strongest absorption/emission line of the chemical agent is used to estimate the temperature difference between the chemical agent cloud and the background. The absolute value of the estimated temperature difference  $|DT_{est}|$  is always smaller than or equal to the real  $|DT|$ . Thus it is possible to calculate a maximum concentration  $\times$  path length value with  $|DT_{est}|$ .

Passive remote sensing is the only method, which allows standoff identification of chemical agents (CA) without an artificial light source. Moreover, this measurement technique allows mobile application (vehicles<sup>1</sup>, ships<sup>19</sup>, and aircrafts<sup>3,11</sup>

etc.) in combination with a fast identification of atmospheric pollutants. There is little maintenance of the instrument and the automatic identification software allows easy handling (visualizing, reporting, warning) for the operator. Thus, the passive remote sensing technique is a powerful tool for the observation of released hazardous chemical agents (e.g. for fire brigades, civil defense departments and environmental protection agencies), but also for chemical process control (e.g. CVD reactors and waste disposal reactors).

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