In-situ monitoring of water vapor and gas temperature in a coal fired power-plant using Near-Infrared Diode Lasers

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Abstract: We report approaches towards quantitative absorption spectroscopy under very low transmission conditions using base band diode laser modulation spectroscopy. Water absorption lines in the 800 nm region were used to derive number-densities and gas temperatures.

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1. Experimental Details

A very simple setup is used to perform in-situ measurements of water -vapor in the combustion chamber of a coal fired power plant. The beam of a Sharp FP-diode laser driven by the Melles Griot DLD06 was directed through the chamber and focused on a silicon detector by means of a gold coated mirror. We used a base band modulation scheme to determine line strengths in the 810nm region. Two overlapping transition bands (000→112 and 000→211) have their origin in this region. We used lines at 12295.6863 cm^{-1} and 12296.0585 cm^{-1} which could simultaneously be observed by modulating the operating current of the laser with a triangular function.

In this application (10 m path, 1100°C-1500°C, 10 Vol.-% H_2O) the peak absorption is about 2%. In addition to that severe and strongly varying interferences (like radiation emission, broad band absorption and scattering by dust and beam deflection by index of refraction fluctuations) are caused by the in-situ absorption path. They lead to transmission fluctuations which are by orders of magnitudes larger than the required absorption resolution. A narrow band filter was used to separate the laser light from thermal radiation. The signal was digitized by means of a 12-bit ADC. Model functions were fitted to the data after correcting for the stated interferences in order to derive density and temperature data.

2. Characterization of the optical path

Laser light that passes the combustion chamber in a coal combustion process is subject to very strong scattering. This is mainly due to the high content of solid particles in the flue gases as ashes and burning coal particles. There are very strong variations in the intensity of light reaching the detector. The intensity varied at frequencies up to kilohertz, while typical observed transmissions were in the 10^{-4} region. At some conditions overall transmissions of the in-situ path of only 10^{-6} were found. The contrast of detected laser light to specious thermal radiation was about 10. These are very poor conditions compared to those that were found in waste incinerators where thermal radiation was relatively small and transmissions of several 10 per cent were typical [1-4].

The detected signal during a short time interval is shown in the upper part of fig. 1. The very sharp spikes reflect the laser current modulation at 1 kHz. The intensity of the transmitted light changes drastically within few milliseconds. The thermal emission is considered to be constant on short time scales and is insinuated in the graph. The distribution of occurred transmissions is shown in the lower part of the figure.

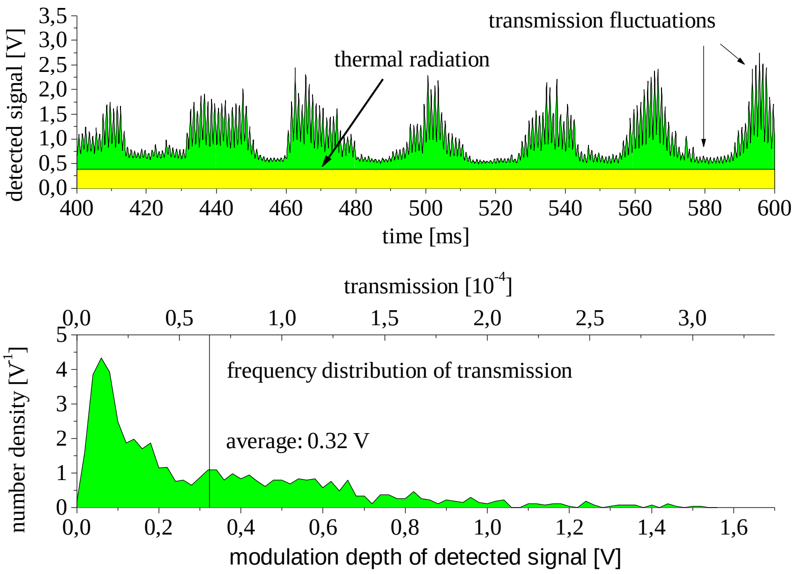

Fig. 1. Transmission properties of the optical path through the combustion chamber. See text for details.

3. Data analysis and results

The signal during a single modulation cycle is shown in fig. 2. It has been averaged over 20 cycles to increase the signal to noise ratio. The number of averaged cycles has to be much higher at lower transmissions to achieve the same signal quality.

The water-vapor absorption lines are so small that they can hardly be seen in the dc-signal. The absorption signal could be revealed at these very demanding conditions by correction for the modulation function and thermal radiation using a new data evaluation strategy. The level of background radiation as well as the laser intensity were derived from the modulation depth of the detected signal. The corrected data and the fitted line functions are shown in the lower part of the figure.

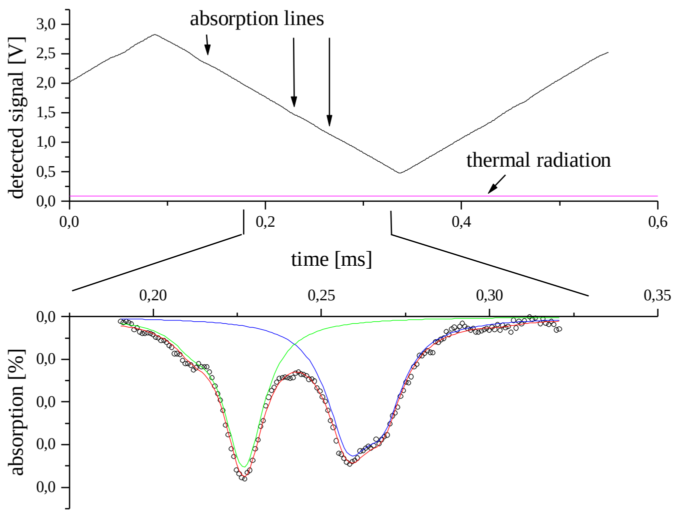

Fig. 2. Data analysis of the detected H_2O signal. Top: DC-Signal. Bottom: transmission corrected signal. See text for details.

Line parameters from the HITRAN compilation were used to obtain values for gas temperature and water-vapour concentration [4]. The line center positions could be used to determine the tuning rate of the diode laser, which is necessary to calculate the pressure independent integrated optical densities. The temperature was derived from the line-strength ratios. The water-vapour number densities were calculated using the isolated absorption line on the left in fig. 1 which is almost temperature independent between 1200 and 1400 Kelvin.

The time evolution of the in-situ H_2O and temperature signal over 4 hours is shown in figure 3. There is a definite correlation between our data and the process parameters. The H_2O number density increased when the coal feed was decreased. This could be due to a pure temperature effect as the density increases at lower temperatures. Temperature changes of about 150 Kelvin would explain the observed variations. In contrast, there is no evidence of this effect in our temperature data. Instead, there is a correlation between temperature and NO_2-concentration which is very temperature sensitive. Further investigation of correlation between these process parameters will be persued.

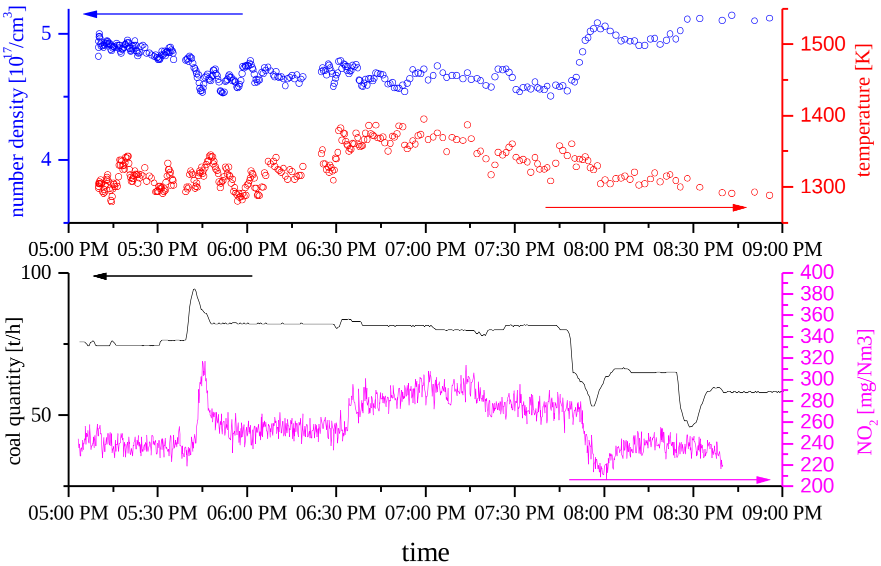

Fig. 3. Time evaluation of the in-situ signals. Top: H_2O concentration and gas temperature. Bottom: coal feed and NO_2 concentration.

4. Conclusions

It has been shown that even under very low transmission conditions (10^{-4} range), high background radiation and strong transmission fluctuations wavelength modulation spectroscopy can be used to quantitatively determine water vapor concentration and gas temperature using a simple base band modulation scheme combined with a new data evaluation strategy. In-situ water vapor and temperature data could be obtained in a 4 hour run in a full scale coal fired power plant and could be correlated to simultaneously gathered process parameters. In spite of transmissions as low as 10^{-4} a fractional absorption resolution of 10^{-3} was achieved with a time resolution of 10 seconds.

5. References

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