

In situ Measurement of CO, H₂O and Gas Temperature in a Lignite-Fired Power-Plant

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Abstract:

A diode laser based *in situ* absorption spectrometer is presented for the simultaneous detection of CO (1560nm), water (813nm) and the gas temperature within the combustion chamber of a 600MW lignite-fired power-plant. A fractional absorption resolution better than 10⁻³ equivalent to a few hundred ppmV CO could be demonstrated with a 30 sec time response.

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1. Introduction

CO is an important indicator of combustion efficiency. High CO concentrations are responsible for corrosion damages or reduction of the service life of power-plants. We realized an *in situ* CO-spectrometer in a 600 MW lignite fired power-plant by using base band diode laser modulation spectroscopy in the near infrared (NIR). In addition we measured the water vapor concentration to account for possible water interference and to determine the gas temperature by means of two-line thermometry [1,2,5]. Pyrometric temperature data were recorded for comparison with the water vapor temperature. The pyrometric data were used to evaluate the presented results. The spectroscopic data of water vapor absorption are under way.

2. Line selection

Two vibrational overtone bands of CO are relevant for NIR diode laser experiments. The first band can be used with recently developed diode lasers near 2.3 μm [3]. However it is very difficult to obtain suitable single mode lasers due to the limited supply. The line strengths of the second overtone band in the 1.56 μm region are about 100 times weaker. In addition, there is a strong interference from H₂O and CO₂ absorption. However, suitable lasers are commonly available and rather inexpensive. From Hitran'96/Hitemp data [4] we find that the R24 transition at 6412 cm⁻¹ is fairly well isolated from neighboring H₂O and CO₂ absorption lines. Figure 1 shows the calculated spectrum for typical conditions in a lignite combustion.

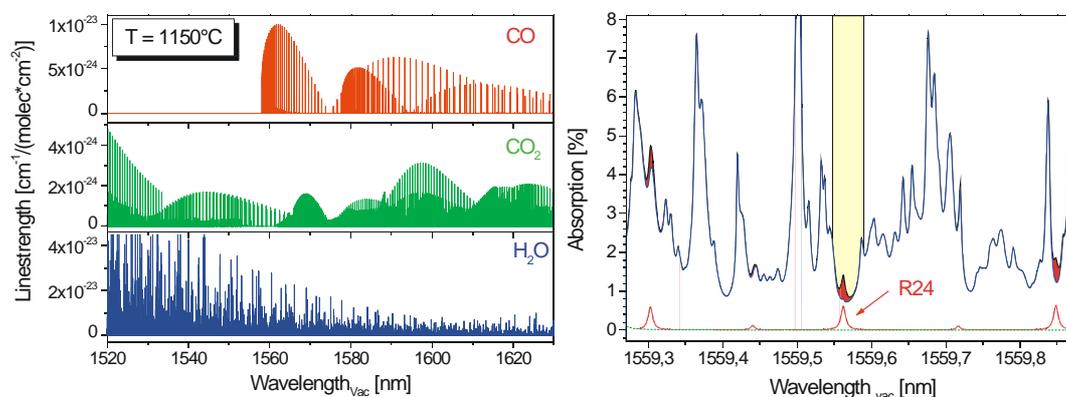


Fig. 1: Left: Line strengths of CO, CO₂ and H₂O in the 1560 nm region at T = 1150 °C (HITRAN'96/HITEMP). right: calculated spectrum for 0.5% CO, 10% H₂O and 10% CO₂ at T = 1150 °C, P = 1 atm, L = 13 m. The R24-transition is most suitable for *in situ* CO detection. The highlighted region indicates the tuning-depth (by modulating the injection current) of the used diode laser.

2. Experimental details

The experimental setup for the *in situ* measurement within the combustion chamber of the power-plant is relatively simple. The beams of a single mode FP-diode laser at 813 nm and a fiber coupled DFB-diode laser at 1.56 μm were closely overlaid -with a spatial distance below 20 mm- and directed through the combustion chamber via a single 25mm mirror. A small fraction of the laser light was separated by a beam splitter and directed through a reference cell filled with pure 100% CO. The reference signal was used to temperature tune the laser to the desired absorption line. The transmitted laser light was collected with a spherical mirror and separated into the two individual wavelengths by a dichroic beam splitter. Optical narrow band filters in front of the silicon and the InGaAs detectors simultaneously suppressed the strong thermal background radiation and minimized crosstalk between the two wavelength channels. A 12bit/5Msample ADC-board digitized the photo detector signals which were then evaluated with a computer. To align the setup under combustion conditions and to direct the invisible laser beams across the combustion chamber onto the detectors at a distance of 14 m we developed a new automatic alignment and beam stabilization arrangement based on a motorized θ -mirror. This new device which is based on the setup presented in [5] is able to cope with highly luminous combustion conditions and severe losses in laser power.

3. Data analysis and results

On its way through the combustion chamber the laser light is severely attenuated by broad band absorption and scattering due to coal or ash particles leading to a power loss in the *in situ* path in the order of 99,9% and more. In addition there is -despite the use of narrowband filters- a time dependent background of thermal radiation which is more than two times higher than the detected laser light. Although the transmission fluctuations are much stronger than the specific absorption of the CO molecules we manage to eliminate these disturbances with the help of rapid tuning capabilities of the laser and the direct (base band) detection of the absorption signals.

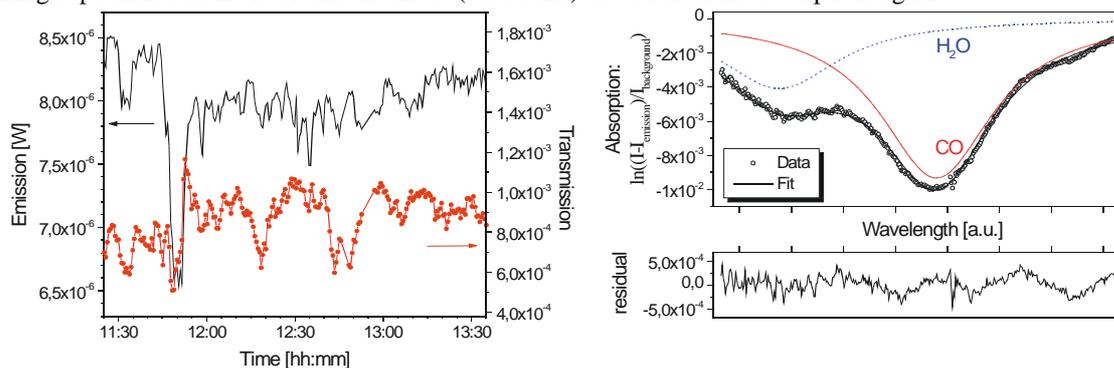


Fig. 2: Left: Time evolution of thermal background emission and transmission of in situ path. Right: In situ absorption signal corrected for thermal radiation and transmission (averaged over 30 seconds). Two lorentzian profiles are fitted to the data to describe the absorption of CO (right) and H₂O (left).

The laser wavelength was tuned over the selected absorption lines by a triangular current modulation at 5 kHz. Due to the fast modulation the thermal emission and the transmission of the in situ path is considered to be constant over a modulation period. This assumption is verified by an analysis of the frequency spectrum of the emission and the transmission, which shows a strong decrease of the disturbances at higher frequencies. Hence, the fraction of the detector signal that is due to thermal emission can be derived by evaluating the modulation depth of the laser light, whereas the transmission is determined by fitting the background signal. The noise level on the absorption signal was decreased further by reducing the bandwidth by averaging subsequent scans over 30 seconds. The left graph in figure 2 shows the temporal behaviour of thermal emission and transmission of the *in situ* path over 2 hours.

For transmission correction the averaged raw signal is separated into specific absorption and background. Contributions to the background come from laser intensity modulation, wings of neighboring absorption lines, wavelength dependence of optical filters and transmission perturbations in the order of a few kHz and above. The right graph in figure 2 shows an averaged scan after subtraction of the thermal emission offset and after division by the background. We used a 3rd order polynomial fit to describe the background and two lorentzian profiles to fit the

absorption lines of CO and H₂O. The integrated area of the line profile is proportional to the number density according to Lambert-Beer's law.

Figure 3 shows for the first time the time evolution of the *in situ* CO concentration in such a large power-plant with such severe transmission and emission disturbances. The increase in CO between 12.30 pm and 12.45 pm has been created intentionally by an increase in the fuel to air ratio via a modification in the air supply.

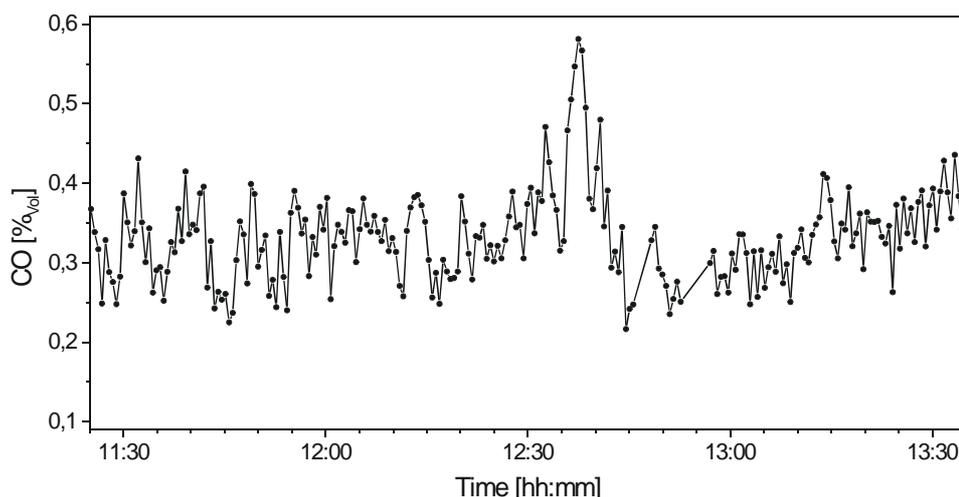


Fig. 3: Time evolution of CO concentration. The time resolution is about 30 seconds. The rise of the CO concentration at $t=12:30$ to $12:45$ is caused by an intentional increase in the fuel to air ratio.

4. Conclusions

In situ measurements of CO and H₂O concentrations and gas temperature could be performed in a 60 hour run in a full scale lignite-fired power-plant. The transmission across the combustion chamber was in the order of 10^{-3} of the initial laser power. Despite the use of narrow band filters we found a strong background radiation which was higher than the collected laser light. Nevertheless we achieved a fractional absorption resolution of better than 10^{-3} with a time resolution of 30 seconds. This is equivalent to a resolution in CO concentration of a few hundred ppm_{Vol}. Especially helpful was a new automatic alignment setup based on a motorized mirror mount, which was able to align laser and detector within a few minutes even at zero visibility along the beam path. The spectrometer is easily extendable to other species like O₂, NH₃, HCl, HF etc. by a simple change of the laser diode and therefore has the capabilities to become a rather universal tool for industrial *in situ* gas analysis in advanced combustion control applications.

5. References

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