

High temperature in-situ IR laser absorption CO-sensor for combustion control

A.J. Faber and R. Koch
TNO Institute of Applied Physics,
Eindhoven, NL

Abstract

In view of improved control of the combustion process in e.g. industrial glass furnaces, accurate in-situ CO-gas sensors are required. With help of reliable in-situ gas sensors, burner control can be optimised. By better burner control, NO_x emissions can be reduced and the radiative heat transfer from combustion chamber to the glass melt and thus the energy efficiency of glass furnaces can be improved.

Currently, for continuous monitoring of the combustion process of glass melting furnaces, solid state oxygen (ZrO₂ /Pt) sensors are used, occasionally. In order to avoid post-combustion in the exhaust of glass furnaces, there should be sufficient oxidant, air or oxygen, to assure complete combustion. However, large air excesses lead to reduction in the thermal efficiency of the furnaces and promote NO_x formation. The residual oxygen concentration in the exhaust gases partly indicate the completeness of the combustion process. However, especially at near- or under-stoichiometric combustion conditions, oxygen measurement in the flue gasses downstream is less suitable for accurate burner control. In-situ CO detection in burner ports at 1400 – 1500 °C, when possible in combination with NO_x, is a better and more sensitive method for optimisation of the combustion process.

For this purpose the following measuring techniques can be considered:

- solid state CO-specific sensors;
- on-line UV emission spectroscopy;
- IR diode laser absorption spectroscopy

No CO-specific solid state sensors are available which can withstand the high temperatures near the flames of about 1400 – 1500 °C.

UV emission spectroscopy of flames offers the possibility to detect the presence of radicals like OH and CH in the flames, however the correlation to CO- and NO_x-levels in the combustion atmosphere is uncertain. The principle of continuous CO-detection with IR laser-absorption techniques in hot flue gasses has been demonstrated in a feasibility study, carried out by TNO in the past.

A major obstacle for practical implementation of the technique, developed in this study, was the technically complex and very expensive IR equipment (nitrogen-cooled laser and detector equipment between 4.5 and 5 μm).

Therefore, the possibility for CO-detection at other (weaker) absorption lines of CO in the near infra red (between 1.55 and 1.6 μm) is under study now. In this spectral region relatively cheap optical components are available, which are used for optical telecommunication (diode lasers, fibre optic components, detectors).

Using the well-known HITRAN database, several CO-absorption bands between 1.55 and 1.6 μm have been identified.

Currently, the attainable accuracy of this method and the interference with other high temperature absorption bands (of H₂O and CO₂) are being examined. In the paper recent experimental results will be presented.

Introduction

For continuous monitoring of the combustion process of glass melting furnaces, oxygen (ZrO_2/Pt) sensors are used, occasionally. In order to avoid post-combustion in the exhaust of glass furnaces, there should be sufficient oxidant, air or oxygen, to assure complete combustion. However, large air excesses lead to reduction in the thermal efficiency of the furnaces and promote NO_x formation. The residual oxygen concentration in the exhaust gases partly indicate the completeness of the combustion process. However, especially at near- or under-stoichiometric combustion conditions, oxygen measurement in the flue gasses downstream is less suitable for accurate burner control.

In-situ CO detection, when possible in combination with NO_x , is a better and more sensitive method for optimisation of the combustion process. In this paper, the possible methods for CO/ NO_x -monitoring and the advantages and disadvantages of these methods will be reviewed. Recent results of ongoing research at TNO will be presented.

Review of in-situ CO monitoring techniques

In view of improving combustion control by in-situ monitoring of CO, the following measuring techniques can be considered:

- solid state CO-specific sensors;
- on-line UV emission spectroscopy;
- IR diode laser absorption spectroscopy

1. Solid state CO specific sensors

One of the possible methods for in-situ monitoring of combustion gases is based on electro-chemical sensors for CO, analogous to the ZrO_2/Pt oxygen sensors. However, the application of this kind of sensors in the glass industry is limited by the high temperature levels (1400 - 1500 °C) in the flue gases of melting furnaces. Currently available electrode materials for CO detection (perovskites and Ga-oxides) can not withstand long-term exposure to temperatures higher than 800 °C.

It has been proposed by Hemmann (1998) to derive CO-concentrations for near-stoichiometric firing and reducing combustion conditions from the mV-signals of a ZrO_2 -oxygen sensor, assuming thermodynamic equilibrium between CO and O_2 . The disadvantage of this approach is that the oxygen sensor will only provide a local measuring value of the flue gas redox state, downstream in the flue gas channel. When the flue gases are not well-mixed or when gas temperatures vary, shifts in the local redox equilibrium will occur, preventing a direct correlation between the oxygen sensor signal and burner stoichiometry.

2. On-line UV- flame emission measurements

A spectroscopic method for monitoring and control of burners makes use of the spectral emission of a flame, especially the radiation of radicals which are formed in the flames, such as OH^\cdot , CH^\cdot , CN^\cdot and C_2 radicals. The spectral emission of these components appear in the UV-domain, especially at wavelengths < 500 nm.

In figure 1 the emission spectra of an oxy-fuel flame are shown under different stoichiometric conditions. In this figure the effects of varying the oxygen supply on the intensity of the CH-emission bands (around 460 nm and 510 nm) can be observed clearly. In principle, these emission bands can be used for monitoring of the combustion process. Continuous measurement of the spectral emission can be realised by a fibre coupled to a burner and a PC with a spectrometer, as proposed by Von Drasek (1998). In combination with a control unit, this system could be used to adjust the burner settings. However, it is still uncertain how well the flame emission spectra correlate to the amount of NO_x , formed under varying combustion conditions.

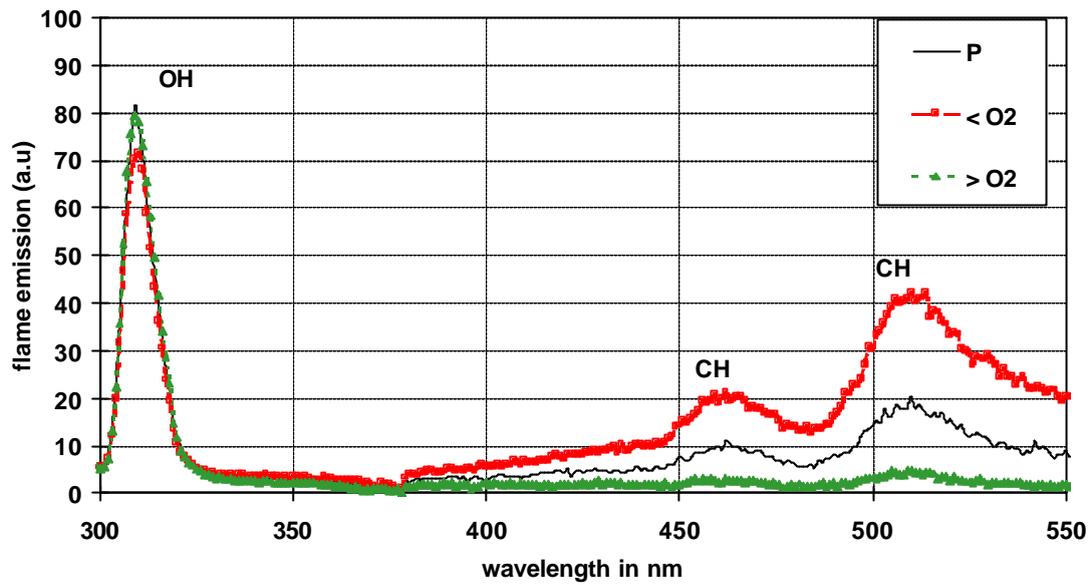


fig. 1 Emission spectra of oxy-fuel flame under different stoichiometric conditions (“P” corresponds to initial burner settings; “< O₂” to reduced oxygen supply and “> O₂” to an increased oxygen supply to the burner)

3. IR diode laser absorption spectroscopy

The principle of continuous CO-detection with IR laser-absorption techniques in hot flue gasses has been demonstrated in a feasibility study, carried out by TNO in the past (Faber, 1999). Figure 2 presents a drawing of the equipment for this method, installed at a glass furnace.

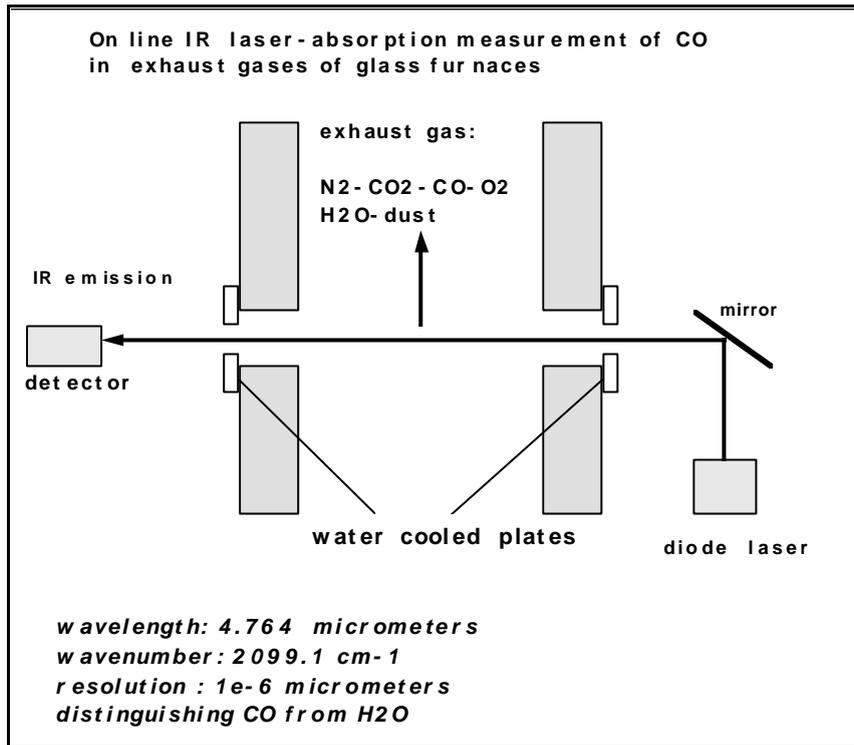


Fig. 2 Measuring configuration for on-line analysis of CO concentration in exhaust of glass furnace

Measurements have been carried out on both laboratory and industrial scale and were compared to CO-analysis by IR spectroscopy in the extracted exhaust gases. Figure 3 shows a comparison of the results of both methods.

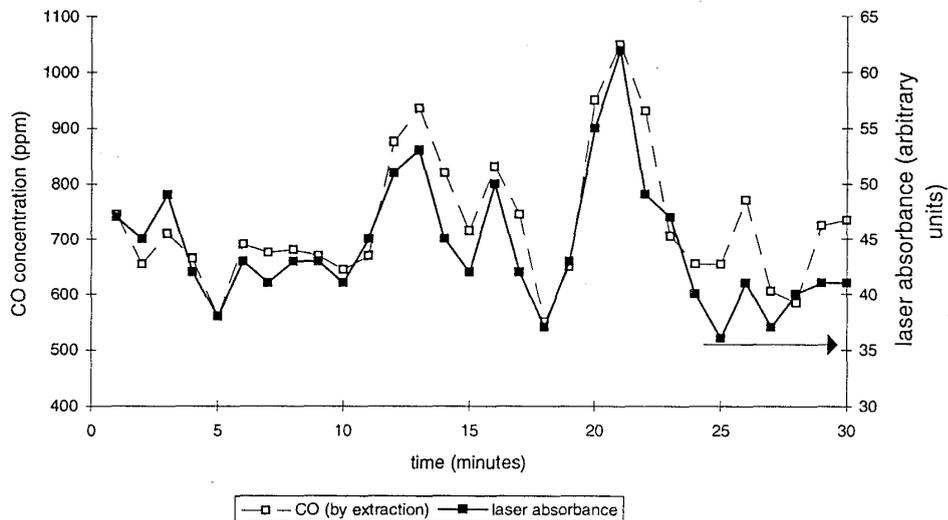


Fig. 3 Comparison of in situ CO monitoring by IR laser absorption and by extractive sampling, followed by IR gas analysis

A major obstacle for practical implementation of the technique, developed in this study, was the technically complex and very expensive IR equipment (nitrogen-cooled laser and detector equipment between 4.5 and 5 μm).

Therefore, the possibility for CO-detection at other (weaker) absorption lines of CO in the near infra red (around 1.5 -1.6 μm) is under study now. In this spectral area relatively “cheap” optical components are available, which are used for optical telecommunication (diode lasers, fibre optic components, detectors). Using the well-known HITRAN HITEMP database, several CO-absorption bands between 1.55 μm and 1.60 μm have been identified.

Currently, the cross interference with other absorption bands (of H_2O and CO_2) and the attainable accuracy of this method are being examined at TNO.

Experimental

The high temperature experimental set-up which is used to study the absorption bands of combustion gases and to identify isolated CO absorption peaks in the NIR is presented schematically in fig. 4. The tube furnace in this set-up contains a transparent fused silica tube through which a CO-containing gas mixture can be flushed and also mixtures of the other combustion gases (CO_2 or H_2O in combination with N_2).

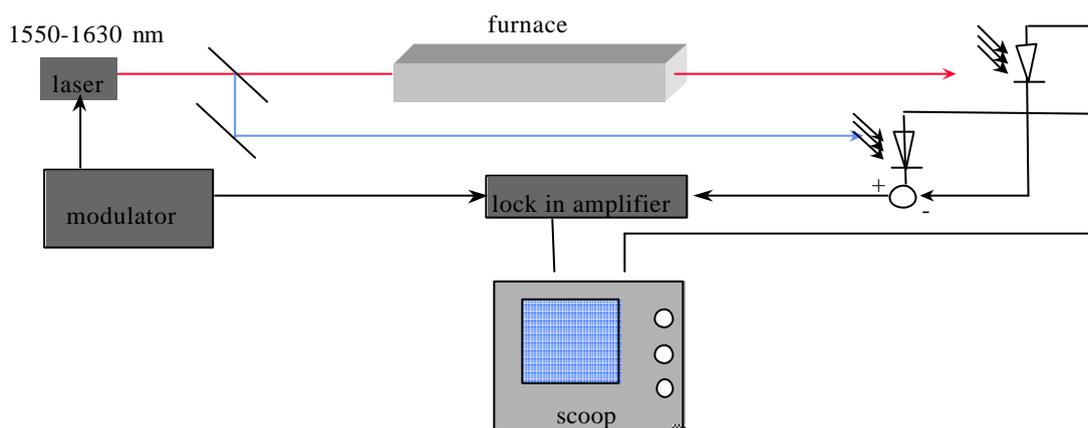


Fig. 4 High temperature experimental set-up to identify suitable CO -absorption bands for an IR-laser CO sensor

As a result of the applied modulation and lock-in detection technique, the second derivative of the gas absorption spectra is measured. Some typical results are presented in fig. 5, showing 3 high temperature (1400 $^{\circ}\text{C}$) absorption spectra between 1590 and 1592 nm of mixtures of N_2 with the following 3 relevant gases: CO, CO_2 and H_2O -vapour, respectively.

In the plotted CO spectrum two absorption peaks at 1590.5 nm and at 1591.9 nm are visible. Furthermore, a lower frequency background signal is visible, due to experimental disturbances, including laser instabilities. The corresponding CO_2 -spectrum has no pronounced absorption peak around 1591.9 nm; the H_2O -absorption spectrum however, seems to have a peak very close to the CO peak around 1591.9 nm.

By this kind of spectral analysis, a few isolated CO absorption peaks in the spectral region 1550 - 1630 nm have been identified. Currently, the sensitivity of the method at the selected CO wavelengths is being studied by flushing the cell with low-concentration CO/ N_2 -gas mixtures (CO-levels in the order of 100 vppm to a few %).

Concluding remarks

Reviewing potential in-situ gas analysis techniques for improving combustion control, it is concluded that optical methods can provide the most reliable, non-invasive gas sensor types.

A (near-)IR diode laser absorption technique for in-situ CO-detection in the hot combustion gases is considered to provide the most sensitive monitoring technique in view of reducing NO_x emission from glass furnaces.

Current research at TNO TPD is directed at identifying suitable high temperature CO absorption peaks, non-overlapping with CO₂ and H₂O bands, in the spectral region around 1.6 μm.

It is envisaged that a prototype CO laser sensor can be built and tested in the near future, probably in co-operation with a sensor supplier.

References

Faber, A.J., van Limpt, H., Koch, R., High temperature sensors for glass furnace combustion chambers, Proc. 5th ESG Conference, Glass Science and Technology in the 21st Century, June 21 - 24, 1999, Prague, p. 26 (Book of Abstracts)

Hemmann, P.: Lambda-Regelung mit Zirkonoxidsonden im unterstöchiometrischen Bereich, Kurzreferate 72. Glastechnische Tagung DGG, 25 - 27 May, 1998, Münster

Von Drasek, W., Philippe, L., Grosman, R., Pascal, A., Oxy-fuel Burner Control Strategy Using Optical Sensors, Proc. XVIII Int. Congress on Glass, July 5 - 10, 1998, San Francisco

Fig. 5: Absorption spectra at 1400 °C of mixtures of N₂ and 40% CO, 40% CO₂ and 60% H₂O, resp., in the region 1590 – 1592 nm (optical path length is 30 cm)

