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SPECTRAL AND TIMERESOLVED RADIATION MEASUREMENTS IN A MODEL GAS TURBINE COMBUSTOR

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BREAK

ABSTRACT

In the context of an extensive experimental investigation of the turbulent, reacting flow in a model gas turbine combustor, the radiation emitted by the confined three-dimensional turbulent propane/air diffusion-flame has been studied. The present study comprises for the first time spectral and time-resolved measurements of the radiative intensity at different axial locations including the reaction zone, the mixing zone and the exit of the model combustor. The radiation measurements are presented together with measurements and CFD-calculations characterizing the reacting flow field. This data set is well suited for the validation of CFD-calculations including radiative heat transfer and also for studying the interaction between turbulence and radiation.

NOMENCLATURE

$C_{spec,\lambda}$	spectroscope constant $[W/(Vm^3sr)]$
$I_{\lambda,n}$	normal monochromatic radiative intensity $[W/(m^3sr)]$
$I_{\lambda,b}$	monochromatic radiative intensity of a blackbody
$\bar{I}_{\lambda,n}$	mean normal monochromatic radiative intensity
p_{CO_2}	partial pressure of CO_2 [bar]
N	sample size
t	time [s]
T	temperature [K]
U_0	detector output voltage [V]
$\sqrt{\bar{u}'^2}$	RMS-value of the velocity [m/s]
z	axial coordinate [mm]
Φ	equivalence ratio
φ	angle between injection and measurement plane
λ	wavelength [m]
$\sigma(I_{\lambda,n})$	standard deviation of radiative intensity $[W/(m^3sr)]$
$\sigma^*(I_{\lambda,n})$	degree of radiative fluctuations

INTRODUCTION

It is well-known that especially in jet-engines a considerable part of the heat load of the combustor liner is caused by radiation. Generally, the ratio of radiative to convective heat transfer is augmented in modern gas turbine designs, because higher pressure and temperature levels are encountered. Thus, detailed knowledge of radiative heat transfer in gas turbine combustors is one of the major issues for the optimization of advanced design concepts.

In combustion systems like gas turbine combustors, the radiative heat transfer between the hot reaction zone and the combustor walls is of major importance. The radiation exchange is determined primarily by the temperature field and by the concentration distribution of soot and combustion gases (CO, CO_2, H_2O), but also their radiative properties and those of the combustor wall material are important. These different aspects of radiative heat transfer are reviewed comprehensively by Viskanta and Mengüc (1987).

By now, there are quite a lot of advanced methods available for calculating the radiative transfer in combustion systems. These include models for gaseous radiation (Ludwig et al. 1973), (Koch 1992), soot (Koch 1992), and the methods for the solution of the radiative transport equation (RTE) in multi-dimensional geometries (Truelove 1988), (Koch et al. 1993). Some of these computational methods have been verified in sooting and non-sooting flames and for different

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fuels (Grosshandler 1976), (Wachter 1993). The application of such methods to a detailed numerical calculation of the radiative heat transfer in gas turbine combustors has been demonstrated by us recently (Koch 1992). Thus, from the theoretical point of view, most of the basic phenomena of radiative transfer in combusting systems are quite well understood.

However, no complete experimental dataset including the flow field, the temperature field, the distribution of species concentration and the radiative heat transfer has been published until now. Thus, the validation of the computational methods for radiative transfer under real combustor conditions is still uncomplete. Furthermore, the interaction between the radiative heat transfer and the turbulent, reacting flow, leading to radiation fluctuations has only been studied theoretically (Song and Viskanta 1987) and experimentally (Sivathanu et al. 1991) for special cases. However, regarding the high turbulence levels in gas turbine combustors, this issue is of major importance.

In the context of an extensive experimental investigation of the turbulent, reacting flow in a model gas turbine combustor, detailed spectral and time-resolved radiation measurements have been carried out at the Institut of Thermische Strömungsmaschinen at the University of Karlsruhe. These radiation measurements will be presented in this paper together with the corresponding measurements and CFD-calculations characterizing the reacting flow field. This dataset is well suited for the verification of numerical radiative heat transfer calculation. Furthermore, on basis of the time resolved radiation measurements, a detailed analysis of the interaction between the radiative heat transfer and turbulence will be presented for the first time. These results give a better insight in this phenomena under typical combustor conditions.

Moreover, a simple, easy-to-use method for the temperature determination from spectral radiation measnrements will be presented and discussed. This method is applicable even in non-homogeneous, non-isothermal combustor flows. Therfore, it can serve for the examination of thermocouple measurements and for the selection of suitable thermocouple temperature corrections accounting for the radiation losses.

FLAME CHARACTERIZATION

The full description of the model combustor, the different measuring techniques and the complete presentation of the data is given by Jeckel and Wittig (1993). Therefore the description of the model combustor and the flame characterization will be kept briefly. The size and the geometry of the model combustor and the flow pattern are shown in figure 1.

A three-dimensional confined turbulent diffusion flame is induced by four radial injecting air jets and propane which is injected at the nozzle plate. The mass-flow of propane is 1 kg/h and the mass-flow of air is 33.5 kg/h resulting in a low overall equivalence ratio of $\Phi = 0.44$. Approximately half of the injection air flows upstream forming a recirculation zone

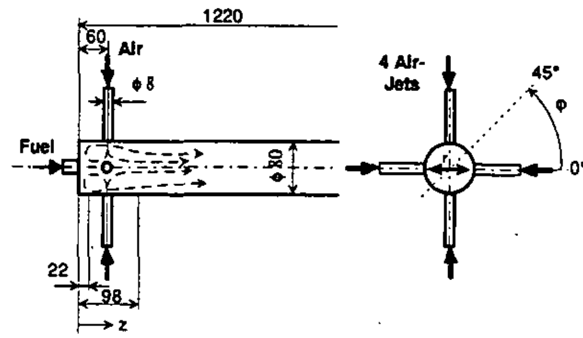

Figure 1: Geometry of the model combustor

in which most of the combustion reactions take place. The size of the recirculation zone is determined by the distance between the nozzle plate and the the air-injection jets. Since these air-injection jets are located at discrete angular locations, a three-dimensional flow field is expected. However, due to highly turbulent mixing, no dependence on the circumferential coordinate φ (Figure 1) has been observed experimentally. Therefore, the measured velocity distribntion (LDA), the temperature distribution (thermocouples - the results are not corrected to account for radiation losses) and the distribution of the concentration of combustion gases (probe measurements) are only represented by values of injection angle $\varphi = 0°$ (see Figure 1).

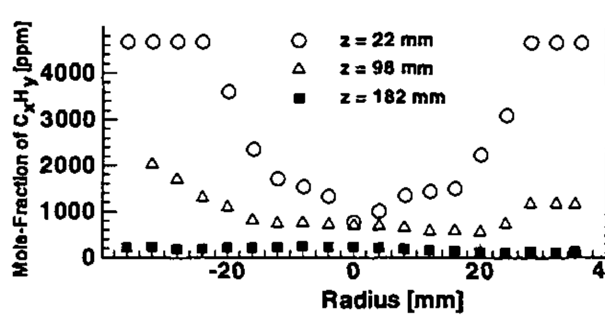

Figure 2: Measured profiles of the mole fraction of unburned hydrocarbons $\varphi = 0$

The solid lines in Figures 3 represent results of onr CFD-calculations (Kurreck et al. 1993) performed by a Finite-Volume Code, developped at the ITS, using the standard $k-\epsilon$ model to represent turbulence and the eddy-dissipation approach (Magnussen and Hjertager 1977) to account for turbulent reaction kinetics. Almost everywhere a good agreement between measurement and prediction has been obtained. However, the highest values of the temperature in the reaction zone do not match. One reason which can be put forward is that the temperatnres measured by thermocouples are not corrected for radiation losses which are a major source of errors in high temperature environment. This point will be considered in more detail in section 5.3.

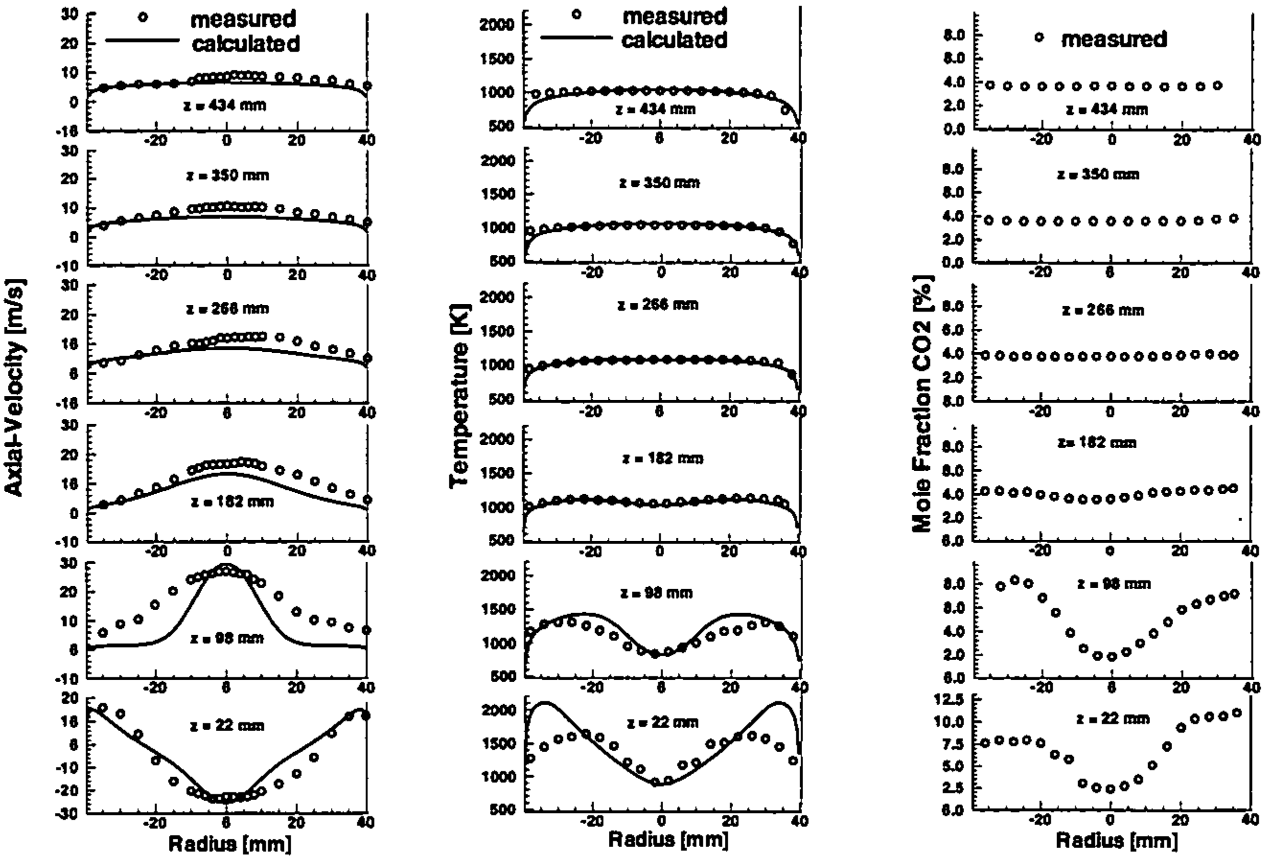

Figure 3: Measured and calculated profiles for $\varphi = 0$

RADIATION MEASUREMENT TECHNIQUE

The emission spectroscopy technique has been applied to tbe investigation of radiative beat transfer towards the combustor walls. In order to avoid radiation emitted by the opposite combustor wall, the walls of tbe combustor are cooled by water to ensure a low wall temperature $\bar{T}_w$ which was measured to be 350 K. In addition, due to tbe well-known low wall temperature, well-defined boundary conditions for both radiative and convective heat transfer bave been obtained. Tbe emission spectroscopy technique is best explained refering to Figure 4.

The spectral radiation directed normally to tbe combustor wall is characterized by tbe normal spectral radiative intensity $I_{\lambda,n}$. It is obtained experimentally by

$$I_{\lambda,n} = U_0 * C_{spec,\lambda} \tag{1}$$

wbere U_0 is tbe detector output voltage and $C_{spec,\lambda}$ is the spectroscope constant of tbe optical arrangement. Tbe spectroscope constant depends on the wavelength of the detected radiation and on tbe optical viewpatb including all losses of the different optical components. It was determined experimentally by calibrating the optical arrangement by means of the black-body source.

Switching between the black-body source and the flame inside the model combustor is achieved by a plane mirror rotated by a stepper motor. Gold coated mirrors have been applied to obtain wavelength independent optical projection properties. Tbe IR-radiation entering the IR-spectroscope is focused by 'Double Cassegrain' optics which have excellent projection characteristics. Tbe radiation is spectrally dispersed by a grating monochromator. The different spectral resolutions selected for the present investigation are listed in table 1.

axial position	$\lambda \leq 2.8\mu m$	$\lambda > 2.8\mu m$
$z = 22mm$	$25nm$	$35nm$
$z = 98mm$	$25nm$	$35nm$
$z \geq 182mm$	$30nm$	$70nm$

Table 1: Selected spectral resolutions of the different radiation measurements

After passing a chopper, the signal is focused on an InSb-

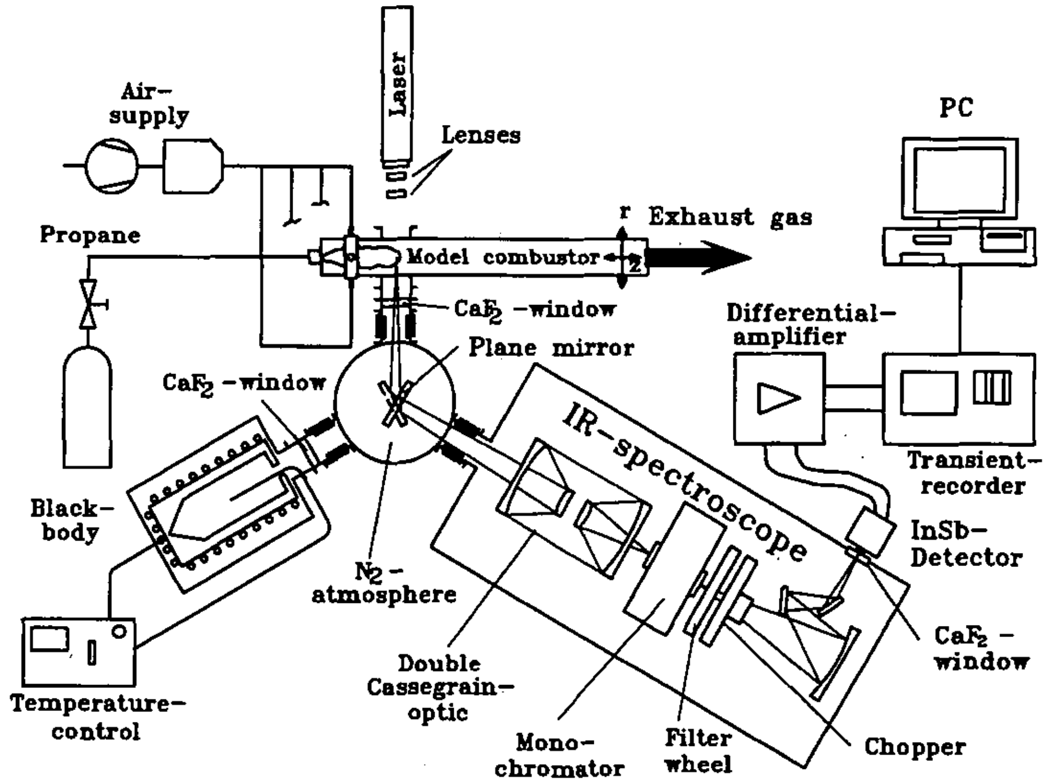

Figure 4: Schematic of the experimental facility showing the symmetric arrangement of IR-spectroscope, blackbody and model combustor

detector (InfraRed Associates) which enables highly time-resolved measurements and high signal noise ratios up to 1000. The detector output is amplified by a differential amplifier, which is powered by a battery pack, and then digitized by a transient recorder. The recorded data were transferred via IEC-Bus to a personal computer.

For a proper calibration of the optical arrangement, the following conditions have to be fulfilled :

1. The optical viewpath for both radiation emitted by black-body and the flame must be the same.
2. Reabsorption of incident radiation due to CO_2 and H_2O must be avoided in the whole measuring device.
3. The size of the probe volume of the spectroscope must be smaller than the optical access to the flame or to the black-body.

Condition 1 is fulfilled by arranging the black-body, the model combustor and the IR-spectroscope on an equal-sided triangular as shown in Figure 4. To account for condition 2, the whole optical arrangement including the black-body source was purged by N_2 in order to avoid reabsorption of the radiation by CO_2 and H_2O. To separate this 'clean' environment from the combustion gases inside the model combustor, a CaF_2-window was used, which was scavenged by air on the combustor side. This scavenging air should keep the window clean and avoid an accumulation of the combustion gases in the small side-chamber between the window and the combustion chamber. However, the mass flow of scavenging air was kept as small as possible to avoid perturbations of the flame. The CaF_2-window in front of the black-body serves as reference. Condition 3 is ensured by a proper selection of the optical components and their arrangement. It has been verified by several tests.

For adjusting the whole optical configuration, a laser source was placed on the opposite side of the model combustor. The measuring location (the distance z of the measuring plane from the nozzle plate) was changed by transversing the model combustor as indicated in Figure 4 instead of transversing the whole optical device.

RESULTS

Due to the strong turbulence of the flame, high fluctuations of the radiative intensity have been observed at all measuring locations. The fluctuations of radiative intensity result from both the fluctuations of temperature and the fluctuations of the concentration of radiating species (CO_2, CO, H_2O).

A typical example of a time-resolved signal of the spectral

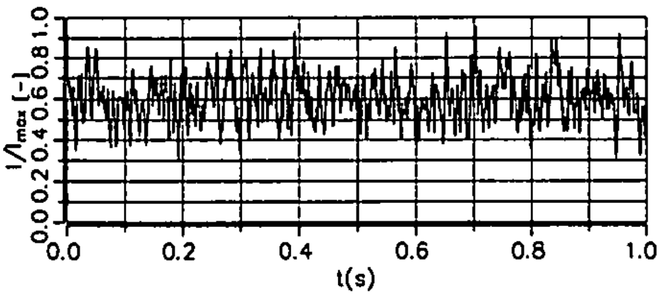

Figure 5: Time-resolved measurement of the spectral radiative intensity $I_{\lambda,n}$ at $\lambda = 4.39\mu m$ (CO_2-band radiation) and $z = 22mm$

intensity ($\lambda = 4.39\mu m$) measured in the reaction zone (at $z = 22mm$) is shown in Figure 5. The fluctuations can yield more than 30% of the average value. A rigorous analysis of turbulent fluctuations of radiative intensity however, is beyond the scope of this paper and is postponed to further research studies. Therefore, in the following, the fluctuating spectral radiative intensity is represented by its mean value and its standard deviation formulated by equation 2 and 3 respectively :

$$\bar{I}_{\lambda,n} = \frac{1}{N}\sum_{i=1}^{N} I_{\lambda,n,i} \tag{2}$$

$$\sigma(I_{\lambda,n}) = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(I_{\lambda,n,i} - \bar{I}_{\lambda,n})^2} \tag{3}$$

For the present investigation, the sample size N was limited to 700 due to time consumption of data processing. For this sample size a statistical error up to 8% has been derived by statistical analysis. This is also confirmed by tests of the reproducability of the mean values. By application of a FFT-analysis to the measured signals it was found that a sampling rate of 600 $1/s$ is best suited to account for all existing turbulent time-scales in the flame. Under these conditions, the mean value of the spectral radiative intensity is identical to the time-averaged value.

In the following, the analysis of the radiation measurements is divided into three subsections. In the first subsection, the time averaged radiation spectra recorded at different locations will be discussed. In the second subsection, the standard deviation of the radiative intensity and its interrelation to turbulence will be investigated. The objective of the third subsection is a comparison of the measured to calculated spectra of the CO_2-band leading to a technique for the determination of the maximum temperature.

Radiation Spectra - Time-averaged Values

The spectra of the time-averaged radiative intensity emitted by the reaction zone ($z = 22mm$) and the mixing zone ($z = 98mm$) are plotted in Figure 6. Due to the lean combustion conditions, no soot radiation has been observed and

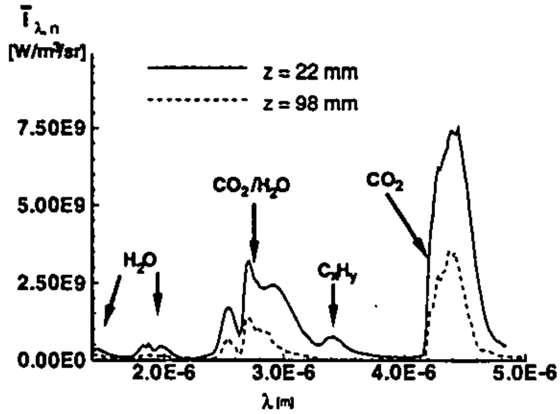

Figure 6: Spectra of the mean radiative intensity at different axial locations ($z \leq 98mm$)

only the typical radiation bands of combustion gases have been found. The very high temperatures and the relatively high concentrations of reaction products CO_2 and H_2O in the upper recirculation zone ($z = 22mm$) are responsible for the high radiative intensity at this location. In this upper recirculation zone, additionally radiation emitted by unburned hydrocarbons has been detected, indicating the non-completed reaction at this location. Considering Figure 6, it can be pointed out that with raising temperatures not only the maximum value of the radiative intensity increases but also the radiation bands are broadened. This well known phenomena plays a key-role in subsection 5.3.

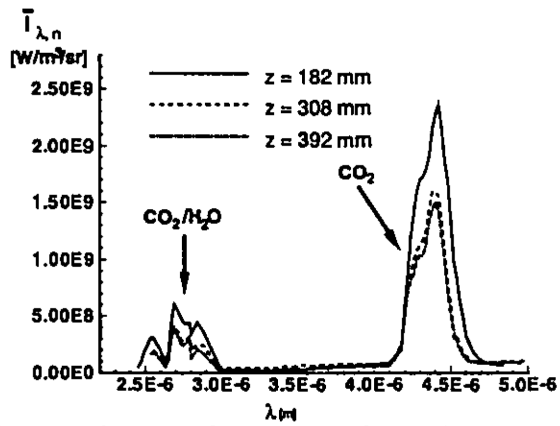

Figure 7: Spectra of the mean radiative intensity at different axial locations ($z \geq 182mm$)

As shown in Figure 7, further downstream from the mixing zone, the radiative intensity decreases with incrasing distance z from the nozzle plate. This is mainly caused by the corresponding decrease of the temperature. However, for distances $z > 308mm$ the reduction of the radiative intensity is almost negligible. This corresponds very well to the fact that the temperature and the gas composition does not change for $z > 308mm$, as previously shown in Figure 3.

Radiation Spectra - Fluctuations

In order to get an impression of the fluctuations, the standard deviation of the radiative intensity expressed by error bars is added to the spectra of the mean radiative intensity in Figure 8 (reaction zone, $z = 22mm$).

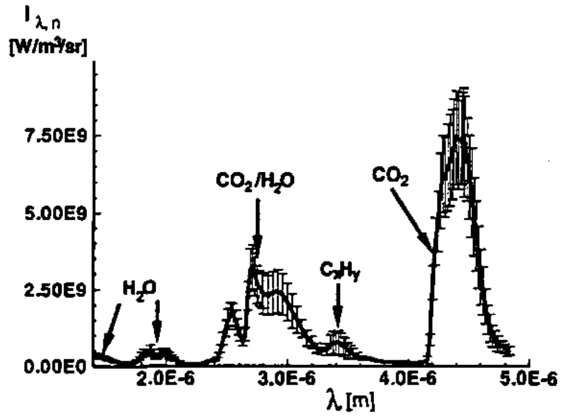

Figure 8: Spectra of the mean value and standard deviation of the radiative intensity at $z = 22mm$

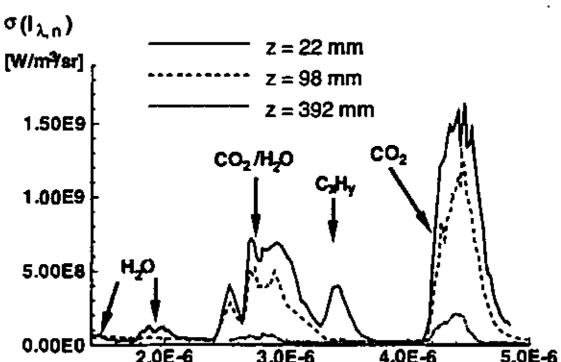

Figure 9: Spectra of the standard deviation of the radiative intensity at different axial locations

As already mentioned, the fluctuations of the radiative intensity are induced by fluctuations of the temperature and fluctuations of the concentrations of CO_2, H_2O and C_xH_y. The temperature fluctuations and the fluctuations of the concentration are generated by turbulence in connection with the gradients of temperature and concentration. Thus, the highest fluctuations of the radiative intensity are to be expected in regions of both high turbulence levels and steep temperature and concentration gradients. Since the relation between radiative intensity and temperature is nonlinear, the radiative fluctuations are enhanced at higher temperatures. Moreover, the radiative fluctuations are dependent on the spectral radiative properties of the combustion gases, which also are affected by temperatnre. Finally, since all the different geometric locations along the line of sight contribute to the detected fluctuations of the radiative intensity, they are a result of an integration over the line of sight and therefore a function of the optical pathlength. The radiation measurements performed by Sivathanu et al.(1991) in a turbulent open C_2H_2-flame demonstated that the radiative fluctuations increase with increasing optical path length. All these different influences on the radiative fluctuations are summarized in the following list :

1. turbulence, turbulence structure
2. gradients of temperature and species concentration
3. time-averaged temperatnre
4. wavelength dependence of the radiative properties of species
5. temperature dependence of the radiative properties of species
6. optical pathlength

The influence of the items 1-5 on the radiative fluctuations will he studied qualitatively in the following. The effect of the optical pathlength will be dropped, because the optical pathlength could not be varied in the present model-combustor. As already mentioned, the radiative fluctuations can be represented by the standard deviation, as defined by Eq. 3. The spectra of the standard deviation at different axial locations are compared in Figure 9.

As expected, the highest standard deviations are found in the spectral regions where the absorption coefficients of the gas-radiation bands reaches its peak values. This is a general effect of the wavelength dependence of the radiative properties (item 5). It can be observed for all the spectra considered. The influence of the time-averaged temperature (item 2) is revealed by the decrease of the standard deviation with increasing distance downstream from the nozzle plate, which is mainly due to the decreasing time-averaged temperature.

In order to investigate the effects 1, 2 and 5 of the list above, a new property, called the degree of fluctuations is introduced. It is defined by :

$$\sigma^*(I_{\lambda,n}) = \frac{\sigma(I_{\lambda,n})}{\bar{I}_{\lambda,n}} \quad (4)$$

Actually, this definition is analogous to the definition of the degree of turbulence, which is a well known property in fluid mechanics. The spectra of the degree of fluctuations of the reaction zone ($z = 22mm$) and the combustor exit ($z = 392mm$) are compared in Figure 10

In the reaction zone ($z = 22mm$), the degree of fluctuations of the different radiation bands of CO_2 and H_2O is almost of the same value of ≈ 0.25, indicating that the same turbulent transport and mixing processes act on both CO_2 and H_2O (item 1, 2). However, one exception is found at the right wing (higher values of λ) of the $4.3\mu m$ CO_2 radiation band, where a higher degree of fluctuations ≈ 0.4 is observed. This is caused by the stronger temperature dependence of the absorption coefficient in this spectral range (item 5). As has been already pointed out in section 5.1, this pronounced temperature dependence is responsible for

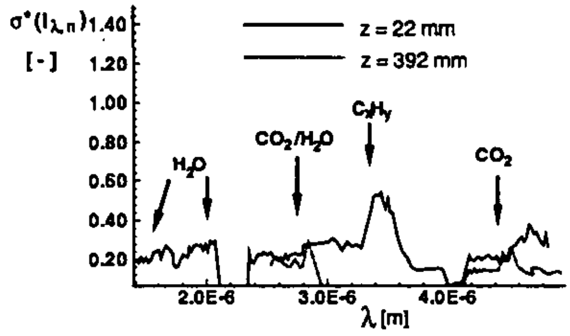

Figure 10: Spectra of the degree of fluctuations at different axial locations

the spreading of the right wing of the 4.3 μm CO_2 radiation band towards higher wavelengths with increasing temperature.

In contrast to CO_2 and H_2O, the degree of fluctuations of 3.4 μm radiation band of C_xH_y reaches values up to ≈ 0.55. Since the same temperature fluctuations und turbulence structnre act on both, the product CO_2 and H_2O and the educt C_xH_y, the different degrees of fluctuations must arise from the different mixing processes (item 2), which is a typical feature of diffusion flames.

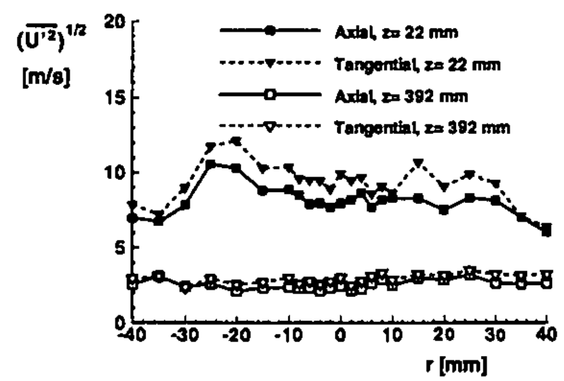

Figure 11: RMS-values of axial and tangential velocity component at $z = 22mm$

The effect of turbulence (item 1) will be discussed by comparing the degrees of fluctuations recorded at the reaction zone ($z = 22\ mm$) and the combustor exit ($z = 392\ mm$). At these both locations, different turbulence levels have been measured as shown by the plots of $\sqrt{u'^2}$, the RMS-value of velocity versus the radial coordinated (Figure 11). Due to the lower turbulence levels at the combustor exit, in general lower degrees of fluctuations are observed compared to the reaction zone. However, not only the differences in turbulence but also the differences for the temperature gradients can be made responsible for this observation.

Generally, it can be concluded, that the fluctations of the radiative intensity arise from several complex phenomena which all act simultaneously. Therefore, these effects are hardly to seperate by experimental investigtions. However, a detailed numerical study based on the presented experimental data may yield a better and also quantitative understanding of the different influences.

Comparison to Calculated Radiation Spectra - Temperature Determination

Since the radiation emitted by hot gases is strongly affected by temperature, radiation measurements can be used to determine the gas temperature. As pointed out by Tourin (1966), there are several techniques available to determine the gas temperature from spectral radiation measurements. However, if non-homogeneous, non-isothermal conditions, like in the model combustor studied, are considered, the applicability and accuracy of those methods is generally quite restricted. Nevertheless, it is possible to determine the maximum temperature along the line of sight at least approximately by comparing the measured radiation spectra to calculated spectra. This will demonstrated and discussed in this section.

The temperature measuring technique is based on the effect, that the shape of gaseous radiation bands is changed by temperature, with higher temperature leading to a broadening of the radiation bands. This broadening effect can be explained by basic quantum mechanics considerations (Ludwig et al. 1973). As a typical example, the broadening of the 4.3 μm-band of CO_2 is shown by plotting the spectral emissivity versus wavelength (Figure 12). Because of the characteristics of the CO_2 molecule, only the right hand side of the radiation band is shifted by temperature.

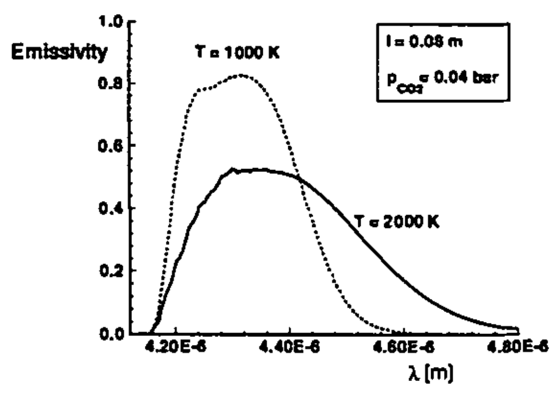

Figure 12: Spectral emissivity of tbe CO_2 4.3 μm band at different temperatures

Thus, considering a non-homogeneous, non-isothermal gas composition, the radiation emitted by the hot zones will he absorbed by colder layers only in the central regions of the radiation band, hut not in the outer regions. Therefore, the temperature of the hot zones can be determined by comparing the outer regions of the measured radiation band to calculated radiation bands of different temperatures, and selecting the temperature which gives the best fit.

Using this technique, the maximum gas temperatures at two positions of the model combustor – one in the reaction zone, one at the combstor outlet – have been determined from the radiation band of CO_2 at 4.3 μm. The methods for calculating the emitted radiation (Koch 1992a) were derived from the quantum mechanical models proposed by Malkmus (1962, 1963). These calculational methods are known to be very accurate and have been verified for different atmospheric flames by e.g.Grosshandler (1976). The partial pressure of CO and CO_2, which are also needed as input data for the calculations, have been determined as concentration-weighted mean-values of the hot zones along the line of sight using the measured temperature and concentrations as shown in Figure 3.

The measured and calculated radiation bands are shown in Figures 13 and 14 for the positions z=22 mm and z=392 mm, respectively. Because of the broadening characteristics of the 4.3 μm band of CO_2, the temperature used in the calculation has been adjusted until the best fit at the right hand side of the band has been achieved. This temperature should correspond to the temperature of the hot gas zone. The differences between the measured and calculated intensity spectra in the central region ($\approx 4.2 - 4.45 \mu m$) are caused by absorption in the colder boundary layer close to the combustor wall.

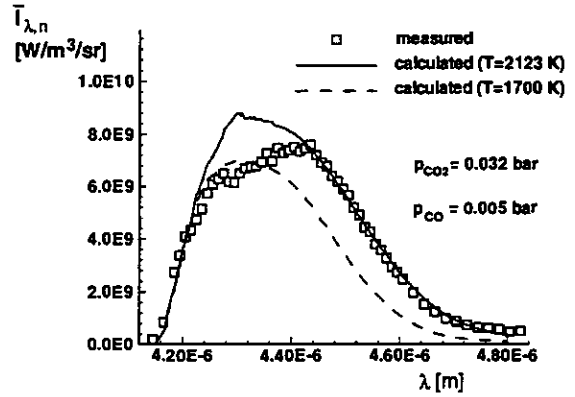

Figure 13: Comparison of measured and calculated spectral radiative intensity for the CO_2 $4.3\mu m$ band at $z = 22mm$.

The hot gas zone temperatures determined from the radiation measurements – T=2123 K for position z=22 mm and T=1075 K for position z=392 m – agree excellently with the results of the CFD-calculation as shown in Figure 3. Moreover, for the position z=392 mm also the agreement with the maximum temperature measured by thermocouples is excellent. However, in the reaction zone (position z=22 mm) the measured maximum temperature (1700 K) is about 400 K below the temperature found by radiation measurements and CFD-calculations. For comparison, also the radiation band computed for the measured temperature of 1700 K is depicted in Figure 13. As this radiation band is shifted to the left of the measured radiation band, there is a strong indication that the temperature of 1700 K mea-

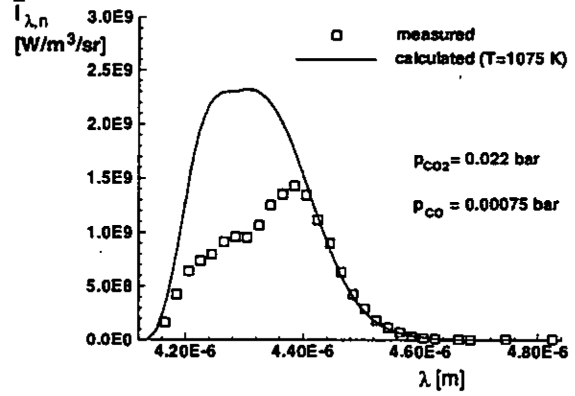

Figure 14: Comparison of measured and calculated spectral radiative intensity for the CO_2 $4.3\mu m$ band at $z = 392mm$.

sured by thermocouples is far to low. This discepancy is mainly due to the fact that the measured temperature data have not been corrected for radiation losses of the thermocouple, which are particularly pronounced in the reaction zone, because of the high temperature levels and the steep temperature gradients.

Thus, it can be concluded that the radiation temperature measurement technique, as applied in the present study, is a valuable tool for determining the maximum gas temperatures even in non-homogeneous, non-isothermal gas compositions. These can be used to determine and improve thermocouple corrections accounting for radiation losses.

CONCLUSION

In the context of an experimental investigation of the turbulent, reacting flow in a model gas turbine combustor at the Institut of Thermische Strõmungsmaschinen, detailed radiation measurements have been performed. In contrast to other studies, these radiation measurements comprise for the first time spectral and time-resolved measurements of the radiative intensity emitted by the confined three-dimensional turbulent propane/air diffusion-flame.

As the combustor was operated under lean non-sooting conditions, all the radiation spectra, recorded at different axial positions along the combustor, show the typical gaseous radiation band of CO_2, H_2O, which are characteristic for all types of hydrocarbon flames. In the reaction zone of the combustor, additionally radiation emitted by the C_xH_y-band at 3.4 μm could be detected, indicating that the chemical reaction has not completed. Generally it was found, that the major contribution to the emitted radiation spectra is made by the CO_2 band at 4.3 μm. This is also typical for hydrocarbon flames.

As expected, the highest emission of radiation was found in the reaction zone because of the high temperatures. Downstream the reaction zone, the emission of radiation drops down due to the decrease of the temperature, which has the major influence on the emitted intensity. Moreover, it was found that the radiation spectra recorded at the two last positions close to the combustor exit are approximately the same. This is caused by the non-reacting, nearly isothermal conditions at these positions.

The measured radiation spectra have been compared to calculated spectra for two positions, one in the reaction zone, the other at the combustor outlet. This comparison revealed, that the radiation spectra are signifantly affected by the absorption of the colder layers close to the walls. Moreover, by fitting the calculated radiation spectra to the measured, the maximum gas temperature could be determined. These temperatures agree excellently to the results of the CFD-calculations and also partially to the temperature measurements performed by thermocouples.

However, the major objective of the present study was the examination of the interaction between turbulence and the fluctuations of the radiative intensity emitted by the flame. In the present study, the spectra of the radiative fluctuations have been derived from time-resolved radiation measurements for the first time. On basis of these fluctuation spectra, the different influences (e.g. turbulence, temperature, temperatnre and concentration gradients, etc.) affecting the radiative fluctuations have been analyzed qualitatively. However, it was found that a detailed quantitative investigation of the radiative fluctuations has to be supported by numerical calculations including an accurate representation of tubulence, reaction kinetics and radiation. This is one major suggestion for further research activities.

ACKNOWLEDGEMENT

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