NEW POSSIBILITIES OF THE ELECTRON BEAM METHOD FOR DIAGNOSTICS OF HIGH-TEMPERATURE SUPERSONIC GAS STREAM OF COMPLICATED MOLECULAR COMPOSITION

N.G. Gorchakova, A.G. Chichenin, V.G. Prikhodko, and V.N. Yarygin

S.S. Kutateladze Institute of Thermophysics SB RAS
630090 Novosibirsk, Russia

Introduction

Today the electron beam diagnostics is one of the main methods for investigation of rarefied gas flows allowing to determine a number of local gas parameters such as density, partial concentration, temperatures of internal degrees of freedom, etc. [1]. The relation between the intensities excited by electron beam spectra and local gas parameters is provided either theoretically or by a calibration curve.

The aim of the present paper is an analysis of the possibilities of electron-beam diagnostics for partial density measurements of high temperature rarefied gases and their mixtures, applying to the mixtures of $N_2 + CO_2$.

Experimental equipment

The experiments were carried out in a methodical unit of the large-scale cryogenic vacuum installation VIKING. The detailed description of VIKING is given in [2].

The scheme of measurements is shown in Fig. 1. The radiation excited by electron beam (accelerating voltage 20 kV, beam current – about 1-3-mA) was measured in optical and X-ray spectral regions.

The system for measuring the intensity of brem-strahlung X-ray radiation consisted of a Soller collimator, an X-ray counter (type BDS-9-04) and a linear intensity meter PI-5 having its output to the electronic automatic potentiometer.

The optical range radiation was focused onto the entrance slit of a monochromator of the medium dispersion SPM-2 which was equipped with a photomultiplier FEU-39. FEU signal was delivered to the standard electronic recording potentiometer.

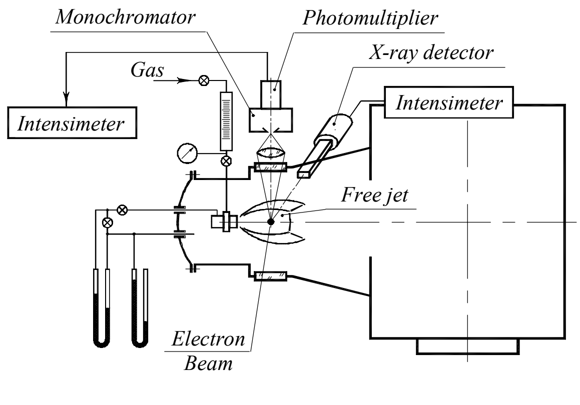

Fig. 1

The ohmic heater supplied by the sonic nozzle was used as a gas dynamic source. It had systems of gas supply, flow rate, pressure and temperature measurements and was mounted on a three-component manipulator enabling the shift of the source with the respect to a fixed observation point to obtain the density flow field under measurements. At the exit of heater the sonic nozzle was fixed having a diameter $d_* = 2$ mm.

By a proper choice of stagnation parameters in the gas dynamic source and the nozzle diameters it is possible

© N.G. Gorchakova, A.G. Chichenin, V.G. Prikhodko, and V.N. Yarygin, 2002

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
23 Aug 2002	N/A	-

Title and Subtitle New Possibilities of the Electron Beam Method for Diagnostics of High-Temperature Supersonic Gas Stream of Complicated Molecular Composition	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Theoretical and Applied Mechanics Institutskaya 4/1 Novosibirsk 530090 Russia	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) EOARD PSC 802 Box 14 FPO 09499-0014	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes See also ADM001433, Conference held International Conference on Methods of Aerophysical Research (11th) Held in Novosibirsk, Russia on 1-7 Jul 2002	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 5	

to realize such a flow regime, at which the adiabatic cooling time at the expansion is significantly shorter than the vibrational relaxation time. In this case the temperature of vibrational degrees of freedom T_v at the axis is "frozen" at the level close to the gas temperature in the stagnation chamber T_o, and the temperature corresponding to the translational degrees of freedom T_t is close to the temperature of rotational degrees of freedom, being significantly lower than T_v. So, for the aim of the given investigation the stagnation parameters and the nozzle throat were chosen in a such way that "freezing" of the vibrational temperature CO_2 T_{vCO_2} was ensured at the level of stagnation gas temperature T_o, and the non-equilibrium state was created between the vibrational and translational degrees of freedom by the expansion of CO_2 from a sonic nozzle into the vacuum chamber.

Method of partial concentration component measurements in gas mixtures at high temperatures

The emission spectra of N_2 and CO_2 in the optic region (λ =2850-5000 Å) were originally observed at a medium spectral resolution (20 Å/mm) using for the gas excitation the electron beam of 20 keV energy and about 3.5 mA current. The slit width of monochromator SPM-2 was 0.06 mm. As it is known there are $\widetilde{B}^2\Sigma_u^+ - \widetilde{X}^2\Pi_g$, $\widetilde{A}^2\Pi_u - \widetilde{X}^2\Pi_g$ band systems of $C0_2^+$ ion and $\widetilde{B}^2\Sigma_u^+ - \widetilde{X}^2\Sigma_g^+$ of N_2^+ ion mainly in this region. The analysis of obtained N_2 and CO_2 spectra excited by the electron beam shows that their spectra largely overlap within the above-cited range. There are no bands in the spectrum of N_2 that are completely devoid of CO_2 spectrum overlapping, sufficiently intense and suitable for density measurements. As an example, N_2 and CO_2 spectra in the region of (0-0) transition of first negative system (FNS) of N_2^+ ion (this region near 3914 Å is usually used for N_2 density measurements) are depicted in Fig. 2.

As it was determined the contribution of CO_2 into (0-0) and (0-1) FNS N_2^+ bands is strongly dependent not only on CO_2 concentration, but also on the level of stagnation temperature T_o (Figs. 3,4), and T_v and T_r respectively. In the left side of Fig. 3 there is an example of overlapping of N_2 and CO_2 spectra. Flow field parameters are indicated above these spectra. The intensity of CO_2 spectrum is shown tenfold to be noticeable. The vertical axis at the right part of this figure corresponds to the ratio of relative integral intensities of N_2 and CO_2 spectra $S' = S/i$, where S – integral intensity of spectrum within $\Delta\lambda$ region, i – electron beam current. These results were obtained downstream of the sonic nozzle at the fixed cross-section $x/d_* =$ const. It should be taken into account that N_2 vibrational temperature is equal to the stagnation gas temperature T_o and that the CO_2 vibrational temperature T_v is "frozen" at the level of T_o in the point of measurement, and that the gas temperature T_r

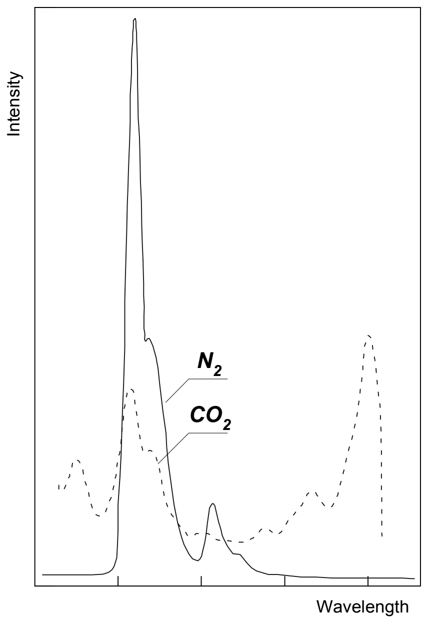

Fig. 2

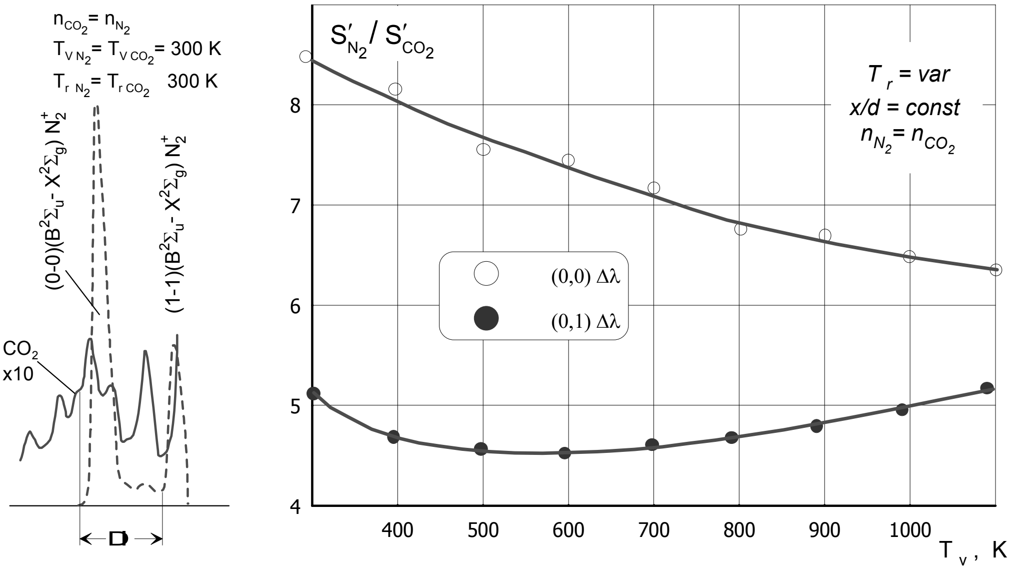

Fig. 3

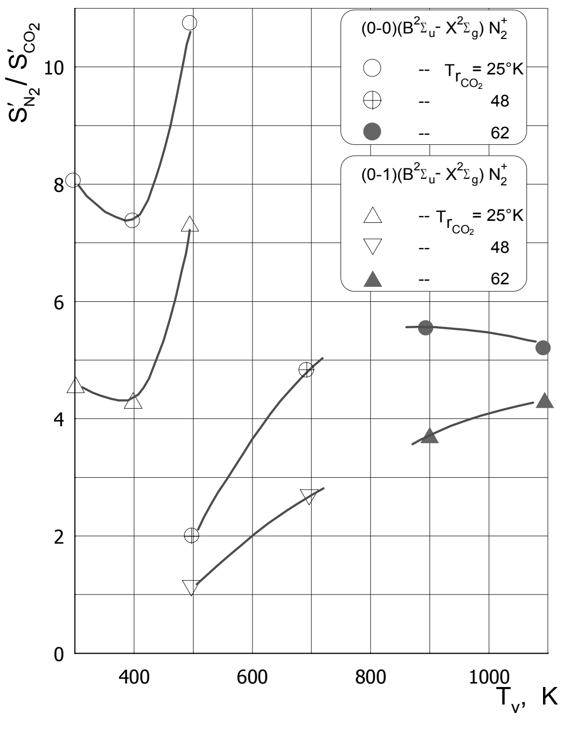

Fig. 4

changes following the changes of T_t. So, in this Figure we notice the simultaneous influence of T_v and T_r of the CO_2 contribution into N_2 spectrum.

To reveal the T_r influence it was only the one manner of measurements that was applied: while changing T_v, the measurement point (i.e. the distance from the nozzle and Mach number, accordingly) was also shifted downstream to keep the value T_r constant. There was no possibility to measure intensities keeping T_r permanent along the whole T_v range, because of low density in suitable points of measurements. So the results are shown for T_r equal to 25 K, 48 K and 62 K. The rotational temperatures were got by numerical calculations of CO_2 jet expansion from the sonic nozzle. It is obvious from Fig. 4 that the T_r varies the ratio S'_{N_2} / S'_{CO_2} rather strongly at a fixed T_v. Due to this fact, the contribution of an "alien" spectrum in optic region becomes almost impossible to be evaluated.

Only in CO_2 spectrum the bands ($\widetilde{B}^2\Sigma_u^+ - \widetilde{X}^2\Pi_g$ transition of CO_2^+ ion) over the wavelength range about 2890 Å are actually free of overlapping by N_2 bands, and therefore they can be used for an independent measurement of CO_2 concentration in the mixture containing N_2. However, when recording the integral value of its intensity it should be noted that with increasing the stagnation temperature T_o and, respectively, T_v and T_r at the measurement point, there occurs the intensity redistribution in the CO_2 spectrum, and short-wave sub-bands transition intensities increase (Fig. 5). This takes place due to the excitation of higher vibrational levels of this electron transition. But in this case the value of integral band-system intensity holds within 100 Å region under gas parameters investigated. So based on it, the method of partial concentration measurement in N_2 + CO_2 mixtures at high temperatures was proposed. The basic idea of this method is to use simultaneously the electron-beam-induced gas radiation in different spectrum regions such as X-ray and the optical ones. This will allow overcoming the problem connected with the overlapping spectra.

Besides, it was established by special measurements that the usage of X-ray region leads to a better spatial localization of measurements. The cross-section electron beam profile has been registered with help of Langmuir probe and X-rays collimator with narrow slit oriented parallel to beam. A typical beam size, determined by the radiation intensity in X-ray region, is much less than that measured within the optic region under the same conditions. The matter is that the secondary electrons do not effect the radiation excitation in the X-ray spectrum region, since their energy level does not exceed tens electron-volt. The data based on the intensity measurements of optical radiation show enlarged half-width of the beam especially at the high gas densities.

The procedure of making measurements with the above method is as follows.

1. In static condition one should get the calibration curve of relative electron-beam excited radiation in optic region for CO_2 and X-ray range – for CO_2 and N_2 versus gas density, namely *Ioptic*/ i = f(n_{CO_2}), $I_{X\text{-ray}}/\ i$ = f(n_{CO_2}), $I_{X\text{-ray}}/\ i$ = f(n_{N_2}).

2. Registering the integral intensity within the range 2900-2800 Å for the flow with unknown N_2/CO_2 ratio and for a

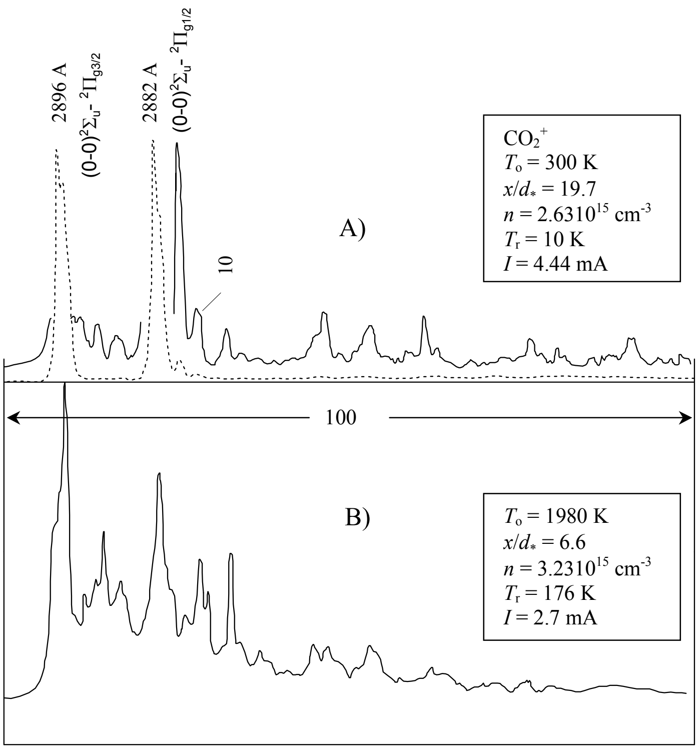

Fig. 5

beam current i, using the calibration curve $I_{optic}/ i = f(n_{CO_2})$, it is possible to determine the corresponding concentration of CO_2 $- n_{CO_2}$.

3. Having this concentration n_{CO2} and using a calibration curve $I_{X\text{-ray}}/ i = f(n_{CO_2})$, it is feasible to find the corresponding intensity in the X-ray region $- S_{CO_2}$.

4. X-ray radiation S_Σ of mixed flow is proportional to a total concentration of component n_Σ: $S_\Sigma = S_{N_2} + S_{CO_2}$.

S_{CO_2} is just determined, and the difference $S_\Sigma - S_{CO_2} = S_{N_2}$ determines the N_2 contribution and thus its concentration n_{N_2} through the calibration curve $I_{X\text{-ray}}/ i = f(n_{N_2})$.

Summary

1. The method of electron-beam partial density measurement in $N_2 + CO_2$ mixtures of an arbitrary composition is developed and verified in the range of temperatures up to 1200 K and densities up to 10^{16} cm^{-3}.

2. The method is based on simultaneous measurements of electron-beam induced gas radiation in different spectrum regions such as X-ray and optical ones. The peculiarity of density measurements of hot gases is the following: the recommended CO_2 spectrum range ($\tilde{B}^2\Sigma_u^+ - \tilde{X}^2\Pi_g$ transition of CO_2^+ ion) extends up to 100 $\mathring{A}$, which should be registered. It is possible to make by two ways:

- using the monochromator, scanning this spectrum region and applying the calculating program to integrate intensities within this range,
- using the special optic filter centralized at 2850 – 2860 $\mathring{A}$ and having its half-width equal to 50 $\mathring{A}$.

The last variant of CO2 density measurement is more suitable for investigation of impulse regime of rarefied gas flows and low level of intensity to be registered.

Acknowledgments. The work was supported by the INTAS Project Ref. No. 2000-0385.

REFERENCES

1. **Gochberg L.A.** The Electron Beam Fluorescence Technique in Hypersonic Aerodynamics // Prog. Aerospace Sci. 1997. Vol. 33. P. 431- 480.
2. **Prikhodko V.G., Khramov G.A., Yarygin V.N.** A Large-Scale Cryogenic Vacuum Plant for Gas-Dynamic Research // Instruments and Experimental Technique. 1966. Vol. 39, No. 2. P. 309-311.