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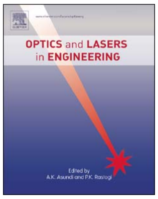

Feasibility of optical computerized tomography for measuring the species concentration distribution of flow fields

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ABSTRACT

In this paper, the feasibility of using optical computerized tomography (OCT) methods for measuring the distribution of species concentration for flow fields is analyzed and discussed. First, feasible methods are chosen for two or three objects composed flow fields from the perspective of the measurable principle. Second, both common gas and plasma are chosen as two typical examples for specific analysis and discussion. The results show that the feasibility and applicable range of OCT methods are related to the temperature, pressure, and species composition of the measured flow fields. Finally, the study indicates that OCT methods are more suitable for measuring the distribution of species composition for common gas rather than plasma. In a word, this study could be helpful for extending the applicable range of OCT methods, which are based on the measurement of the refractive index.

1. Introduction

Optical computerized tomography (OCT) methods have played an important role in visualizing and diagnosing various cold and hot flow fields [1–5]. In principle, they can only record the refractive index variation, but can not well visualize the real structure and border of the measured flow fields. In essence, the spatial distribution of species composition is crucial to reconstruct temperature and electron number density distributions from the experimentally measured refractive index. Unfortunately, to date, there has been no particularly good method for obtaining the distribution of specific species composition for flow fields. Considering the advantages of OCT methods, such as real time, stability, lack of contact, and supplying 3-D distribution, the feasibility of using them for measuring the distribution of flow field species concentration will be discussed in this paper. In addition, to make the study more representative, both common gas and plasma are chosen as typical examples for practical analysis and discussion.

2. Refractive index models

2.1. Common gas

The refractive index n of a gas flow field that is composed of a sort of neutral particle is described by [6]:

$$n - 1 = \frac{1}{L}\left(A + \frac{B}{\lambda^2}\right)N_n, \tag{1}$$

where L indicates the Loschmidt number ($2.687 \times 10^{-19} cm^{-3}$), A and B are the constants relevant to the specific composition of the measured flow field [7], λ represents the probe wavelength, and N_n is the number density of neutral particles.

For a multicomposition flow field, the refractive index should meet the principle of superposition, like:

$$\begin{aligned} n - 1 &= \frac{1}{L}\sum_i \left(A_i + \frac{B_i}{\lambda^2}\right)N_n = \frac{1}{L}\sum_i \left(A_i + \frac{B_i}{\lambda^2}\right)\gamma_i N_t \\ &= \frac{1}{L}\left(\sum_i A_i\gamma_i + \frac{\sum_i B_i\gamma_i}{\lambda^2}\right)N_t = \frac{1}{L}\left(A + \frac{B}{\lambda^2}\right)N_t, \end{aligned} \tag{2}$$

where $A = \sum_i \gamma_i A_i$ and $B = \sum_i \gamma_i B_i$, γ_i represent the mole fraction of the *i*-

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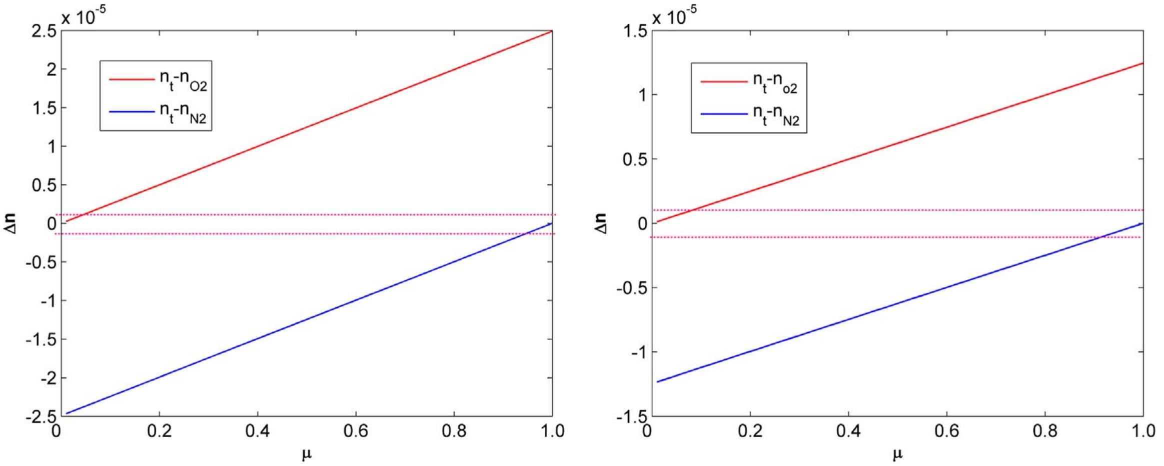
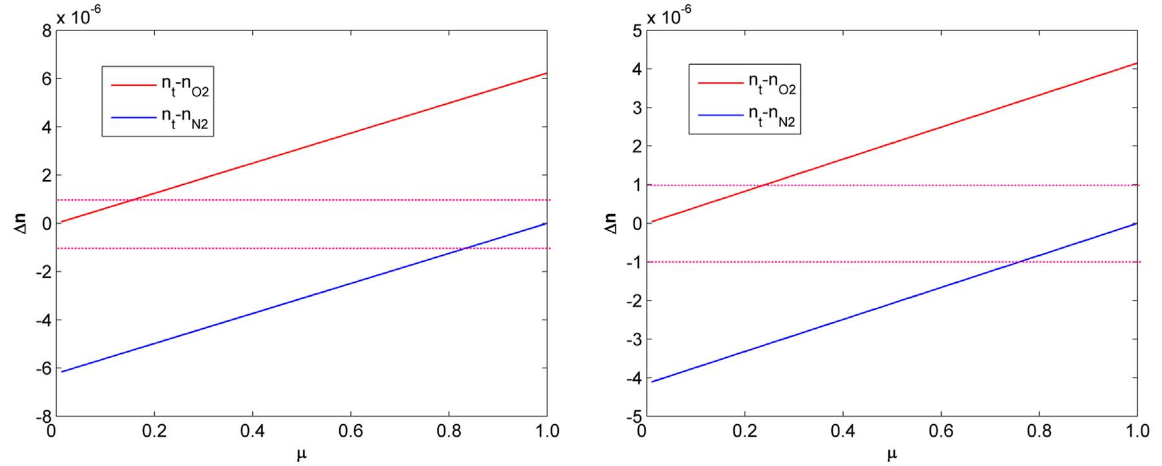


(a) T = 300K (b) T = 600K



(c) T = 900K (d) T = 1800K

Fig. 1. The dependence of the refractive index difference on the ratio (a) 300 K, (b) 600 K, (c) 900 K, and (d) 1800 K.

th composition, A_i and B_i are the constants of the i-th composition, and N_t denotes the total particle number density of the flow field.

Considering the pressure equation in thermodynamics, the dependence of the refractive index on temperature, pressure, and composition can be written as:

$$n - 1 = \frac{1}{L}\left(A + \frac{B}{\lambda^2}\right)\frac{P}{\kappa T}. \tag{3}$$

where κ is the Boltzmann constant and P and T indicate the pressure and the temperature of the flow field, respectively.

Eq. (3) shows that the determination of species composition and pressure for the measured flow field becomes the key step of temperature reconstruction. These parameters can even directly determine the accuracy of parameter reconstruction, which implies the importance of the structural visualization for complex flow fields with high temperatures and illuminant. This point can be attributed to the idea that the determination of species composition should be on the basis of structural visualization of the measured flow field.

2.2. Arc plasma

The refractive index of pure arc plasma is usually described as [8]:

$$n - 1 = \frac{1}{L}\left(A + \frac{B}{\lambda^2}\right)(N_n + \delta N_i) - 4.46 \times 10^{-14}\lambda^2 N_e, \tag{4}$$

where N_n, N_i, and N_e indicate the number densities of neutral particles, ions, and electrons of the plasma, respectively, and the contribution of ions to the refractive index is δ times the neutral particles.

To be feasible for temperature reconstruction, the refractive index should be expressed as the function of temperature and pressure based on the first ionization, such as [9]:

$$n - 1 = \left[\frac{1}{L}\left(A + \frac{B}{\lambda^2}\right)(1 - (1 - \delta)\alpha_1) - 4.46 \times 10^{-14}\lambda^2\alpha_1\right]\frac{P}{(1 + \alpha_1)\kappa T}, \tag{5}$$

where α_1 represents the first ionization degree of the arc plasma.

3. Basic principle

In this part, the basic principle of measuring the species composition distribution is discussed for different situations. The method and conclusion are suitable for both common gas and plasma flow fields.

3.1. Two objects mixed

Supposing the flow field is composed of two objects (such as oxygen and nitrogen, whether they are in the state of common gas or plasma), which lead to the total refractive index n_t, that should be described as: