The Use of Nitrogen as a Diluent in cw DF Lasers

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Introduction

THE use of nitrogen as the diluent gas in cw DF lasers is of interest if the waste gases are to be absorbed in a chemical pump system, which hardly can absorb noble gases like helium. On the other hand, it is known that the laser power and efficiency are lowered if nitrogen is used instead of helium.[1,2] Clearly, this is partially caused by deactivating collisions among DF and N_2 molecules which are far more frequent than for the atoms as collision partners. The purpose of this Note is to show that the laser performance is also influenced by the lower diffusivity and heat conductivity of N_2.

Experimental Observations

The experiments were conducted with a combustion-driven supersonic diffusion laser. For the experiments described herein, H_2 was used as the fuel and F_2 as the oxidizer in the combustion chamber. N_2 or He was fed as a diluent to both the combustion chamber and the secondary nozzles. The nozzle grid consists of conical primary and secondary nozzles with exit diameters of 1.7 and 1.3 mm respectively. Only half of the grid area is covered by nozzle exits. The remaining base area permits expansion of the gas flows during the laser reaction. Under the design conditions for this nozzle grid the larger part of the diluent is fed to the secondary nozzles. However, in the case of N_2 we found that the laser power generally was lowered when the secondary diluent flow was increased to significant amounts. In a recent theoretical paper[3] the deteriorating effect of N_2 as secondary diluent was also mentioned. This is demonstrated in Fig. 1 where the laser power P and the specific power σ (power per total mass flow) are plotted against the molar ratio $R_L \cdot \psi_S$ of the secondary diluent to the available fluorine. (The nomenclature of Ref. 3 is used here: R_L is the ratio of the molar flows of secondary fuel and available fluorine and ψ_S is the ratio of the molar flows of secondary diluent and secondary fuel.) As a typical example, two experiments with N_2 are shown which were performed under the same operating conditions except for the secondary diluent flow. For the higher secondary flow the laser power is significantly lower and the specific power has dropped to nearly half. On the other hand, with He the highest laser powers are obtained for comparatively large molar fractions of the secondary diluent. This is demonstrated in the results of two experiments with He as shown in Fig. 1, where the operating conditions differed only in the secondary diluent flow.

In order to understand this phenomenon, the rotational temperatures of the DF molecules were measured spectroscopically via the first overtone emission. The uncertainty of the measured values is typically 5%. Figures 2a and 2b show the results of six pairs of experiments with N_2 and He, respectively. For each pair the operating conditions were the same except for the secondary diluent flow. The reproducibility of the molar flow of available fluorine ($\dot{N}_F/2+\dot{N}_{F2}$) is about 5%. Since the primary diluent ratio, ψ_p, was only slightly varied in these tests, a correlation between ψ_p and the temperature is obscured by experimental inaccuracies. The graph shows clearly that in the case of N_2 (Fig. 2a) the increase of the secondary diluent flow effects no significant drop of the temperature. However, with He as a diluent (Fig. 2b) the temperature is significantly lower for the higher diluent flows.

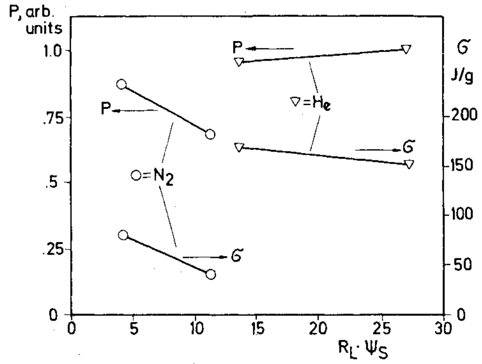

Fig. 1 Effect of the secondary diluent flow on the laser power P and the specific power σ.

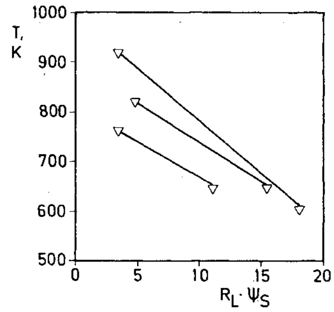

Fig. 2a Effect of the secondary diluent flow on the rotational temperature, N_2 case.

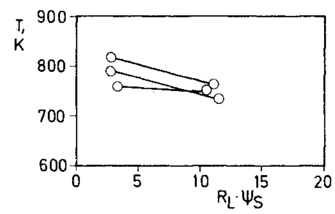

Fig. 2b Effect of the secondary diluent flow on the rotational temperature, He case.

Discussion

The difference in the laser performance is explained as follows. He as secondary diluent is effective in reducing the static temperature and thus improves the partial inversion. Indeed the increased total molar flow causes higher cavity pressures but as a net effect the benefit from the temperature reduction prevails. N_2 as a secondary diluent is ineffective in absorbing the heat of the laser reaction. Therefore, the prevailing effect of high secondary diluent flows is the increase of the cavity pressure, which is detrimental to the laser efficiency.

The ineffectiveness of N_2 as a secondary diluent may have the following causes: According to the results of Shackleford et al.[4] the mixing process is diffusion dominated under our experimental conditions. Since N_2 diffuses much slower than D_2 into the fluorine containing gas streams the secondary diluent is not present in the reaction zones. Furthermore, the heat conductivity of N_2 is comparatively very low. Thus the heat capacity of the secondary diluent is not effective in absorbing the heat released in the reaction zones.

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Flow Visualization in Combustion Gases Using Nitric Oxide Fluorescence

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Introduction

A TECHNIQUE using imaging of planar laser-induced fluorescence (PLIF) for quantitative, simultaneous multiple-point measurements of the OH concentration in flames has recently been reported.[1,2] Measurements of this type have potential for elucidating the interactions between the chemistry and fluid mechanics of combustion flows. In this Note a further extension of the technique, making use of NO fluorescence, is described. This work was motivated partially by the desire to investigate the suitability of NO as a seed material for visualizing species concentration and temperature (for example in mixing studies) and partially by an interest in NO kinetics.

Experimental Setup

A schematic of the experimental setup is shown in Fig. 1. The frequency-doubled output of a Nd:Yag-pumped dye laser was mixed with the residual 1.06 μm beam of the Nd:Yag laser in a KDP crystal to obtain output near 225 nm. A vertical sheet (6-16 cm high and 0.2 mm thick) of the laser output ($\sim$1 mJ/pulse) was transmitted across the flowfield under study. Detection of the resulting fluorescence was accomplished using an image-intensified Reticon MC520/RS520 camera system containing a 100×100 photodiode array. A color glass filter (Schott glass UG-5) mounted in front of the camera was used to reduce stray and scattered light. In some experiments an additional interference filter ($\lambda = 252$ nm, bandwidth $= 24$ nm) was used to eliminate the influence of flame luminosity and scattered light. The output of the photodiode array was digitized using a Data Translation 2782 A/D converter interfaced with an LSI 11/23 computer. A more detailed description and discussion of the sensitivity of the system has been reported previously.[3]

Two combustor flowfields were used in this feasibility study. The first was an atmospheric pressure, laminar premixed CH_4/air flame stabilized on a 7-cm-diam flat flame burner. The second combustor flowfield was an atmospheric

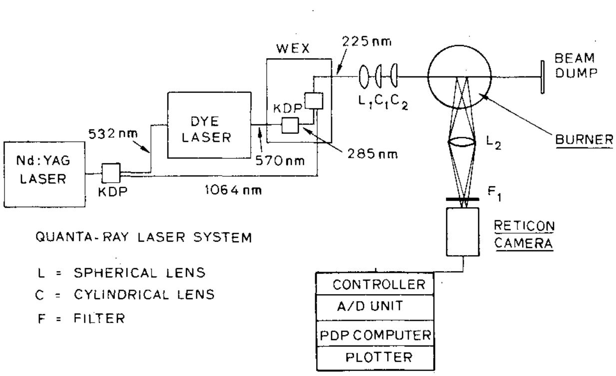

Fig. 1 Experimental setup.

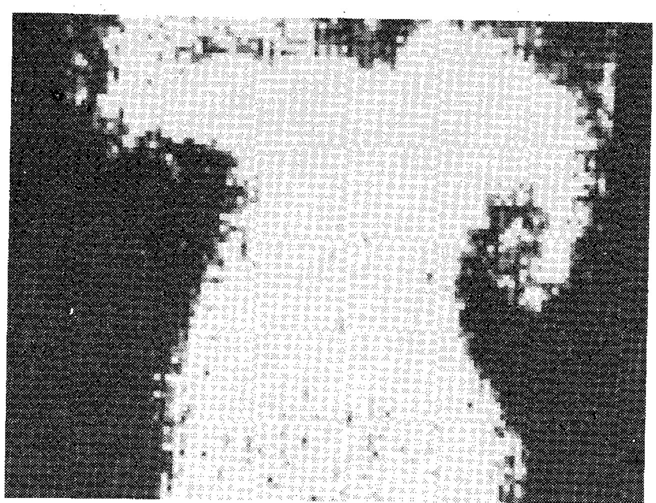

Fig. 2 Single-shot digital picture of NO mole fraction distribution in a laminar, premixed CH_4/air flame. NO seed level is 1900 ppm in the inlet flow. Each pixel indicates the level of fluorescence from a volume $0.8 \times 0.8 \times 0.2$ mm in size. Laser was tuned to the $Q_1(35)$ line of NO so that the intensity levels are indicative of the mole fraction in the flowfield.

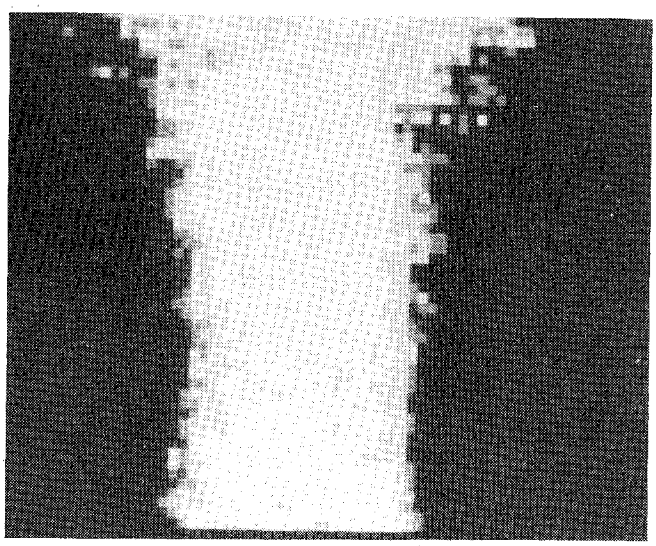

Fig. 3 Single-shot digital picture of NO concentration distribution in a turbulent, premixed CH_4/air flame. Each pixel indicates the level of fluorescence from a volume of $0.8 \times 0.8 \times 0.2$ mm in size. NO premixed to main flow with a seed level of 3800 ppm. Laser was tuned to the $Q_1(35)$ line of NO.

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