Effect of Nitrogen-Oxide Addition on Low-Temperature Powling-Burner Flames

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Flat low-temperature flames were established on a Powling burner using rich diethyl-ether/air mixtures. Nitrogen monoxide or nitrogen dioxide was added into the mixtures, and the temperature development, chemical-species history and emission spectra from the low-temperature flames were examined. Nitrogen-oxide addition retarded the cool-flame appearance and reduced the distance/time between cool and blue flames where the excited oxygen molecule could be found. Nitrogen oxides promote fuel decomposition reactions in the post cool-flame period that results in rapid blue-flame onsets, but the pre cool-flame reactions are emaciated.

Key Words: Ignition, Low-Temperature Flame, Preflame Reaction, Nitrogen Oxide, Spectroscopic Measurement, Internal Combustion Engine, Ignition Control

1. Introduction

The burned gases are always introduced into / mixed with fresh mixtures in the reciprocating-piston internal combustion engine with / without exhaust-gas recirculation. The effect of burned gases contained in the mixtures is not weak on the preflame reactions prior to the hot-flame ignition. Temperature dependence became a quarter on the ignition induction time [1]. Hot-flame occurrence caused by mixture compression could be eliminated by low-volatile chemical-compound-vapor addition into the mixture probably through the formaldehyde-generation/consumption control during the preflame period, but when the $21O_2/79Ar$ synthetic air is used instead of natural air as oxidizer, no eliminating effect can be found [2]. It would be indicated that some nitrogen-related compound are closely take part in the ignition promotion/retardation phenomena.

Flat low-temperature Powling-burner flames with / without nitrogen-oxide seeding into the mixtures are examined as to the temperature development, emission spectra and chemical-species history, to elucidate the effects of nitrogen oxides on low-temperature oxidation of fuel/air mixtures in the most simple, undoubted system, and to find out ignition-control procedures to realize premixed compression-ignition (HCCI) engines.

2. Experimentals

A modified Powling burner at atmospheric pressure was used to stabilize flat two-stage low-temperature flames of rich diethyl-ether/air mixtures in vertically-flowing laminar streams. The details are shown in our paper formerly published [3], though the present apparatus was improved for a higher-level flame stabilization. A fuel/air mixture flowed with almost uniform velocity distribution from an inner burner tube surface, which was a porous ceramic plate. An outer quartz shielding tube (inner diameter: 105 mm, height: 172 mm) supported a stabilizing ceramic screen at the top way-out position. The stabilizing screen was a ceramic-fiber matrix including heaters electrically controlled in temperature.

Temperature profiles in the two-stage flames were measured with a type K thermocouple having 50 μm in diameter, coated with SiO_2 to eliminate catalytic effects on the wire surface. A gas sample was removed continuously through a quartz probe into gaschromatographs (Shimadzu: GC-4 BPT/F) for constituent analysis of stable chemical-species.

Light emission was focused onto a 50-μm slit of a monochrometer (Japan Spectroscopy: CT-25N) to obtain emission spectra, and was detected by a cooled photomultiplier (Hamamatsu Photonics: R3896, 190~900 nm). The spatial resolution was less than 1 mm. For the wavelength higher than 620 nm, a red-color glass filter (Toshiba: R-62) was used to eliminate the secondary reflection.

3. Results and Discussion

Typical temperature traverses obtained by thermocouple measurements are shown in Fig. 1 together with flame pictures in the case the nitrogen monoxide NO is added into the diethyl-ether/air mixture with an equivalence ratio of 3.0. The spectroscopic emission distribution in this case is shown in Fig. 2. In each picture the lower thin flame is a cool flame and the upper thick one was a blue flame followed by a yellow column. The emission spectra shown were the ones of the middle position of each flame on the centerline of the burner tube. The blue flame was located apart from the cool flame when the equivalence ratio was higher than 3.0. If no nitrogen monoxide added, cool-flame heat release appeared at 82 mm above the burner surface and then degenerated for a while; the most typical cool-flame characteristic. The heat release due to the blue-flame onset began at 88 mm position. The nitrogen-monoxide addition of 600 ppm did not change the flames substantially. The cool-flame appearance, however, was retarded when the nitrogen-monoxide content was raised to 1 400 ppm, associated with less cool-flame degeneration and faster blue-flame heat release. The heat-release rate was enhanced to be 111 percent in the blue-flame region.

We have obtained the nitrogen-oxide consumption/generation history in a low-temperature Powling-burner flames with a relatively low content of 240 ppm nitrogen-oxide seeding also in the previous paper [4]. Initially seeded nitrogen oxide was consumed in the cool flame, but the nitrogen dioxide was generated. It has been reported that the nitrogen-oxide oxidation to the nitrogen dioxide would be promoted under hydrocarbon coexistence [5]. The nitrogen-oxide addition into the mixture would result in the nitrogen-dioxide supply for the blue-flame onset.

The temperature profiles and emission spectra in the nitrogen-dioxide NO_2 addition case are shown in Figs. 3 and 4 respectively. A remarkable delay of cool-flame appearance can be found in Fig. 3 when the nitrogen-dioxide concentration is raised up to 1 300 ppm. The cool-

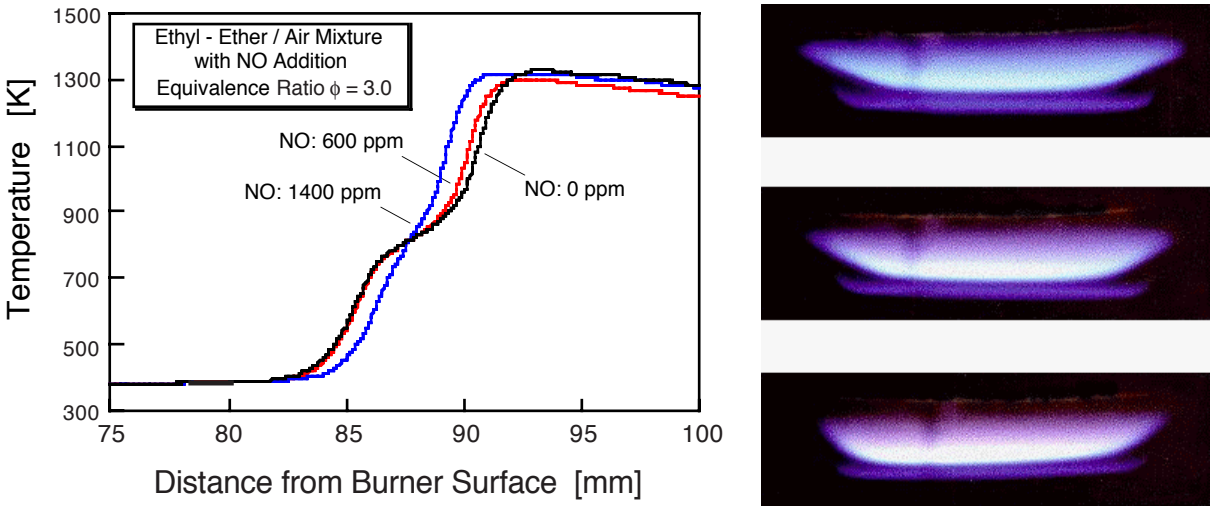

Fig. 1 Temperature profiles of NO-seeded low-temperature flame. Pictures: No NO seeded, 600-ppm NO seeded and 1400-ppm NO seeded from top to bottom.

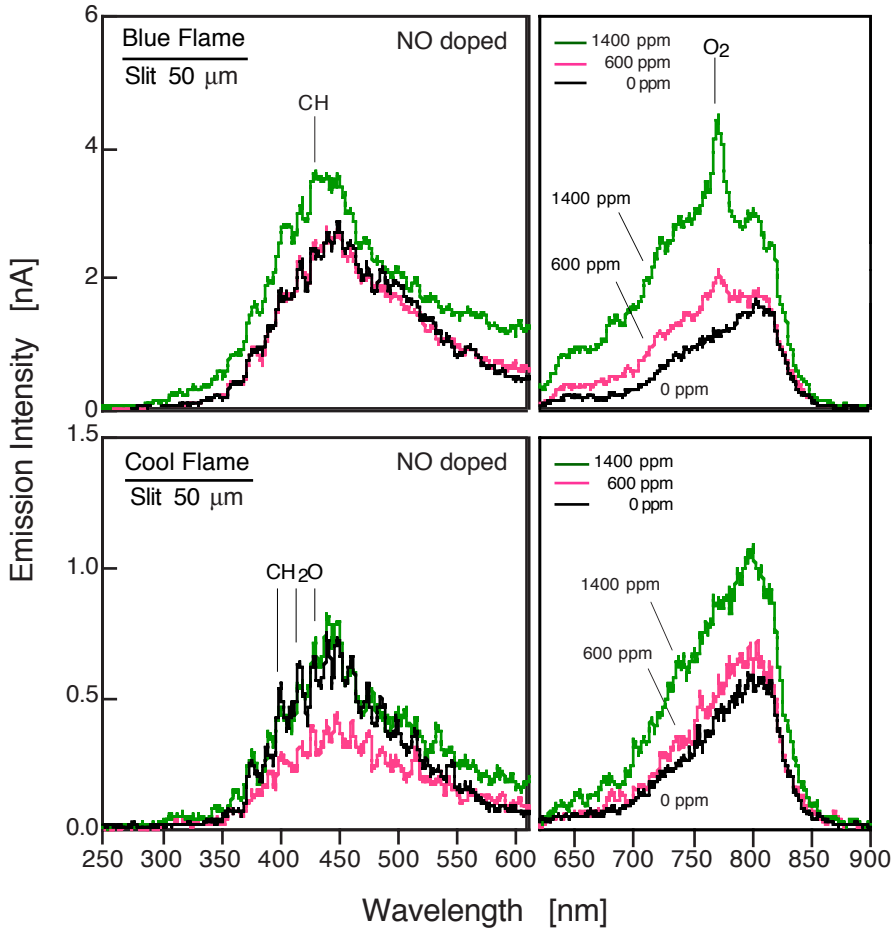

Fig. 2 Emission spectra of NO-seeded low-temperature flame

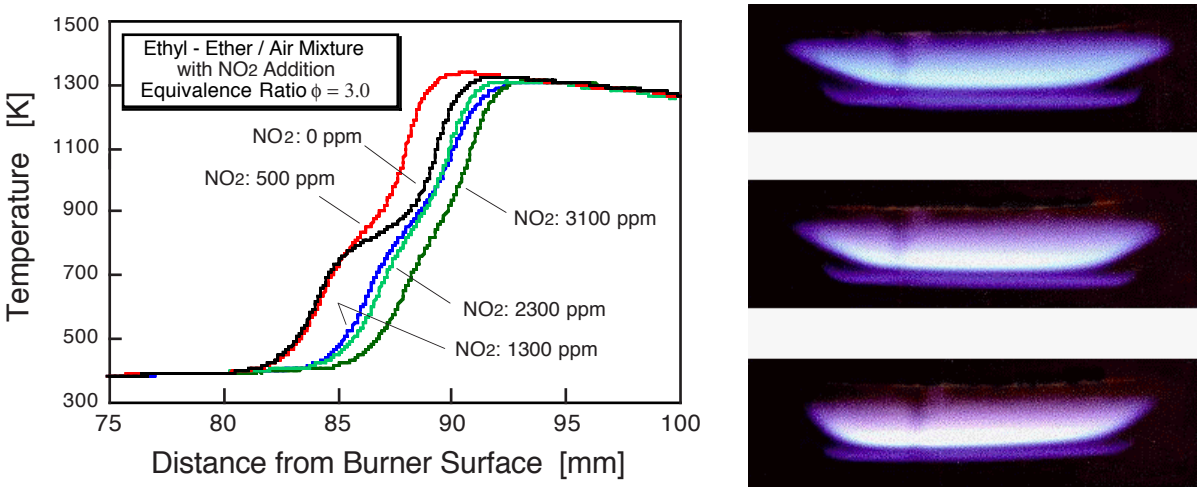

Fig. 3 Temperature profiles of NO_2-seeded low-temperature flame. Pictures: No NO_2 seeded, 500-ppm NO_2 seeded and 2300-ppm NO_2 seeded from top to bottom.

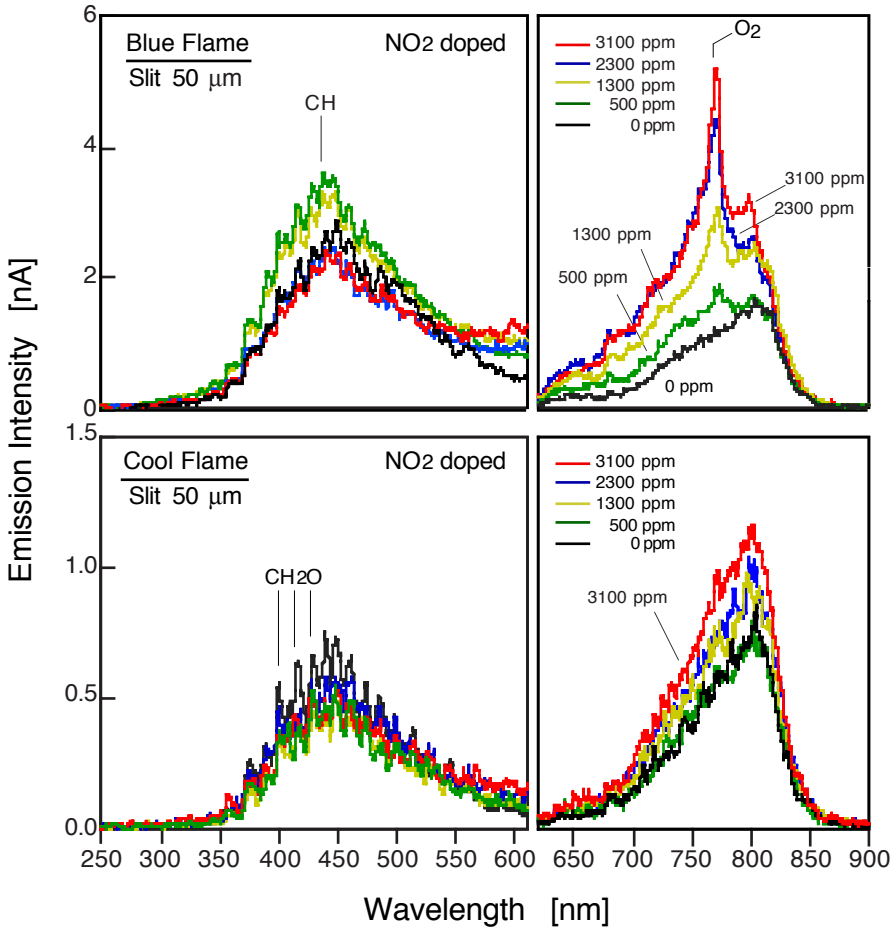

Fig. 4 Emission spectra of NO_2-seeded low-temperature flames

flame onset is usually the most insensitive to almost all factors; the temperature, pressure or mixture strength (3). This would be an advanced knowledge on the cool-flame characteristic.

Another remarkable change caused by nitrogen-oxide addition was the higher emission peak of 768 nm. The emission peak of 768 nm corresponds to the Atmospheric Bands of excited oxygen molecule. When more cool-flame retardation and less cool-flame degeneration appear, the emission peak in the blue-flame spectra becomes more conspicuous. It can be recognized from the pictures in Figs. 1 and 3 that the deep-blue colored flames changes into pale-blue ones due to the enhanced sub-infrared emission contribution.

4. Concluding Remarks

Nitrogen oxides were seeded to a rich diethyl-ether/air mixture with an equivalence ratio of 3.0, and the temperature development, chemical species and emission spectra from the low-temperature flames were examined. The features of this paper are as follows:

- Nitrogen-oxide addition of higher than 1 300 ppm into the mixture retarded the cool-flame appearance, especially in the nitrogen-dioxide addition case a remarkable retardation can be obtained.
- Nitrogen-oxide addition reduced the distance/time between cool and blue flames where the excited oxygen molecule (768 nm, Atmospheric Bands) could be found.
- Nitrogen oxides promote fuel decomposition reactions in the post cool-flame period, which results in rapid blue-flame onsets, but the pre cool-flame reactions are emaciated.

Effect of nitrogen-oxide addition is not identical between the cool and blue flames. In the blue-flame, the final precursor for the hot-flame ignition, the inorganic oxygen atom O and hydroxyl OH radicals would play an important role, instead of the organic radicals, such as alkoxyl radical RO and hydroperoxo HO_2, which are dominant in the cool-flame period. The knowledge would contain a key factor to find real ignition-control procedures for the novel internal combustion engine systems.

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