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Combustion using highly preheated air, together with diluted air and/or fuel, is a clean combustion concept that combines high efficiency and low pollutant emissions in industrial heating processes. Having names such as flameless oxidation, high efficiency combustion and MILD combustion, these methods allow the use of recuperated heat in high-temperature processes without the penalty of increased NO_x emissions, and offer the possibility of substantially homogenizing the temperature field in furnaces. To permit the optimization of NO_x control, and to provide insight into the ultimate low-NO_x potential of these methods, in the proposed research we investigate the paths to NO formation in dilute, high temperature combustion. Towards this end, we have performed laser-diagnostic measurements of flame structure, using Raman and LIF in a laminar coflow geometry, combined with detailed numerical simulations. An important part of this research is the analysis of the preheating and dilution of the fuel and/or oxidizer on spatial structure and NO formation.

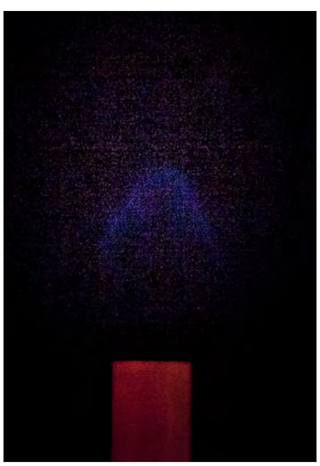

Figure 1.*Photograph of a laminar diluted methane jet in hot diluted coflow.*

To follow the changes in the flame structure upon its transition to the MILD region, the investigation of flames burning with varying degree of preheating and dilution of coflow and fuel streams is carried out.
The predictive power of detailed simulations made using the GRI-Mech 3.0 chemical mechanism is tested by comparison of the measured and calculated distributions of temperature and major species concentrations.
In total, three laminar diffusion flames with different degree of preheating of coflow and fuel were studied. These flames are non-preheated (Case NP), preheated (Case P) and Mild (Case M). Case NP and P were burned using the home-made diffusion burner with electrical preheating of gases (EPDB- electrically preheated diffusion burner). The flame temperature and major species (CO, CO_2, N_2, H_2, H_2O, CH_4 and O_2) were measured using spontaneous Raman scattering and NO species using Laser induced Florescence. A photograph of the mild case is shown in Fig. 1; the barely visible flame is indicative of the substantial dilution of fuel and oxidizer.

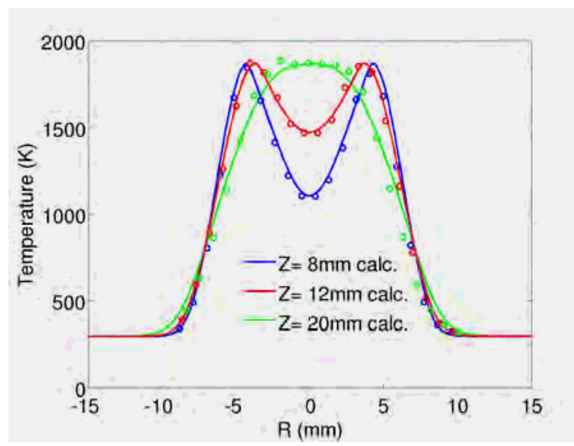

Figure 2.*The measured and calculated temperature in Case NP at three different heights as a function of the radial distance.*

The mathematical description of the model is governed by a set of conservation equations for mass, momentum, energy and species in the cylindrical coordinate. The GRI Mech. 3.0chemical mechanism is used to obtain the required thermodynamic and transport data involved. Mixture-Averaged transport is used to calculate diffusion velocities of each species. Radiation effects were also added to the calculation using an optically-thin approximation.

Measurements of the diffusion burner are compared against computations and a good agreement was found for major species and temperature (see Fig 2).NO concentrations obtained by Laser Induced

Fluorescence are compared with computations as shown in Fig. 3. It is seen that the amount of NO is predicted with a reasonable accuracy (see Fig 3).

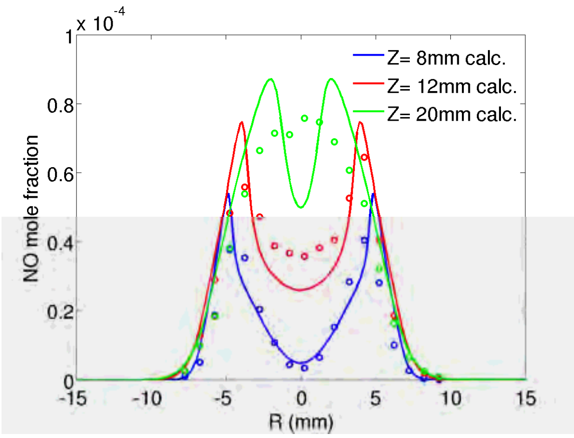

Figure 3. *The measured and calculated NO in Case NP at three different heights as a function of the radial distance.*

Additionally, measurements have been performed using the Laminar Jet-in-Hot-Coflow burner for Case M. In this burner the diluted oxidizer coflow is generated by a lean premixed ceramic burner. In essence, this geometry is a diluted laminar "jet in hot coflow". Computations of this flame have also been performed using detailed chemistry of GRI 3.0 and Mixture-Averaged transport.

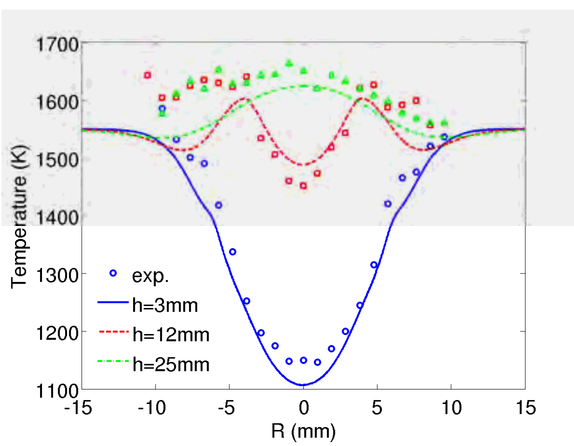

Figure 4. *The measured and calculated temperature in Case M at three different heights as a function of the radial distance.*

A comparison of computations and measurements of temperature is shown for this flame in Fig. 4 at three different heights above the fuel jet exit. The "mild" increase in temperature in the mixing layer (~200 K) is indicative of MILD combustion under these conditions. NO concentrations of this burner are also compared with computations (see Fig. 5). It can be seen that NO concentrations are below 10 ppm and that the majority of the NO is formed in the coflow. The MILD combustion process in this flame causes at most an additional 2 ppm of NO, which demonstrates the extremely low-NO_x potential of this combustion concept.

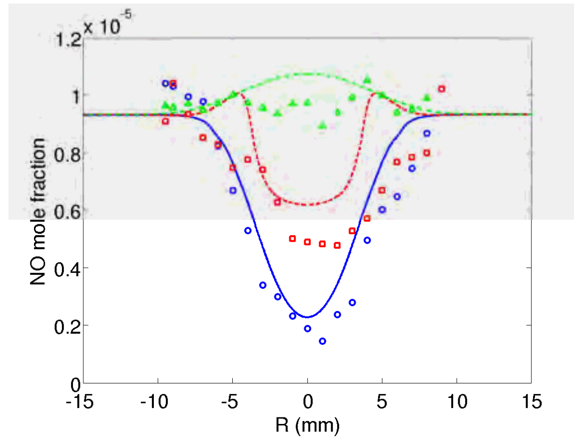

Figure 5. *The measured and calculated NO in Case M at three different heights as a function of the radial distance.*

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