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Structure and Radiation Properties of Large-scale Natural Gas/Air Diffusion Flames

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Recent data from large-scale turbulent natural gas/air diffusion flames (135–210 MW) were used to evaluate analysis of flame structure and radiation properties. The conserved-scalar formalism, in conjunction with the laminar flamelet concept, was used to estimate flame structure. The discrete-transfer method, in conjunction with a narrow-band radiation model, was used to predict radiative heat fluxes. The narrow-band model considered the nonluminous gas bands of water vapor, carbon dioxide, methane and carbon monoxide in the 1000–6000 nm wavelength range. Structure predictions were encouraging, with discrepancies for mean temperatures (*ca* 200 K in the hottest portions of the flames) comparable to experimental uncertainties, due to thermocouple errors, flame disturbances from ambient winds and lifting and external expansion effects near the injector. Radiative heat flux predictions were also reasonably good, e.g. predictions based on mean scalar properties were generally 15% lower than the measurements. The findings also suggest that continuum radiation from soot is negligible for these flames.

INTRODUCTION

Radiation from turbulent diffusion flames dominates energy transport from unwanted fires, influencing their burning and growth rates. Flame radiation is also a serious hazard to personnel and equipment during fires resulting from blowout of oil and gas wells, even though these fires do not spread in the conventional sense. Furthermore, the design of industrial flares involves consideration of flame radiation properties for similar reasons. Motivated by these problems, the present study considers the structure and radiation properties of large-scale turbulent diffusion flames.

Several recent studies have considered the structure and radiation properties of laboratory-scale turbulent diffusion flames (flame heights *ca* 1 m).[1–9] Methods for predicting flame structure and radiative heat fluxes were evaluated using measurements for vertically-upward fuel flow in still air. The following fuels were considered: methane,[1–4] propane,[5] carbon monoxide,[6] hydrogen,[7] ethylene[8] and acetylene.[9] Predictions of structure and radiation properties were encouraging for these laboratory-scale flames; however, the potential of these methods has not been evaluated for large-scale flames which are often encountered in practice.

The objective of the present investigation was to remove this deficiency by using data recently obtained from large-scale turbulent diffusion flames[10,11] to evaluate structure and radiation predictions. The measurements involved vertically-upward injection of natural gas (96% methane by volume) in still air. Seven flames were tested (flame heights *ca* 25 m) with chemical energy release rates in the range of 135–210 MW. Measurements were made of mean temperatures and radiative heat fluxes, providing a reasonable data base to evaluate both structure and radiation predictions.

The paper begins with a description of the measurements. This is followed by a summary of theoretical methods used to compute flame structure and radiative heat fluxes. Auxiliary measurements in laminar flames, used to find the relationship between the extent of mixing and scalar properties, are then described. The paper concludes with a comparison between predictions and measurements for the turbulent flames. The present discussion is brief, and further details concerning theory and experiments (including a complete tabulation of data) are provided by Gore[9] and Pfenning.[11]

MEASUREMENTS

Test arrangements

The general character of the large-scale flames can be seen from Fig. 1. The scale of the flames can be measured by noting that the instrument mast at the left-hand side of Fig. 1 is 24.4 m high. The lower third of the visible portion of the flame is blue while the remainder is yellow, which is very similar to the appearance of laboratory-scale natural gas/air diffusion flames.[1–4,9] While the yellow color suggests potential continuum radiation from soot, measurements in the laboratory flames showed that continuum radiation in the infrared was negligible.[1–4] Evidence from the present study, to be discussed later, leads to a similar conclusion for the large-scale flames.

The composition of the natural gas used for the large-scale flames is summarized in Table 1. The gas composition used during the earlier laboratory tests,[1–4] as well

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