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Radiative heat flux characteristics of methane flames in oxy-fuel atmospheres

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ABSTRACT

Oxy-fuel combustion is a promising alternative for power generation with CO_2 capture, where the fuel is burned in an atmosphere enriched with oxygen and CO_2 is used as a diluent. This type of combustion is characterised by uncommon characteristics in terms of thermal heat transfer budget as compared to air supported systems. The study presents experimental results of radiative heat flux along the flame axis and radiant fractions of non-premixed jet methane flames developing in oxy-fuel environments with oxygen concentrations ranging from 35% to 70%, as well as in air. The flames investigated have inlet Reynolds numbers from 468 to 2340. The data collected have highlighted the effects of the flame structure and thermo-chemical properties of oxy-fuel combustion on the heat flux radiated by the flames. It was first observed that peak heat flux increases considerably with oxygen concentration. More generally the radiant fraction increases with both increasing Reynolds number in the laminar regime and oxygen concentration. It was found that despite a difference in flame temperature, the radiative characteristics of the flames (heat flux distributions and radiant fraction) in air were similar to those with 35% O_2 in CO_2. The radiative properties of flames in oxy-fuel atmosphere with CO_2 as diluents appear to be dominated by the flame temperature.

1. Introduction

Increasing concerns about the effects of global warming and its relation to industrial activities have resulted in the development of new technologies enabling the capture of CO_2 for further sequestration, in order to lower greenhouse gas emissions. These innovative solutions have an efficiency penalty however and none of them can be foreseen as a clear technology winner. Research and development is therefore carried out on several fronts. One of the alternatives termed oxy-fuel combustion is based on separating the oxygen from the air (through an Air Separation Unit) and injecting it into the combustion unit leading to reaction products ideally composed of solely CO_2 and steam. The technology can in principle be applied to any power cycles and any fossil fuels from natural gas [1–4] to coal [5,6]. The prime advantage of the method is that the capture of CO_2 is simple and cost effective, but the efficiency penalty comes from the energy demanding air separation stage. As far as the combustion is concerned, several challenges arise: excessive temperatures beyond material integrity, unusual combustion properties (flame speed, flammability limits, stabilisation), operation at stoichiometric condition, ease of triggering of thermo-acoustic instabilities, CO burn out, and thermal heat transfer [5,7,8]. To solve the high temperature problem, dilution is necessary and CO_2 is the obvious inert since it is already present in the flue gas that can be recycled. The oxy-fuel technology is per today at pilot stage for coal-fired power plants (e.g. [4,9]), but still requires further development for more complex pressurized combustion systems as in gas turbines.

Radiative heat transfer is an important flame property for the design of combustion systems. In that respect, the particularity of oxy-fuel combustion is that the product gases are composed of radiating species (CO_2 and H_2O), whereas they only represent a few percents in air supported combustion. Their contribution in heat transfer depends on the partial pressure, the temperature, and the path length [10]. Earlier work on oxy-fuel combustion are reported already from the 1990's [11,12], with focus on coal as fuel. The study of Andersson et al. [13] in propane-fired oxy-fuel boiler has shown that the flame in 27% O_2 in CO_2 has a similar behaviour as in air, but with radiative heat flux up to 30% higher, whereas similar temperature profiles were achieved already with 21% O_2 in CO_2. Radiative heat fluxes measurements made by Tan et al. [3] indicated that similar heat distribution were only achieved at 28% for a natural gas flame. However, the measurements were made with a hemispherical probe and not corrected for background wall radiation, and the measurements of Andersson and Johnsson [14] only cover two axial locations. Nevertheless, the largest discrepancy probably comes from the different propensity of the fuels used to generate soot. Andersson et al. [13] concluded that oxy-fuel operation at 27% increases in-flame soot volume fraction (as clearly demonstrated elsewhere [15,16]), and is responsible for most of the increase in radiation. It is difficult

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