Laser Diagnostics in MILD Combustion

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Preface

This document is the culmination of many years of study, and is the thesis submitted for the award of Doctoral of Philosophy. The topic of research is the Moderate or Intense Low oxygen Dilution (MILD) combustion regime, which is studied using laser diagnostic techniques. MILD combustion is a particular combustion mode which offers the desirable combination of higher thermal efficiency and lower pollutant emissions, as compared to conventional combustion systems. The importance of developing efficient and low pollutant combustion systems is increasingly important with the current issues of global climate change and the ever diminishing supplies of energy resources. The work presented in this thesis uses an experimental burner to study fundamental aspects of MILD combustion. The intention of this work is to help in the development of the world's understanding of this unique combustion regime so that it can be used to benefit combustion systems and everyone who relies on them.

Declarations

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Paul R. Medwell

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Abstract

Despite mounting concerns of looming global warming and fuel shortages, combustion will remain the predominant source of fulfilling the world's ever-increasing demand for energy in the foreseeable future. In light of these issues, the combustion regime known as Moderate and Intense Low oxygen Dilution (MILD) combustion has the potential of offering increased efficiency whilst lowering pollutant emissions. Essentially, MILD combustion relies on the reuse of the exhaust gases from the combustion process to simultaneously dilute the oxygen concentration of the oxidant stream, and increase its temperature. The benefit of this technique is that it results in a vast reduction in emissions, especially oxides of nitrogen. In addition, the thermal efficiency of the combustion process is increased, reducing fuel demands, as well as producing a more uniform heating profile and subsequently better product quality for many applications.

The recirculation of exhaust gas and heat has been utilised for applications in the past. MILD combustion aims to extend the advantages of heat recovery and exhaust gas recirculation beyond the boundaries that are otherwise possible using conventional techniques. The relatively new concept of MILD combustion is a major advancement to the previous technology, and many fundamental issues have not yet been resolved. In a furnace environment, the dilution and preheating of the reactants generate a unique "distributed" reaction zone. There is a need to better understand the structure of this combustion regime and the parameters which control it.

To emulate MILD combustion conditions in a controlled experimental environment, a Jet in Hot Coflow (JHC) burner is used in this study. The MILD combustion regime is examined using laser diagnostic techniques. The two key flame intermediates hydroxyl radical (OH) and formaldehyde (H_2CO), as well as temperature, are imaged simultaneously to reveal details relating to the reaction zone. Simultaneous imaging enables not only the spatial distribution of each scalar to be investigated, but also the combined effect of the interactions of the three measured scalars.

The role of four key variables are investigated as part of this work, namely; the

coflow oxygen (O_2) level, the jet Reynolds number, fuel dilution and fuel type. Also considered is the effect of surrounding air entrainment into the hot and diluted coflow, which causes a deviation from MILD combustion conditions.

The local oxygen (O_2) concentration is a key parameter in the establishment of MILD combustion conditions. The effect of lowering the O_2 level is to lead to reductions in the OH and temperature in the reaction zone, in effect leading to a less intense reaction. When comparatively high oxygen laden, cold surrounding air mixes with the hot and low O_2 coflow, MILD combustion conditions no longer exist. In this case, the flame front can become locally extinguished and subsequent premixing with the high O_2 concentrations can lead to increased reaction rates and hence higher temperatures. It is therefore essential that fresh air must be excluded from a MILD combustor to maintain the stable reaction which typifies MILD combustion.

It is found that the flame structure is relatively insensitive to both the type of hydrocarbon fuel and the Reynolds number. Each of these parameters can lead to changes in some intermediate species, namely formaldehyde, yet the OH and temperature measurements show comparatively minor variation. Nevertheless, fuel type and Reynolds number, in the form of increased flow convolution, can lead to striking differences in the flame structure. One of the most prominent effects is noted with the dilution of the fuel with various diluents. Some of the flames visually appear lifted, whereas the measurements reveal the occurrence of pre-ignition reactions in the "lifted" region. The unique characteristics of the stabilisation for these particular cases has lead to the term transitional flames.

The fundamental aspects discovered by this study shed new light on the reaction zone structure under MILD combustion conditions. By advancing understanding of MILD combustion, future combustion systems will be able to better utilise the efficiency increases and lower pollutant benefits it offers.

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