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ScienceDirect
Fuel 87 (2008) 1042–1049
FUEL
www.fuelfirst.com

Factors influencing the ignition of flames from air-fired swirl pf burners retrofitted to oxy-fuel

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Received 10 May 2007; received in revised form 21 June 2007; accepted 26 June 2007
Available online 30 July 2007

Abstract

Combustion tests were undertaken in a vertical pilot-scale furnace (1.2 MWt) at the IHI test facility in Aioi, Japan, to compare the performance of an air fired swirl burner retrofitted to oxy fired pf coal combustion with the oxy fired feed conditions established to match the furnace heat transfer for the air fired case. A turn down test at a reduced load was also conducted to study the impact on flame stability and furnace performance.

Experimental results include gas temperature measurements using pyrometry to infer the ignition location of the flames, flue gas composition analysis, and residence time and carbon burnout. Theoretical computational fluid dynamics (CFD) modelling studies using the Fluent 6.2 code were made to infer mechanisms for flame ignition changes.

Previous research has identified that differences in the gas compositions of air and oxy systems increase particle ignition times and reduce flame propagation velocity in laminar systems. The current study also suggests changes in jet aerodynamics, due to burner primary and secondary velocity differences (and hence the momentum flux ratio of the flows) also influence flame shape and type.

For the oxy fuel retrofit considered, the higher momentum flux of the primary stream of the oxy-fuel burner causes the predicted ignition to be delayed and occur further distant from the burner nozzle, with the difference being accentuated at low load. However, the study was limited to experimental flames being all Type-0 (low swirl with no internal recirculation), and therefore future work consider higher swirl flames (with internal recirculation) more common in industry.

Keywords: Oxy-fuel combustion; Ignition delay; Fluent CFD modelling

1. Introduction

Coal contributes to 37% of worldwide electricity generation and is expected to play an important role in global energy supply [1]. Traditionally, electricity is generated by combusting coal with air resulting in carbon dioxide emissions. This is a source of greenhouse gas and has been associated with global warming. New low CO_2 emission concepts must therefore be developed [1], particularly those suitable for the existing utility fleet. For existing plants, CO_2 emissions can be concentrated either by removal of nitrogen from flue gases or by removal of nitrogen from the feed air, to provide a CO_2 rich stream ready for capture and storage. This latter technology is called oxy-fuel technology. This technology recycles flue gas back into the furnace to establish the same heat flux profiles in the boiler as conventional air firing boiler. However, differences in the ignition of flames from existing pf burners retrofitted to oxy-fuel are expected. This paper identifies these differences and their underlying mechanisms using experiments with both air and oxy-fuel in a pilot-scale furnace using the same coal and mathematical modelling.

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doi:10.1016/j.fuel.2007.06.026

2. Air and oxy combustion

Fig. 1 shows a schematic of air and oxy combustion process, with recirculated flue gas used to control temperatures and furnace heat transfer. In air combustion, the primary air stream is used to transport coal with a separate secondary air stream used to provide the balance of the air. In an oxy combustion retrofit, part of the recirculated flue gas (RFG) known as primary RFG is used to transport coal, and the remaining flue gas known as secondary RFG usually includes the direct O_2 feed.

The differences between air and oxy combustion are:

- Combustion medium in air (O_2/N_2) and oxy/RFG ($O_2/CO_2/H_2O$).
- Composition of combustion products, gases and particulate concentrations.
- Thermal properties (density, specific heat capacity, viscosity) as well as radiative properties (emissivity) of the furnace gases (as quantified in Table 1), thereby affecting.
- Temperature and heat flux profiles in the combustion chamber, combustion and heat transfer efficiency.

The qualitative trends in the burner flows – both primary and secondary – for a retrofit can be inferred from Fig. 1 using the differences in properties between the dominant gases for air firing, being N_2, and for oxy-fuel, being CO_2, given on Table 1. The higher heat capacity for CO_2 requires a higher O_2 proportion for the gases fed through the burner to establish similar adiabatic flame temperatures for air firing, typically 30% by volume [2]. As this exceeds the O_2 proportion compared to air, the total volumetric flow through the burners is reduced. The velocity of the primary gas must be maintained to keep the pf in suspension, requiring a minimum velocity of typically 17 m/s. As the density of CO_2 is also higher than N_2, the mass flow of the primary flow is increased. The balance of the mass of the RFG fed to the secondary stream is thereby reduced. For a retrofit therefore, the velocity of the secondary flow is reduced. For swirl burners, the secondary flow is usually swirled; the primary is not, so that the overall swirl level of the combined burner flows will be reduced.

In summary, for a retrofit, changes to the mass flows and velocities of the primary and secondary streams due to the different heat capacity and densities of the main gases – N_2 and CO_2 – will change burner aerodynamics, thereby influencing flame ignition and flame shape.

Table 2 shows typical flue gas composition for air and oxy fired for a given Australian pf coal (Coal-A). It can be noted that the concentration of the radiating gases – CO_2 and H_2O – is much higher in oxy fired compared to air fired case, the pilot scale furnace input conditions were determined such as to match the furnace heat transfer for a retrofit application. Heat and mass balance calculations conducted by maintaining the same 3.3% (wet) O_2 concentration levels in the flue gases for both oxy-fuel and air firing and matching furnace radiative heat transfer, indicate

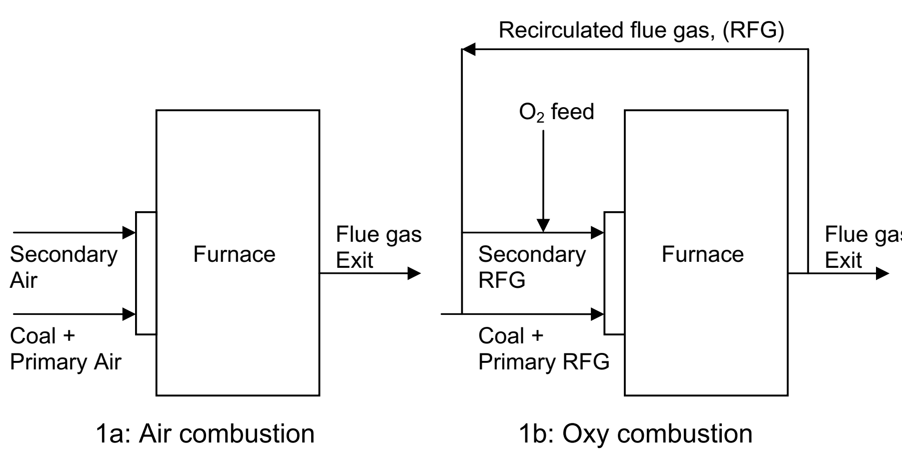

Fig. 1. Schematic of air and oxy-fuel combustion flow sheets, indicating the recirculated flue gas (RFG) forming the burner flows and oxygen added to the secondary flow. In practice the RFG may be dried, but this was not the case in the experiments.

Table 1
Property table for gases at 1400 K and atmospheric pressure

	H_2O	O_2	N_2	CO_2
Density (ρ) (kg/m^3)	0.157	0.278	0.244	0.383
Thermal conductivity (k) (W/m K)	1.3631e−01	8.721e−02	8.1839e−02	9.7193e−02
Specific heat capacity @ const. pressure (c_p) (kJ/kmol K)	45.67	36.08	34.18	57.83
Dynamic viscosity (μ) (kg/m s)	5.0184e−05	5.8105e−05	4.877e−05	5.023e−05
Kinematic viscosity (v) (m^2/s)	3.20e−04	2.09e−04	2.00e−04	1.31e−04