1. Introduction

The CO$_2$ Capture Project (CCP) is an international effort funded by six of the world's leading energy companies. For the past ten years, this project has been addressing the issue of reducing emissions in a manner that will contribute to an environmentally acceptable and competitively priced continuous energy supply for the world.

The Oxy-firing tests were performed in a simulated process heater as part of a range of activities sponsored by the 3rd phase of the CO$_2$ Capture Project (CCP3), followed by computational fluid dynamics (CFD) analyses of the test furnace under those test conditions. The objective of the tests was to evaluate the feasibility of utilizing commercial process heater burners for oxy-firing, and to compare burner performance with conventional air-firing. The CFD analyses were meant to provide greater insight into the operational changes as the conventional burner is switched from air-firing to oxy-firing mode. A low-NO$_x$ (PSFG) burner and an ultra-low NO$_x$ (COOLstar™) burner were used in the tests, along with two fuel types. A test matrix similar to that recommended in API RP-535 (Burners for Fired Heaters in General Refinery Services) was used. CFD simulations utilized a commercial code, ANSYS FLUENT 13.0, along with a user-defined methodology to calculate the absorption coefficients and emissivities under oxy-firing conditions.

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2. Next

High flame temperatures generated by combustion with pure oxygen necessitates external flue gas recirculation to moderate the temperature. This has consequences for flame shape and size, temperature and heat flux profile, and overall heater performance and operational efficiency. Heater simulations using FRNC-5 were used to define the external flue gas recirculation rates, and oxygen concentrations in the oxidant, used during the burner tests, and subsequent CFD simulations.

Burner performance under oxy-fired conditions was very similar to that for air-firing; however, small changes in heat flux profile were observed. Carbon monoxide (CO) mole fraction of 2000 ppmvd was used to determine the flame dimensions. A CO probe was used to measure the length and the width of the flame using this criterion. Temperature measurements utilized velocity thermocouples installed at the floor, at 15 ft elevation in the furnace and at the furnace exit. The heat flux profile was measured with a calibrated water-cooled flux probe. The radiometer in the flux probe was designed to measure the incident radiant heat flux. Emissions measurements included continuous monitoring of O₂, CO and NOₓ concentrations at the stack.

An important observation during the tests was that the time required to reach a steady nitrogen content in the flue gas took much longer than expected. The concentration of nitrogen in the recycled flue gas stream remained in the 15% - 20% range, on a volume basis, due to air leakage into the firebox – due mainly to the high vacuum levels required to overcome the significant backpressure caused by the presence of a boiler upstream of the ID fan. The boiler was required to simulate heater convection section, lowering the flue gas temperature at or below a 550 °F limit imposed by the metallurgy of the ID fan. The effect of leakage was lower when the test furnace was operated at lower negative pressure; however, the amount of air leakage in an operating heater will be highly dependent on how well the heater is sealed.

3. Next Sections

In general, excellent agreement between the CFD results and the test furnace data were obtained. Bulk flue gas flow patterns and temperature distributions were similar to what was observed and measured in the test furnace. Carbon monoxide (CO) mole fraction contours were used to visualize the flame envelope. The radiation calculations for oxy-fired cases were supplemented with a user-defined function designed to calculate flue gas absorption coefficients and emissivity values for the elevated water and carbon dioxide concentrations in the flue gas stream. The measured fuel gas flow, and the measured and predicted flue gas compositions, provided for the comparison between measured and predicted heater efficiencies.

For the COOLstar™ burner, the CFD model consistently under-predicted the flame length by an average of about 10%. This is well within the experimental uncertainty of the test data and demonstrates excellent agreement. The incident heat flux profile results compared fairly well with the experimental data and were also within the uncertainty of the test data. The best agreement between CFD result and test data was obtained for the RFG-air case where the location of the peak heat flux, as well as the overall flux profile, agreed very well with the measured data. Similarly, the natural gas-air case showed good agreement between the predicted and measured locations of peak heat flux. The absorbed duty was about 6% higher for oxy-firing compared to air-fired operation, in line with expectations based on the FRNC-5 simulations conducted prior to the tests.

Flame length predictions for the PSFG burner were within 30% of test measurements. The higher deviation in flame length, compared to the COOLstar™ burner, was partly due to the flame structure, and the measurement technique employed. However, the consistent, and somewhat higher than expected, over-prediction suggests that an improvement in the CFD model is needed. The predicted incident radiant flux profiles showed reasonable agreement with the incident flux values measured by the radiometer. An increase in absorbed duty for oxy-firing, similar to that observed for the COOLstar™ burner, was also observed for the PSFG burner.
The burner test campaign and related CFD simulations demonstrate that conventional burners can be utilized for oxy-firing in process heaters to obtain performance similar to that for air-firing. However, the leakage of tramp air would be a potential deterrent since it would result in significantly higher cost of CO$_2$ purification. CFD simulation tools can be applied to evaluate, or predict, the performance of oxy-fired process heaters quite well. The prediction of radiative properties of the CO$_2$- and H$_2$O-enriched flue gas, and consequent prediction of heat transfer, is considered an area for further development.

4. Acknowledgements

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