Experimental Investigation of an Oxy-fuel Gas turbine Burner

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ABSTRACT

Power production with CO_2 capture by using the oxy-fuel combustion concept has been proven to be a competitive technology for coal based power plants. Its application to natural gas combined cycle has however been limited due to the need to entirely re-design the gas turbine to operate in a semi-closed mode with CO_2 as the working fluid. This study presents results of an experimental test campaign using a new oxy-fuel burner designed at SINTEF in a high pressure oxy-fuel combustion facility (HIPROX) with a design pressure of 10 bar and 100 kW input load. The swirl stabilized oxy-burner uses a mixture of CO_2 and O_2 as oxidizer and generates a flame in a cylindrical double wall quartz combustor. An additional CO_2 stream, used to cool the flame tube, is injected further downstream in the dilution section. The stability of the methane fired oxyburner has been mapped for various O_2 concentrations in the oxidizer and excess O_2 ratios. One important result is that CO emission is high compared to typical values for combustion in air, even at 30% excess O_2 ratio. CO oxidation is recognized to be more kinetically challenging in oxy-fuel mode because of the high CO_2 concentrations, even though their emissions are well controlled in boilers. The problem is exacerbated in gas turbine conditions because of the low residence time in the combustion chamber and the presence of a cool CO_2 dilution stream quenching the chemical reactions. The effect of primary zone combustion temperature on CO is studied by controlling the O_2 concentration. The effect of pressure on oxy-fuel combustion has been tested up to 5 bar in this study. CO emissions are found to be also quite pressure dependent as it first drops when the pressure is increased, but rise again slightly from 2 bar up. This is believed to be the consequence of flame structure and unfortunate location of secondary CO2 cooling jets.

RESULTS AND DISCUSSION

Quite high oxygen concentrations were needed to obtain stable combustion with this burner because of the high impulse strategy used in its design to stay away from flashback behaviour. At higher power, the blow-off occurred at higher oxygen concentration as the gas velocity increases with power. Figure 1 shows the CO emission as function of excess oxygen at a fixed O2C of 45% reaching percentage levels. As expected, the CO formation decreases with increasing excess oxygen but the level is still high at 30% excess oxygen. This is a challenge as the excess oxygen should be kept as close to zero as possible to obtain an exhaust consisting of almost only CO_2 and water.

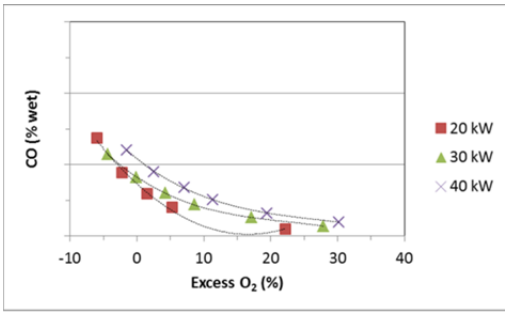

Figure 1 CO emission as function of excess oxygen

Figure 2 shows the CO emissions as a function of the oxygen concentration in the oxidiser stream at stoichiometric condition. The corresponding adiabatic flame temperature is shown in figure 3. Even though the adiabatic flame temperature is about 200 K higher at the highest O2C than at the lowest, the level of CO is not much different. This may be a result of competing effects, e.g. the effects of flame temperature and residence time.

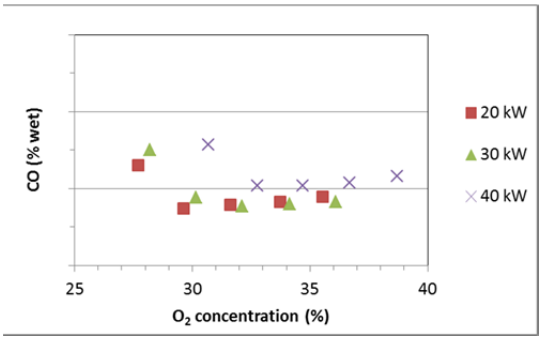

Figure 2 CO emission as function of oxygen concentration

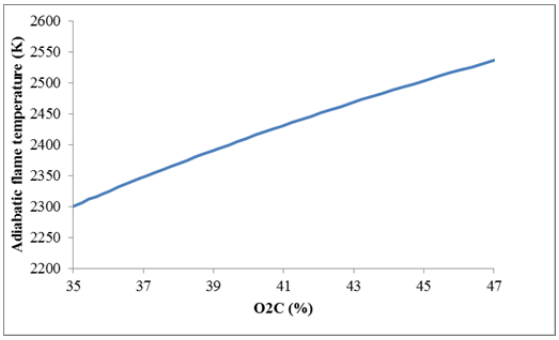

Figure 3 Adiabatic flame temperature for stoichiometric mixture as function of O2C

Even though the CO levels are high, it is much lower than the equilibrium concentration at adiabatic flame temperature which is very high at these conditions. As an example, stoichiometric combustion of methane with 45% O2C has an equilibrium CO concentration of about 9 %-vol at 2504 K (adiabatic flame temperature), which represents about 52 % of CH_4 fuel on mole basis. The experiments also showed that all the methane was converted as the methane level was measured to zero ppm in all the experiments. This may indicate that the high CO level is not caused by poor mixing but is rather a result of too low residence time and/ or quenching of the reactions from high temperature when the CO_2 used for cooling is injected just downstream the combustion chamber.

The effect of pressure on CO formation was observed to first decrease abruptly when increasing the pressure. But above 2 bar the CO levels rise again slightly despite the residence times becoming longer. The increase of pressure affect the flame shape (cf. Figure 4) and it is believed that the CO2 cooling jets meant to mix with the flame products are quenching local regions of high CO.

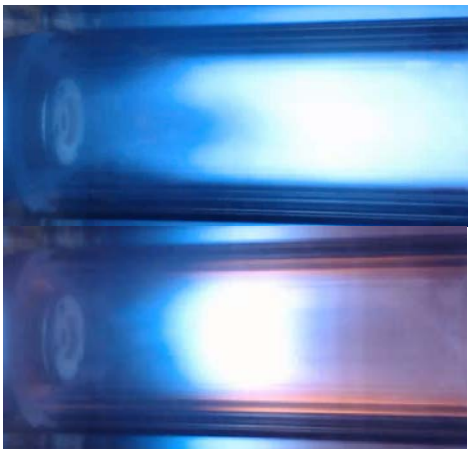

Figure 4 Flame at 1 atm (top) and 3 bara (bottom)