Ultra wet combustor technology for highly efficient and clean gas turbines

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Long Abstract

Introduction

Humidified gas turbines operating at ultra-wet conditions offer a significant increase in efficiency compared to the dry gas turbine cycle. In single-cycle application, ultra-wet gas turbines reach efficiencies comparable to state of the art combined-cycle power plants with up to 55% - 60%,but with much lower installation costs and emission levels. In contrast to the complex combined-cycle plants, ultra-wet gas turbines have a substantially smaller footprint. With short start-up times and excellent load control capabilities, they can also be used to compensate for the rapid fluctuations in wind energy. Ultra-wet gas turbines have a high fuel flexibility and can be operated on natural gas, hydrogen-rich fuels from biomass or coal gasification, and pure hydrogen, at very low NOx and CO emissions. Current gas turbine technology is not able to operate on hydrogen-rich fuels efficiently and at low emis- sions. This is mostly caused by the high reactivity of hydrogen, which leads to a flame speed that is about one order of magnitude higher than that of natural gas, resulting in an increased risk of flame flashback. The presence of hydrogen in the fuel can also lead to increased NOx emissions due to higher local temperatures. In ultra-wet gas turbines, the reactivity of the hydrogen is significantly lower, allowing for clean and efficient operation using hydrogen-rich fuels.

The current study is investigating premixed combustion of natural gas and hydrogen over a wide range of equivalence ratios from lean blowout to near- stoichiometric conditions, and steam and nitrogen content in the air between 0% and 30%. The influence of dilution on NOx and CO emissions formation, flame shape, and combustor temperature distribution is investigated in gas-fired tests. A UV probe is used to measure the local OH radical concentration in the flame using the species' absorption characteristics. The OH* chemiluminescence of the flame is measured in order to determine the flame shape and position, and for a qualitative comparison with simulation results.

A reactor network is designed and validated with the experimental results. It is used to gain further insight into the emission formation for natural gas and hydrogen. A lean flame, and a flame close to stoichiometric conditions, are investigated at three different flame temperatures. Rate-of-production analysis and sensitivity analysis reveal the influence of steam and nitrogen dilution on important species concentrations and on NOx formation.

1. Experiments

The experiments are conducted with a generic, premixed burner (Fig. 1), which provides a nearly homogeneous mixture of fuel, air and steam at the burner outlet. For the current study, the injector is set to a constant swirl number of S = 0.7. Steam and nitrogen can be used as diluents, and are premixed with the heated air upstream of the injector.

2. Modelling

The combustion process is modeled with a reactor network with the software Cantera to gain detailed insight into the NOx and CO formation at wet conditions. Two different reaction mechanisms are used: the GRI-Mech 3.0 mechanism, and the "Detailed reaction mechanism for small hydrocarbons combustion, Release 0.5" by Konnov. For comparison with the measured OH* chemiluminescence, a sub-mechanism for the OH* kinetics is added to the mechanisms for these specific simulations, which is based on the work by Petersen et al. Since the concentration of OH* is very low compared to its ground species, the effect on the whole combustion mechanism is small. Pure methane is used in the simulations of the natural gas flame.

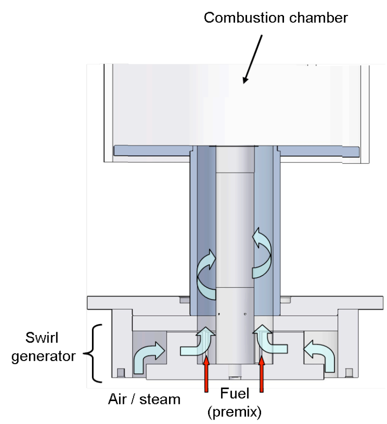

Figure 1. The injector

3. Results

The influence of steam and nitrogen dilution on the flame shape and emission formation is discussed based on the experimental results, and the reactor network is validated with these data. Subsequently, the model is used for a detailed investigation of the influence of steam and nitrogen dilution on the NOx formation.Without dilution, the measured NOx emissions are relatively low at lean conditions (Fig. 3). Towards higher equivalence ratios and temperatures, however, NOx increases rapidly due to the increased contribution of the thermal pathway. For the same equivalence ratio, hydrogen fuel leads to higher emission levels than natural gas due to the higher flame temperature, while for the same temperature, both fuels lead to similar NOx concentrations in the exhaust gas. The experiments were conducted with a premixed combustion system at atmospheric conditions. At higher pressure, this would not be possible with hydrogen due to risk of flashback. Instead, diffusion type combustors are used in current gas turbines for hydrogen-rich fuels, which usually lead to high NOx emissions.

With steam dilution, NOx emissions are significantly reduced for natural gas as well as for hydrogen. This is the case also for the same flame temperature, when the equivalence ratio (combustor power) is increased to compensate for the higher heat capacity of the added steam (Fig. 3).

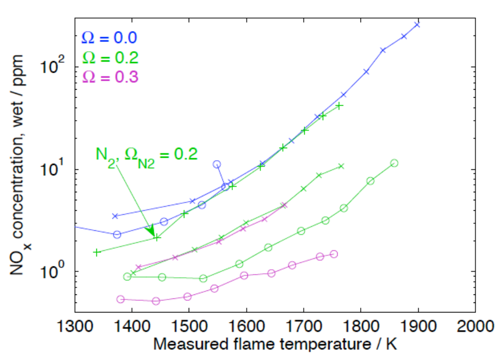

Figure 3: Measured NOx concentration versus measured flame temperature for natural gas (—×—) and hydrogen (—◦—). The equivalence ratio was decreased from φ =0.95 (dry H2 flame from φ =0.55) to blowout for each curve (*Tin* =623 K).