Popular Science Summary

Title

Ammonia Combustion: Design Principles and Case Studies

Author

Boonsita Kittiwirayanon

Heading

The benefit of being patient towards lowering emissions from ammonia flames

Introduction

Burning ammonia with the delayed secondary air injection strategy reaches NOx emissions lower than the regulation limit.

Main text

Gas turbines have been essential machinery for industrial development due to their abilities to generate peak power demand as well as on-site power for industrial facilities. A combustor, one of the main components in gas turbines studied here, is used to raise the working fluid temperature by burning the fuels. However, since natural gas, which is the main conventional fuel for this machinery, is a fossil fuel that has harmful effects on the climate, we need to phase it out in favour of using green fuels. Here, ammonia derived from renewable electricity is chosen, but since the nitrogen atom contained in ammonia (NH_3) results in NOx emissions, many combustion concepts for minimising pollutants are studied. One of the promising concepts is an RQL burner.

In the RQL combustor, the ammonia and air are burned in such a ratio that the amount of ammonia is in excess for the complete combustion, resulting in a rich condition (R). When the reaction occurs in the primary zone, it is necessary, especially for ammonia flames, to wait for the chemical species to relax towards their equilibrium levels. Then, the secondary air is injected in a quick-mixing manner (Q) to burn the combusted gases in a lean condition (L) in the secondary zone. This strategy makes use of species close to equilibrium level, where they are so low in reaction with air that the combustion in the secondary zone doesn't cause more emissions. However, the combustor cannot be infinitely long. To find the best secondary air injection, a numerical study of combustion and species relaxation in the primary zone is carried out.

In this study, two numerical analyses are performed. First, a reacting-flow simulation is conducted to see the instantaneous flow fields and the species formations in the primary zone. The simulation is done using CFD in Star-CCM+ with the LES method. Then, chemical compositions from different lengths of combustion chambers are taken out and mixed with air to figure out the trend of emission levels caused by secondary air entering at various points. This calculation is done using the chemical reaction network in Cantera.

The CFD results show a recirculation and a good mixing of partially-cracked ammonia and air in the primary zone on the burner based on the SGT-750 4th generation DLE burner. The design with swirls helps stabilise the flame, and this is necessary since ammonia is less reactive compared to hydrogen and other traditional fuels. Partial cracking of ammonia results in the blend of $NH_3/H_2/N_2$, which is to help tackle such a problem. Moreover, the CFD results illustrate the length and time required for species relaxation.

In terms of total emissions, this study observed the ammonia flame at different levels of richness. It is found that slightly rich flames have less concentration of ammonia to destroy, resulting in fast relaxation. Thus, it is safe to inject the air at the early positions. In contrast, it is safer to be patient and inject the air far away for richer flames, but the emission formation in this type of flame is normally lower. Therefore, if time and size are allowed, richer flames with a faraway secondary air injection can result in ten-ish ppm of NOx emissions.

RQL has been found to be a good strategy for ammonia combustion in gas turbines. Since they are still novel, the combination of primary and secondary mixings is studied here. More details and analyses of the NOx formation pathways and the influence of wall cooling are provided in the full report.

These findings widen the opportunity and flexibility of non-fossil fuel combustion in gas turbines, for example, in the Power-to-X project. Since the primary green fuels derived from renewable electricity, like hydrogen, are difficult to handle, ammonia can be further produced from hydrogen and is regarded as a hydrogen carrier. The use of ammonia instead of hydrogen reduces the complexity and cost of design and operation. Since the most challenging aspects of the combustion of ammonia, like instability and high emissions, are tackled here, we are one step closer to real implementation.