PUBLIC SUMMARY – ENGLISH

INTRODUCTION

Hydrogen combustion in gas turbines is a clean and carbon-free solution for the energy transition. The power generation from variable renewable sources is increasing, thus requiring flexible measures to balance the load of the energy grid. The excess renewable energy can be used to produce hydrogen which can be used as a fuel in gas turbines at times of insufficient supply of renewable energy. Hydrogen fired gas plants in combination with wind and solar electricity production form the end perspective of a CO_2-emission free NW-European electricity system that is fully based on renewable energy sources.

This hydrogen transition is feasible in the Netherlands due to the presence of a dense natural gas infrastructure. GASUNIE plans to partly convert this infrastructure to a hydrogen transportation infrastructure, connecting hydrogen producers and consumers, such as industrial clusters and gas power plants. Retrofitting of existing gas power plants to hydrogen fired power plants can provide a significant and timely contribution to the balancing of the electricity grid.

The purpose of this project is to demonstrate a high hydrogen modular retrofit for existing machines, applicable to a range of gas turbines from 1MW to 300MW, substantially reducing carbon output while capable of flexibly switching between natural gas and high hydrogen operation. Technical basis for the demonstration of the flexible modular retrofit solution is the novel and proven FlameSheet™ combustion system which delivers maximum flexibility while minimizing cost.

The RVO hydrogen program focuses on future carbon free hydrogen value chains. Hydrogen can deliver a carbon free solution for industry (including high temperature heat), mobility, housing for low temperature heat and the power sector. The ambition of the program is to enable joint innovation between Dutch companies and institutes to be able to deliver economic value on the short to medium term.

This project fits very well within the ambitions and objectives of the hydrogen program of RVO as it has the objective to deliver an innovative hydrogen burner design for gas turbine application. The control of stable combustion is one of the main challenges for the application of hydrogen in highly efficient and low NO_x gas turbines. As soon as these hydrogen burners become available as a retrofit for existing gas turbine installation, it will become possible to modify existing gas turbine installations for an energy system with hydrogen as energy carrier. This opportunity means that these gas turbine installations can deliver stability to the electricity grid with zero carbon emissions at minimum investment and operational costs. This stability is required to enable even more wind and solar on the grid.

The main applicant, Ansaldo Thomassen, is a leader in the field of high hydrogen application in gas turbines. The new knowledge and innovations from this project will improve the international competitive position of all partners. The manufacturers of gas turbines and gas turbine retrofits (OPRA Turbines and Ansaldo Thomassen) will have a significant competitive edge in the field of low NO_x hydrogen burners for gas turbine applications. The knowledge from this project will enable the operators (Vattenfall, EMMTEC Services and Nouryon) to make significant progress in the realization of low NO_x, carbon free production of power and heat.

The modification of existing gas turbines to enable carbon free power and heat generation has a direct impact on the growth of business of Ansaldo Thomassen and OPRA Turbines and its associated national and international supply chains for the manufacturing and supply of engine hardware and conversions systems.

During future phases of the project and during the life cycle of the product optimization, coordination with the Technical University Delft will be sustained leading to fundamental work at the University and practical internships and graduation assignments within the partnership.

PROJECT SET UP

In this project the participants, all with facilities based in the Netherlands, participate and each contributed to their field of expertise. The design and manufacturing of the new burner hardware and validation of test results was carried out by Ansaldo Thomassen. The TU Delft developed the flashback model and validated the combustor design and model at a small-scale laboratory burner. OPRA turbines prepared and executed the full-scale test as well as the design of the burner and validation of the test results. The final use of the combustor together with the gas turbine testing and application was evaluated by Vattenfall, EMMTEC services and Nouryon/AkzoNobel Industrial Chemicals BV.

RESULTS

TU Delft made significant improvements to an existing model from TU Munich including application to general geometries and flow conditions, coupling to CFD software and application for gas turbine temperature premix conditions. The model has been improved based upon a number of cases from literature. The model has also been validated against the FlameSheet^{TM} experiments by TU Delft and at the OPRA atmospheric test facility.

Ansaldo Thomassen has designed the various configuration of the FlameSheet^{TM} combustor using multiple design techniques. The configurations were scaled downward from F-class size parts to OPRA OP16 size parts while reviewing all critical parameters as geometry, pressures, flows and intensities. Thermal modelling was used to calculate the temperatures that the parts of the combustor are exposed to, in order to select the appropriate materials and coatings. Furthermore, computational fluid dynamics (CFD) was used to determine the aerodynamic behaviour of the main flame path to understand the recirculation zone, ensure stable flame, review fuel mixing behaviour and flashback prediction. The assembly of new design OP16 size hydrogen ready FlameSheet^{TM} can be seen in Figure 1.

A number of FlameSheet™ combustor variants were evaluated. The objective of operating a range of variants was to understand and map sensitivity of emissions and flashback, especially operating in premixed conditions with 100% hydrogen at high flame temperature. The results obtained were at atmospheric operating pressure, but full engine temperature conditions. Series of tests were completed for multiple configurations on natural gas, where the fuel air ratio was tailored for flashback robustness, with special consideration of boundary layer fuel/air ratio. For each variant, the hydrogen operation was then mapped in a similar procedure for NO_x performance across a range of flame temperatures, until a point of flashback or an upper threshold flame temperature was achieved. As expected, the NO_x values increase with increasing hydrogen content in the fuel, and the magnitude of this increase in NO_x is also a function of the operating flame temperature. This translates to a need for low NO_x when operating on natural gas, as well as ensuring well optimized premixing of the fuel and air. While not each configuration tested was able to operate at maximum flame temperature without flashback, this was achieved on some of the builds. Figure 3 illustrates the NO_x behaviour on a build in which no flashback was observed, and operations were only limited by the maximum operating temperature limits of the system. At normal full baseload operating flame temperature NO_x below 25 ppm (ppmv @ 15% O_2 dry) was demonstrated with 100% hydrogen operation. Figure 2 illustrates the operation of the configuration used for the results plotted in Figure 3.

Note that with 100% hydrogen the flame becomes invisible, and so the color seen is a reflection of the glowing while operating at elevated temperature (above normal baseload operation).

Figure 1 FlameSheet™ Combustor Hardware

Figure 2 100% hydrogen - baseload conditions

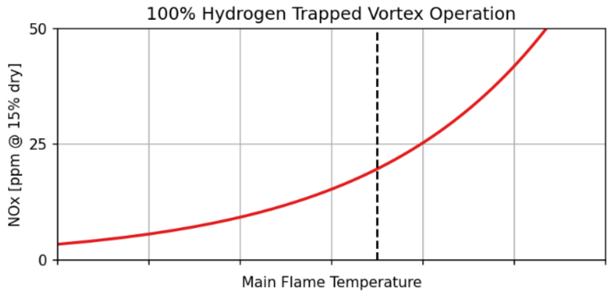

Figure 3 NO_x emissions at 100% hydrogen trapped vortex operation. Black dashed line indicates baseload operation.

CONCLUSIONS & RECOMMENDATIONS

The data from the test campaign showed promising first results. The different builds of the FlameSheet™ design were able to run at baseload, however the aggressive emissions were not met, although robust solutions were demonstrated. Operation with 100% natural gas as well as 100% hydrogen was achieved. Moreover, switching from fully hydrogen operation to only natural gas is demonstrated. The test data also showed that the results obtained through computational fluid dynamics were in accordance with the test results. As expected, flashback prevention was not achieved for every build with 100% hydrogen, which provided valuable insight in comparing builds which were able and unable to achieve this flashback goal.

A state-of-the-art atmospheric combustion test facility was successfully upgraded to allow flexible testing from 100% natural gas to 100% hydrogen. Diagnostic tools allowed the characterization of key operating parameters including temperatures, pressures, emissions, combustion dynamics and optical visualization.

Operations using the identical FlameSheet™ combustion hardware were achieved with fuel constituents ranging from 100% natural gas to 100% hydrogen. A number of geometrical adjustments were evaluated to map flashback margins and emission effects. While the overall emissions objective of sub 9 ppm NO_x with 100% hydrogen at full baseload operating temperature was not achieved, the emission sensitivity of the variants tested illustrated the adjustments needed to achieve this objective.

The test results show the design is in the right direction which enables to continue improving the current designs. Future work can focus on the validation of the results at high pressure conditions. Also, the findings from the test data can be implemented in new designs to improve performance at high pressure test.

Subsequent work will build upon the lessons learned with 100% hydrogen operation to optimize the combustion system for sub 9 ppm NO_x emissions at full baseload operating temperatures. Flexible operations from 100% natural gas to 100% hydrogen will be maintained while achieving this objective. Future work will include both full pressure combustion rig tests, as well as installation in the OP16 gas turbine.

The FlameSheet™ combustion system has been in commercial service on F-class gas turbines since 2015, and the fleet continues to grow. The modularity of the FlameSheet™ combustion system will allow the retrofit implementation of this hydrogen capable combustion technology in a range of machines from 1MW to 300MW and above.

Public releases

- Press Release - High Hydrogen, Ansaldo Energia, April 15 2019
- Interview - GTW May-June 2019, GTW, May 1st 2019
- Ansaldo Thomassen webinars, October 8th 2020
- OPRA Turbines webinars, September 17th, 2020; May 20th, 2020; December 9th 2020

In progress for publication

- Publication ASME Turbo Expo 2021 "Development and Atmospheric Testing of a High Hydrogen FlameSheet™ Combustor for the OP16 Gas Turbine"
- Publication ETN IGTC 2021 "High Hydrogen Gas Turbine Retrofit Solution to Eliminate Carbon Emissions"

All public releases, publications or more information in the development project and our partnership can be provided by contacting Robin Lieve / Ansaldo Thomassen (robin.lieve@ath.ansaldoenergia.com)

This project was executed within our partnership between Ansaldo Thomassen, OPRA Turbines, Technical University Delft, Vattenfall, EMMTEC Services and Nouryon with great dedication and enthusiasm. Ansaldo Thomassen as leading entity would like to thank all partners so far and for the continuing efforts in next phases that will come to eliminate carbon emissions in Gas Turbines.