AN INNOVATIVE CONCEPT FOR THE COMPLETE AND LOW-NOX COMBUSTION OF NON-CARBON ECO-FUELS USING A THERMO-ACOUSTICALLY-DRIVEN, HYDROGEN-POWERED PILOT STAGE

Nina PAULITSCH*[1], Fabrice GIULIANI[1], Andrea HOFER[1], Johannes HOFER[2]

Motivation

The problem of climate change, triggered by a high concentration of pollutants in the atmosphere and the scarcity of fossil resources, increases the need of low emission thermal utilisation of novel, non-carbon eco-fuels such as hydrogen, ammonia (both for energy and propulsion) or hydrogen sulphide (sulphur acid production and regeneration). While all of these listed eco-fuels have the potential to decarbonise industry and the energy sector, they also pose demanding challenges regarding combustion. To address these challenges the consortium consisting in Combustion Bay One e.U., FH JOANNEUM GmbH and P&P Industries AG is working on the project called BLUETIFUEL, supported by the FFG.

The BLUETIFUEL project

BLUETIFUEL stands for *blue* flames for low emission combus*tio*n using non-carbon eco-*fuel*s. The strategy behind: The Power-to-X technology provides promising energy storage for renewable resources. Excess electricity from solar, wind or hydro power can be used to generate a non-conventional, non-carbon eco-fuel such as hydrogen, ammonia or hydrogen sulphide, which can be thermally utilised in high-temperature applications in process engineering, chemical and metallurgical sector or to cover the electrical residual load or heat demand of a country. The overall vision of the project is illustrated in Figure 1.

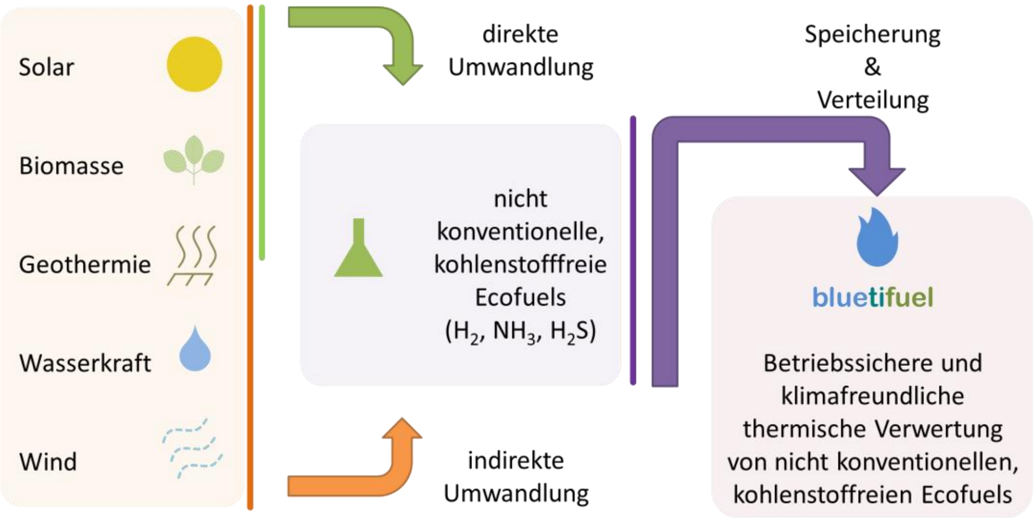

Figure 1: Vision and strategy of the project BLUETIFUEL

All of these eco-fuels pose their individual challenges regarding combustion and safety, which needs to be addressed. Hydrogen is very sensitive to the injection conditions due to its high laminar flame speed what is represented in a high probability to flashback. Furthermore, the elevated flame temperature of hydrogen leads to an elevated formation of thermal nitric oxides [1]. By using hydrogen highly diluted with air while simultaneously running a thermo-acoustic excitation, the temperature decreases to a level where nearly no thermal NOx formation happens while a stable combustion process is guaranteed.

While hydrogen is highly reactive, as evidenced by its wide flammability range, the combustion behaviour of a mixture of ammonia and air occurs very unstable and lies in a narrower flammability range with a higher necessary ignition temperature. This is related to the low laminar flame speed of

[1] Combustion Bay One e.U., 8010 Graz, Tel +43 (0)316 22 89 80, Office@CBOne.at, www.CBOne.at
[2] P&P Industries AG, 8074 Raaba, Austria, www.pp-industries.at

ammonia, which is only one fifth of the laminar flame speed of methane. Furthermore, due to the presence of bound nitrogen in ammonia, fuel nitric oxides can be released during a combustion process with insufficient retention time [2]. To address this problem ammonia is doped with jets of hydrogen.

The aim of the project is to develop a highly digitalised combustion technology for complete and low-emission combustion of hydrogen, ammonia and hydrogen sulphide for industrial purposes based on precisely controlled forced flame turbulence. The idea is that due to the controlled increased flame activity a better reactant mixing takes place, which guarantees a complete burnout of the partially toxic eco-fuels. Furthermore, results of a previous work showed that the flame pulsation process provides the opportunity to run reliably an otherwise unstable combustion process [3].

Early results

A novel three-staged burner design, adapted to the needs of the eco-fuels, enables the thermo-acoustic excitation via the pilot stage. In order to achieve effective thermo-acoustic pulsation, an apparatus called “siren E” was developed specific for application in industrial use. The siren is a robust pulsation apparatus with independently adjustable frequency and noise amplitude that can operate under elevated temperature and pressure conditions [4]-[5]. By scanning through a certain frequency range during combustion, eigenfrequencies of the flame can be detected which increases flame turbulences when excited.

To verify the method for eigenfrequency detection by using siren E, initial combustion tests are first carried out with propane on the so-called “MethaNull” test rig. There, the main aspect is to meet the same operating points and eigenfrequencies as in a previous work [3].

Then, initial combustion tests with premixed hydrogen are performed successfully up to a thermal power of 7.5 kW. First, different methods for the injection of hydrogen are tested resulting in a prioritised premixed variant. Using this premixing injection method in the test setup the response to thermo-acoustic excitation via loudspeaker and siren is investigated. CFD simulations are carried out for the initial estimation of the flame position. All experimental and computed results are presented in detail in this paper.

Referenzen

[1] T. Lieuwen, V. McDonell, E. Petersen and D. Santavicca. "Fuel Flexibility Influences on Premixed Combustor Blowout, Flashback, Autoignition, and Stability." ASME. *J. Eng. Gas Turbines Power*. January 2008; 130(1): 011506. https://doi.org/10.1115/1.2771243

[2] H. Kobayashi, A. Hayakawa, K. K. A. Somarathne, and E. C. Okafor (2019). “Science and technology of ammonia combustion.” *Proceedings of the Combustion Institute*, *37*(1), 109-133.

[3] F. Giuliani, V. Moosbrugger, M. Stütz and T. Leitgeb-Simandl. "Optimisation of Support Fuel Consumption Burning Low Heat Value Gas Using Controlled Combustion Oscillations.” *Proceedings of the ASME Turbo Expo 2015*: Turbine Technical Conference and Exposition. Montreal, Quebec, Canada. June 15-19, 2015. GT2015-42377. https://doi.org/10.1115/GT2015-42377

[4] F. Giuliani, A. Lang, KJ. Gradl, P. Siebenhofer and J. Fritzer. "Air Flow Modulation for Refined Control of the Combustion Dynamics Using a Novel Actuator." *Proceedings of the ASME 2011 Turbo Expo*: Turbine Technical Conference and Exposition. Vancouver, British Columbia, Canada. June 6-10, 2011. GT2011-45071. https://doi.org/10.1115/GT2011-45071

[5] F. Giuliani, M. Stütz, N. Paulitsch and L. Andracher. “Progress on Forcing Pulsations for Acoustic, Thermoacoustic or Flow Control Purpose in a Pressurised Vessel by Means of a Siren." *Proceedings of the ASME Turbo Expo 2020*: Turbomachinery Technical Conference and Exposition. Virtual, Online. September 21-25, 2020. GT2020-16015. https://doi.org/10.1115/GT2020-16015