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Bio-HyPP

Deliverable No	**Title**	**Submission Due Date**	**WP/Lead**
D4.2	Hybrid Power Plant emulator (real MGT with SOFC emulator) with optimised components	31.05.2018	WP4 / DLR
Short Summary	This document describes the deliverable D4.2 „Hybrid Power Plant emulator (real MGT with SOFC emulator) with optimised components ". This deliverable is of the type "demonstrator", so it describes a test rig/ hardware that has been set up and installed in the laboratory.		
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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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FLOX®	flameless oxidation
MGT	Micro gas turbine
MGT test rig	Hybrid power plant test rig consisting of real MGT and emulated SOFC
NG	Natural gas
SIL	safety integrated level
SOFC	Solid Oxide Fuel Cell
SOFC test rig	Hybrid power plant test rig consisting of real SOFC and emulated MGT
TÜV	technical supervisory association
WP	Work package

1 Introduction

The aim of the Bio-HyPP project is the development of a full scale technology demonstrator of a hybrid power plant [2] – a combination of solid oxide fuel cells and a micro gas turbine. For the analysis of the characteristics of the MGT subsystem (incl. the control strategy [6]) and the SOFC influences onto the MGT, the MGT hybrid power plant test rig (real MGT with emulated SOFC) has been set up. The SOFC properties being emulated are: pressure loss, residence time, temperature increase and the SOFC off-gas (composition and temperature).

The influence of the MGT on the SOFC will be studied in a SOFC hybrid power plant test rig by the Institute of Engineering Thermodynamics. The system characteristics and the control concepts will be tested and optimized for both test plants before the final concept of the hybrid power plant can be verified.

As a part of WP4 "System Integration and Demonstration" the MGT test rig has been installed in lab environment. This report of D4.2 covers the development of the MGT test rig including the integration of optimized components. It is subdivided into four chapters.

Chapter 2 describes the objectives of the deliverable.

Chapter 3 describes the layout of the test rig and the components used for SOFC emulation.

In chapter 4, the test rig layout, design engineering, instrumentation and the optimized components are shown.

Finally, Chapter 5 draws the conclusions.

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2 Objectives and requirements

As part of WP4 "System Integration and Demonstration" the MGT test rig (real MGT with emulated SOFC) has to be built and set-up in lab environment.

This includes:

- Analysis of the layout of the test rig
- Design engineering
- Component selection
- Manufacturing
- Set-up in the lab
- Integration of optimized components
- Heat insulation
- Instrumentation
- Electric wiring and control
- Safety measures including safety control

Results from other work packages have been taken into account for the definition of the test rig's layout. Thermodynamic performance modelling (WP1) has been used to choose the layout (flow diagram) and the necessity and the parameters for optimization of components. Within WP2, the components have been optimized matching with the boundary conditions of the hybrid power plant.

3 Hybrid Power Plant emulator

3.1 Layout of the test rig

The layout of the MGT test rig (real MGT with emulated SOFC) has been derived from the intended layout for the real coupled hybrid power plant. In the hybrid power plant (Figure 1) air is compressed by the compressor of the MGT, used for purging the pressure vessel of the SOFC, afterwards it is preheated in the recuperator and then fed to the cathode side of the SOFC. At the same time, the fuel (natural gas or biogas) is desulphurised and reformed and then fed into the anode side to the SOFC. The recirculation of anode exhaust is increasing the water content and pre-heating the gas into the anode. In the SOFC, gas and oxygen are chemically transformed and electricity is generated. The residual fuel in the SOFC off-gas is then oxidized in the combustion chamber. In the turbine the hot exhaust gases are expanded and led through the recuperator.

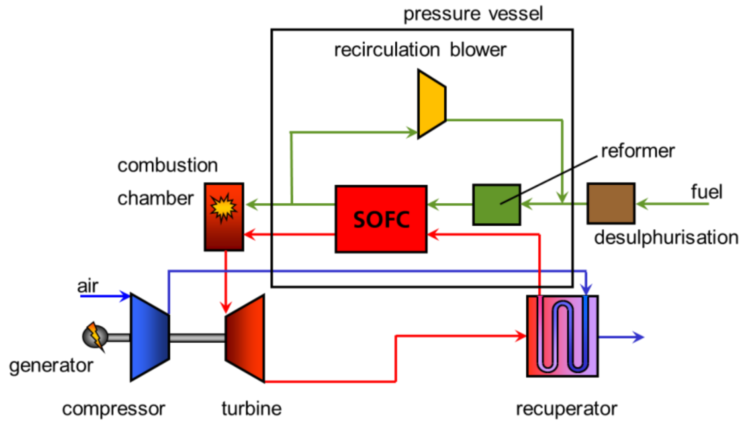

Figure 1: Plant Layout of the real coupled top-efficiency hybrid power plant

For the layout of the MGT test rig, the MGT components have been kept as real operating hardware parts while the influences of the SOFC on the MGT are being emulated (Table 1). Temperature increase is emulated by an electrical heater, pressure drop and retention time by mechanical structures and the SOFC off-gas is emulated by a hot steam generator and N_2 injection.

Table 1: Emulation of SOFC influences in the MGT test rig

SOFC-influence on MGT	Emulated by
Pressure drop and retention time through the pressure vessel of the SOFC	Pressure vessel
Temperature increase through the pressure vessel	Electrical heater
Pressure drop and retention time through the SOFC	Bend pipe
Temperature increase through the SOFC	Electrical heater
Composition and temperature of the SOFC off-gas into the combustion chamber	Hot steam generator[1]
Composition of the air outlet from the SOFC into the combustion chamber	Injection of nitrogen (N_2) into the inlet air

Besides the emulation devices of the SOFC, the MGT test rig has been equipped with various bypass-possibilities to be able to bypass either the recuperator or the pressure vessel purge emulator or the SOFC fuel cell emulator. The overall schematic layout of the MGT test rig is represented in Figure 2.

[1] Hot steam generator: To emulate the SOFC off-gas with its high steam content, an additional combustion chamber is used: H_2 and O_2 are burnt to hot steam and CO and CO2 are added to the steam to generate the right off-gas composition.

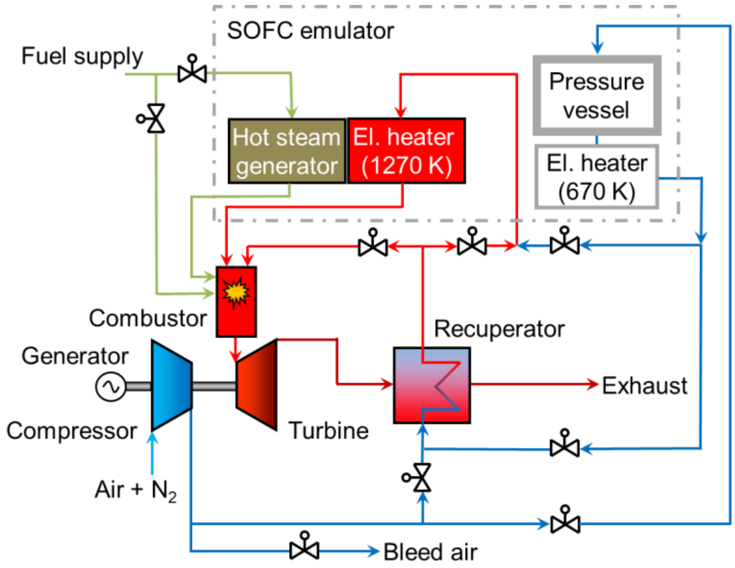

Figure 2: Plant Layout of the MGT hybrid power plant emulation test rig (real MGT with emulated SOFC)

3.2 Design engineering

The challenge of the design engineering for the MGT system has been the combination of the requirement of lots of instrumentation, especially mass flow measurements in each path of the system (needing long pipes for inlet zones for accurate measurement) and the bypasses with the heat expansion of this partly hot (up to 1270K) system. So, the design engineering has been an iterative process with certain focus on expansion joints to compensate the heat expansion.

For the cold paths (up to 400°C), the material 1.4307 has been chosen. For the hot paths (up to 870°C) the material 1.4828 has been used. Screws and sealing have been chosen accordingly.

The final design with the original components, paths and bypasses can be seen in Figure 3. The support structure and the heat insulation of the system have been faded out, so the paths can be seen clearer. The test rig has been implemented with vessel, pipes, combustor and SOFC emulator.

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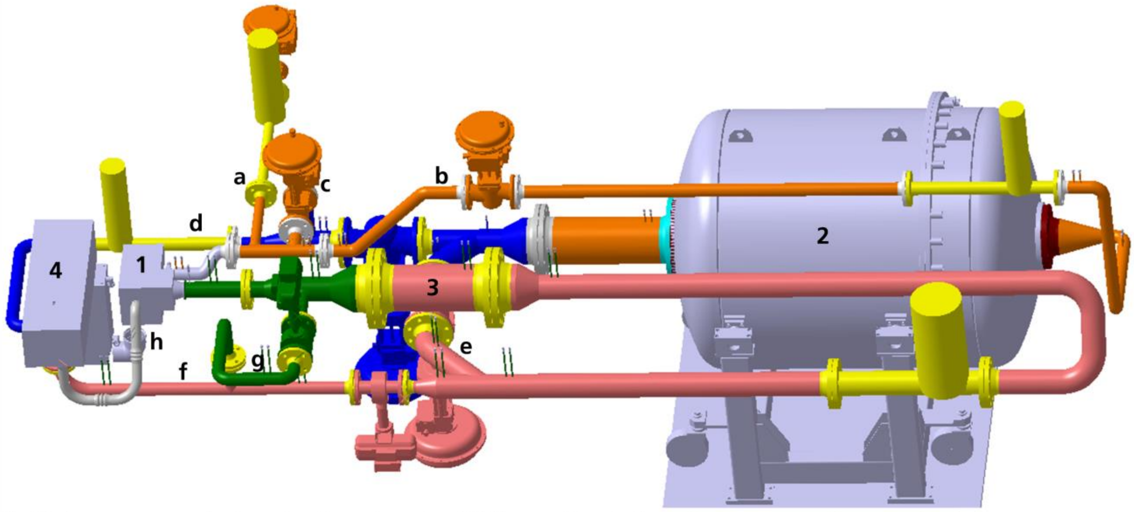

1	Turbo components / combustion chamber MGT	a	Bleed-Air path	e	Recuperator bypass
2	SOFC vessel emulator	b	Vessel purge path	f	SOFC path
3	SOFC stack emulator	c	Vessel purge bypass	g	SOFC bypass
4	Recuperator MGT	d	Recuperator path	h	Exhaust path to recuperator

Figure 3: Engineered design of the MGT test rig

The final set-up of pipes and components (including support structure, but without heat insulation) without the pressure vessel can be seen in Figure 4 and Figure 5.

Figure 4: Set-up of the MGT test rig (without insulation)

Figure 5: Set-up of the MGT test rig (without insulation), whole view

3.3 Instrumentation

3.3.1 Instrumentation for characterisation and control

The control of the test rig consists of the control of the MGT, the different emulation devices, bypass valves and gas supply. It includes all actuators and sensors of the instrumentation.

To be able to analyse the test rig in detail, mass flow, temperature and pressure measurements have been planned at various locations along the different paths of the system. In total, around 300 measurement points have been chosen and integrated into the control PLC (programmable logic controller).

The system control contains the safety reactions, the single control loops and the state machine (Figure 6). The system control is based on different PID controllers interconnected with each other. The control concept is described in detail in deliverable D4.1 "Control system for operation of the hybrid plant with MGT and SOFC" (confidential).

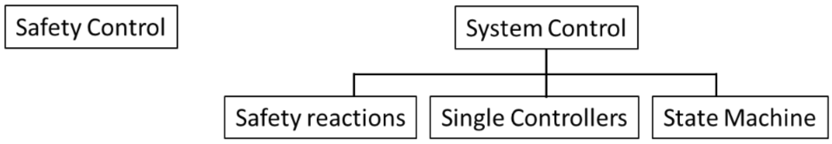

Figure 6: Overview of the control functionalities

3.3.2 Personal safety control

A special focus has been towards personal safety in the lab environment. The test rig needing to operate over-night implies that the test rig must be able to run without a human operator and also with people being present in the lab.

The concept has been developed in collaboration with the German TÜV (technical supervisory association), resulting in an additional safety control system superordinate to the control system of the test rig. Safety classifications of the components in the safety chain have been chosen, being classified in SIL levels (safety integrated level). The safety control system is interconnected with the lab safety system, using the lab safety installations (emergency stop, gas detection, smoke detection, etc.). The safety concept has been validated and checked by the TÜV, ensuring high safety for people in and around the lab.

3.4 Optimized components

Within Thermodynamic performance modelling of WP1 all the components of the chosen hybrid power plant configuration have been analysed or tested concerning their usability for the hybrid power plant.

The turbo components (compressor, turbine, generator, air bearings), heat exchanger, combustion chamber and recuperator have been optimized for the hybrid power plant. Thermodynamic modelling has brought the insight that the combustion chamber and the recuperator in their optimized version are mandatory for operation of the hybrid power plant demonstrator.

So, recuperator and combustion chamber have been manufactured and integrated into the test rig and will be tested in the test rig to verify the concept for real coupling.

The other components will be integrated into the stand-alone MGT (WP2) to avoid time-consuming changes in the power electronics and also in the control code of the hybrid test rig.

3.4.1 Recuperator

The recuperator needs to have a lower pressure drop on HP side as it is directly relevant for the pressure difference between the inside of the cathode and the exterior of the SOFC (vessel purge, see Figure 1) which is required to be below 50mbar.

To have both low pressure loss between cathode and outside and a good heat transfer, the recuperator has been designed in a new layout (wider cell, split nozzles, larger tubes and fabricated manifolds). The recuperator being ready for integration can be seen in Figure 7. Details of the recuperator requirements, the development and the undergone aerodynamic tests are logged in deliverable D2.8 (confidential).

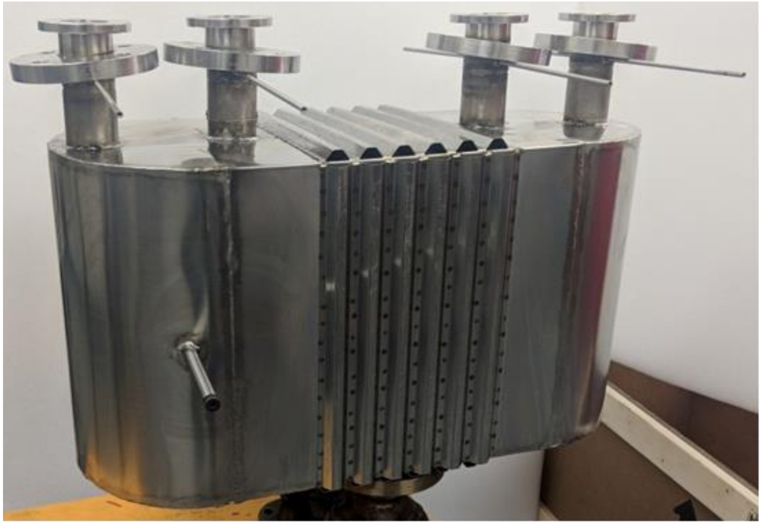

Figure 7: Newly manufactured recuperator

3.4.2 Combustion chamber

The combustion system is needed to cope with both SOFC excess fuel (SOFC off-gas) combustion and biogas or natural gas fired combustion with high inlet temperatures up to 850°C. Therefore, a combustion system based on the FLOX® ("flameless oxidation" [1]) concept with respect to a stable and safe combustion at the entire operating range of the hybrid power plant has been developed ([3], [4], [5] and Deliverable 2.3 "Combined Combustion System available for integration", confidential) and manufactured.

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Figure 8: Combustor for integration into the test rig

For the integration into the MGT test rig a few more parts, such as a new combustor pressure vessel and adaption pieces have been developed.

3.4.3 Integration of recuperator and combustion chamber

In the last months, the optimized components recuperator and combined combustion chamber (suitable for SOFC off-gas, biogas and natural gas) have been integrated into the test rig (Figure 9, Figure 10 and Figure 11). Additionally, the hot steam generator that emulates the SOFC off-gas at high temperature has been mounted.

Figure 9: Optimized recuperator integrated into the MGT test rig

Figure 10: Optimized recuperator with heat insulation

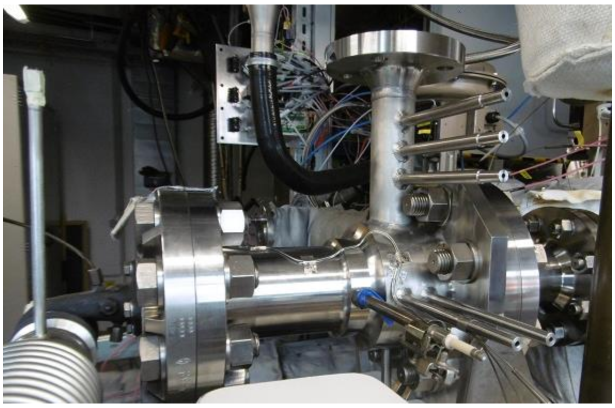

Figure 11: Combined SOFC off-gas, biogas and natural gas combustion chamber integrated into the MGT test rig

Due to the different size of the optimized components piping of the original MGT test rig needed to be adapted and the oil and water circuit of the test rig have been changed as well.

The test rig has been readily installed by now and re-commissioning has been started with a first cold spin test.

3.5 Control of SOFC emulation

For the emulation of the SOFC in the MGT test rig, two modes are planned. First of all, we have the possibility to manually set the parameters of the temperature increases and composition of temperature of the SOFC off-gas representing SOFC influences onto the MGT (see Table 1). To set the parameters, experimental data is taken from the SOFC test rig with emulated MGT.

Additionally, a hardware-in-the-loop model has been implemented and integrated into the MGT test rig. This will be validated with experimental data taken from the SOFC test rig.

4 Conclusion

The MGT test rig with emulation components for the SOFC (see Table 1) has been set up and installed. It consists of original MGT components and an optimized recuperator and the combined NG/biogas/SOFC off-gas combustion chamber.

Experimental tests have been started and analysis will be done in combination with the analysis of data gained from the SOFC test rig (with emulated MGT).

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