Funded by the European Union

BRAVA

Clean Hydrogen Partnership

The project is supported by the Clean Hydrogen Partnership and its members Hydrogen Europe and Hydrogen Europe Research

Clean Hydrogen
Project BRAVA
No. 101101409

WP6 - Deliverable D6.1 – Report
Improvements Anode Path

Deliverable Details

Deliverable No.	6.1
Related WP	6
Deliverable Title	Improvements Anode Path H2 Recirculation
Deliverable Date	30.06.2024
Deliverable Type	REPORT
Dissemination level	Public–PU
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Final approval	Patrick Hönicke

Change History

Version	Date	Changes	Done by	Approved by
V1	25.06.2024	First Version	Julia Radius	William Resende

List of Acronyms and Abbreviations

Abbr.	Description	Abbr.	Description
Pt	Platinum		
RH	Relative humidity		
PITM	Platinum in the membrane		
PGS	Power Generation System		

Table of Contents

1. Executive Public Summary **4**
2. Introduction **5**
3. Passive Recirculation **7**
4. Dead Ended **9**
5. Conclusions **12**
6. Acknowledgments **13**
7. Appendix A - Quality Assurance Form **15**

List of Figures

Fig. 2.1 - Baseline recirculation system 5
Fig. 2.2 - Passive recirculation system 6
Fig. 2.3 - Dead Ended system 7
Fig. 3.1 - Schematics of an ejector 8
Fig. 3.2 - Suction pressure obtained for a given primary pressure at the ejector 8
Fig. 4.1 - Cell Voltage and fuel loss for dead ended concept 10
Fig. 4.2 - Durability test data comparison 10
Fig. 4.3 - Summary of dead ended concept versus recirculation 11

List of Tables

Table 2.1 - Advantages and disadvantages of active recirculation concept 5
Table 2.2 - Advantages and disadvantages of passive concept 6
Table 2.3 - Advantages and disadvantages of dead ended concept 7
Table 4.1 - Degradation causes and failure modes 11

1. Executive Public Summary

- This report contains high level results of the activities performed during the first phase of the WP6
- The aim of this phase was to evaluate the potential options to the current anode recirculation concept
- The two options evaluated were the passive recirculation (with the use of an ejector) and the dead ended concept
- With an ejector solution, the upstream pressure needs to be higher which leads to an oversize of the liquid hydrogen tank. This trade off is not favorable.
- The dead ended concept shows promise, however key points like optimization of fuel cell stack to improve water management as well as operating strategies (purge cycle) are important to make the concept work

2. Introduction

A typical anode path in a fuel cell system is shown in the picture below

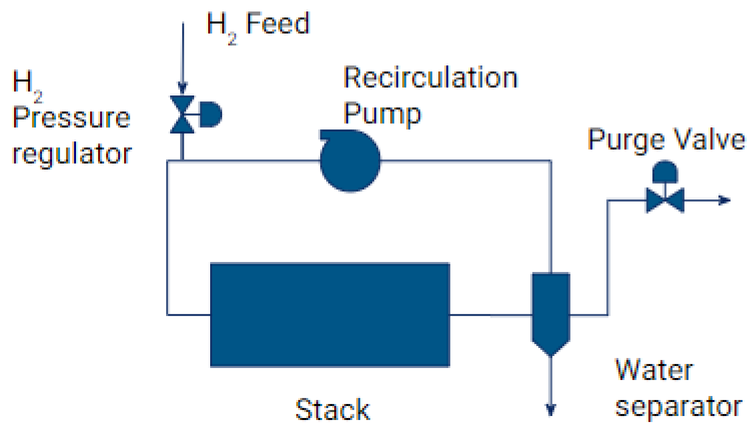

Fig. 2.1 - Active anode recirculation loop

This architecture of anode has the following advantages and disadvantages

Advantages	Disadvantages
• Uniform recirculated mixture • Recirculation independent of gas feed • Good water management	• System weight and volume • Power consumption • System complexity and pump reliability • Additional sources of leakages

Table 2.1 - Advantages and disadvantages of the active recirculation

As weight and volume are key issues faced by fuel cell propulsion systems for aviation, two alternative options have been proposed.

The first option is the passive recirculation. In this concept the hydrogen feed is sent through an ejector which makes use of the venturi effect and this will recirculate the exhaust of the fuel cell. The schematics of this concept is shown below in Fig 2.2

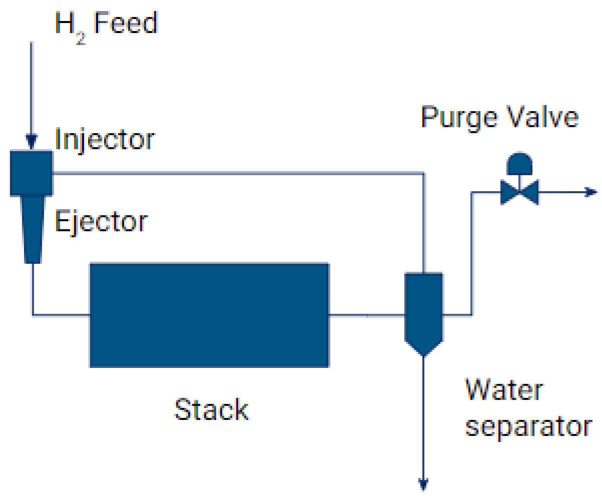

Fig 2.2: Passive recirculation system

The advantages and disadvantages of this concept are shown in the table below

Advantages	Disadvantages
● Weight reduction and volume reduction, ● no power consumption ● Lower cost	● Pressure pulsing at low loads need to be well controlled ● Additional sources of leakages

Table 2.2 - Advantages and Disadvantages of the passive recirculation concept

The second alternative to manage the anode is the dead-ended concept. The concept is shown below in Fig 2.3

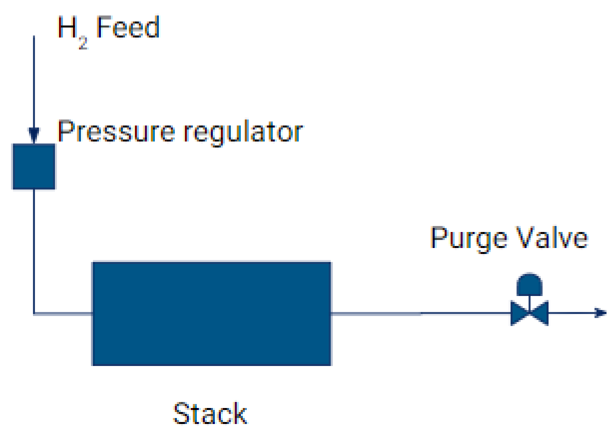

Fig 2.3: Dead ended system

The advantages and disadvantages of this concept are shown in Table 2.3.

Advantages	Disadvantages
• Weight and volume reduction • Very low power consumption • Lower cost	• Potentially higher degradation and/or fuel consumption • Higher voltage variation

Table 2.3 - Advantages and disadvantages of the dead ended system

3. Passive Recirculation

The main component in a passive recirculation is the so called ejector. The ejector makes use of the venturi effect to recirculate unused hydrogen. The picture below a half ejector, that used for simulations.

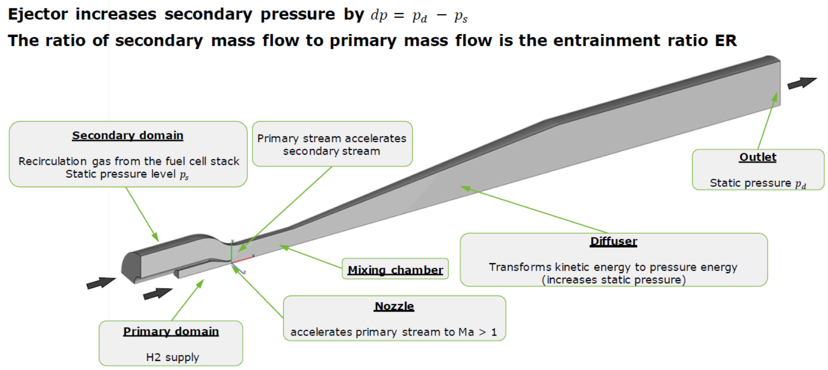

Fig 3.1 - half ejector showing its most important parts

The basic question for an ejector is if the available upstream pressure is enough to provide enough suction pressure for a given entrainment ratio (ratio between primary flow and recirculated flow).

For BRAVA the requirements have been set between 150 and 200 mbar and an entrainment ratio between 4 and 6.

The graph below shows the results for the simulations showing the sensitivity of the ejector to the upstream pressure

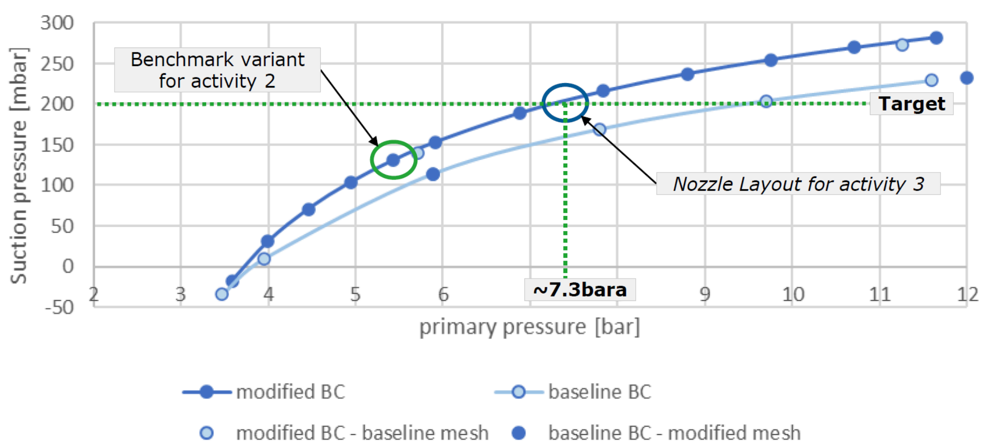

Fig 3.2 - Suction pressure obtained for a given primary pressure at the ejector

The graph in Fig 3.2 shows that the minimum upstream pressure that could match the requirement is between 7 and 8 bara. This is the pressure upstream of the ejector. So at the interface with the high pressure regulator, one needs to reserve 1 bara for pressure drop across the valve.

Therefore the upstream pressure required will be between 8 and 9 bara.
These pressures are typically available in compressed gas applications. In the case of BRAVA, the base assumption is a liquid feed hydrogen system. With this assumption, the upstream pressures for the fuel cell system are typically much lower (by a factor of 2 to 3) than what would be necessary and calculated for the ejector.

4. Dead Ended

Since the passive recirculation can not be used with the requirements of a liquid cooled fed system and pressure drop and recirculation requirements, the team has researched another alternative named Dead Ended. In a dead ended system the hydrogen gas is not recirculated. The gas is fed to the fuel cell stack and as the gas is consumed the pressure difference drives the flow from the injector valve to the stack.

A dead ended operation brings new challenges for the optimization. Since there is no constant flow of gas, water tends to accumulate in the anode and only be removed when a purge valve opens. In addition, the end of the cell tends to accumulate more nitrogen which might lead to partial starvation scenarios from time to time.

The team has then looked into a potential solution and tests were made on short stack level to demonstrate the concept, including a durability test.

The first tests focused on looking at the design space of operating condition, finding what are potential combinations that will lead to a good combination of

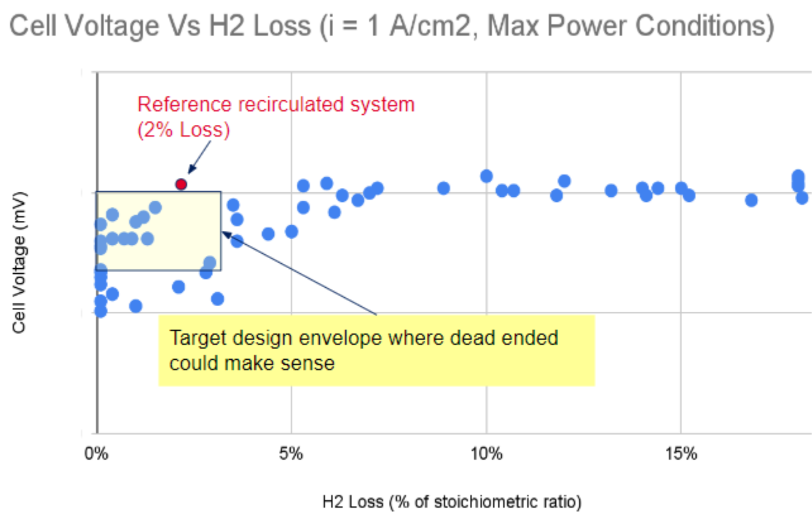

Fig 4.1 - Cell Voltage and fuel loss

With this test the team was able to determine some combinations of operating conditions that would enable the dead ended concept. After this test the team has also tested the durability with one short stack operating under recirculation conditions and another one running under dead ended mode. The results of the test can be seen below

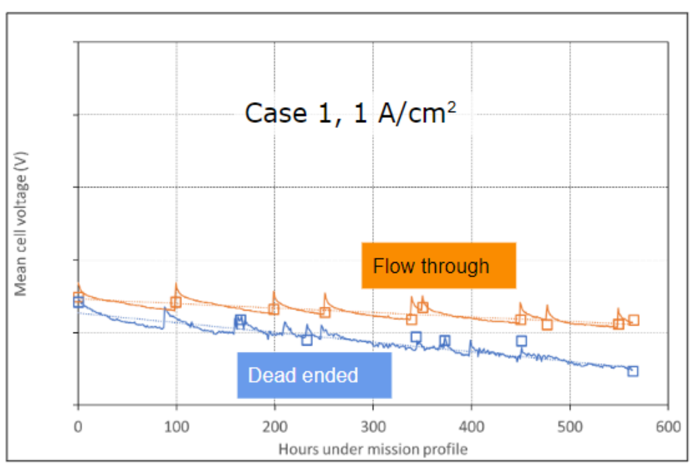

Fig 4.2 : Durability test data comparison between flow through and dead ended

AS one can see in the graph above the degradation rate for the dead ended stack is about 2x bigger than a stack operating under typical recirculation conditions.

The team has analyzed the samples after the test with failure analysis and other methods. The summary of the degradation analysis is shown below

Degradation Fingerprint	Cause	Severity compared to baseline
Membrane cross leak	RH cycling/RH difference between outlet/inlet	No observed difference
Cathode Carbon corrosion	H2 starvation caused by liquid water accumulation in the anode	More severe
Pt dissolution & Migration (Pt Band formation and PITM)	H2 starvation caused by liquid water accumulation in the anode	More severe
Pt Dissolution & Agglomeration	Frequent and fast voltage cycling	More severe

Table 4.1 - Degradation analysis and failure modes

Based on these inputs the team was able to compare the two recirculation concepts and summarize in the graph below

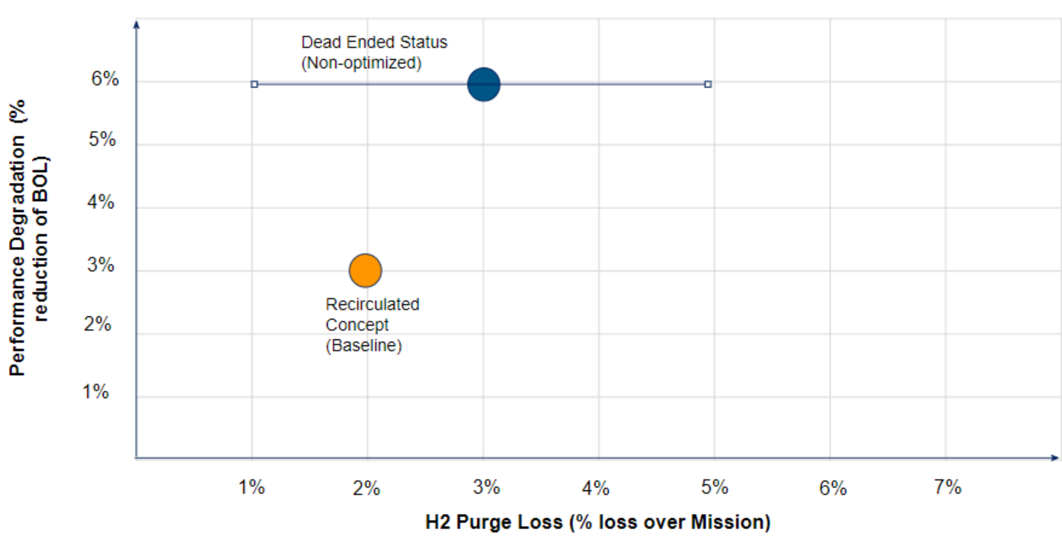

Fig 4.3 : Summary of dead ended concept versus recirculation

Based on the graph above the dead ended concept has a larger degradation and the H2 loss due to purge can range from 1% to 5%, whereas the blue dot marks what we have obtained during the test. These first tests were done with stacks that were not designed to operate under dead ended conditions and also without optimization of the purge strategy. Even though the concept might be worse at a first glance, the benefits of removing several components compensate for these issues and therefore make it interesting for integration in the POD.

5. Conclusions

Two alternative anode subsystem architectures were evaluated in these activities. The passive recirculation alternative has been discarded due to incompatibility with the liquid hydrogen feed system, which is not capable of supplying a high enough pressure that can ensure the targeted suction pressure as well as the entrainment ratios.

Given that this was the main alternative described in the proposal, the team has looked for an alternative solution, and the dead ended concept was also evaluated. The dead ended concept ended up being interesting, because it leads to the reduction in number of components making the system simpler. However, the system tends to have lower performance as well as more degradation. This can be, based on the first evaluations, better designed and the differences between the baseline system and dead ended can be minimized so as to make it a viable system

The team will now proceed to evaluate the optimization levers available and implement in a new design and evaluate further.

The numbers obtained so far will be used later on in the next activity to be implemented in the overall PGS concept.

6. Acknowledgments

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Partner short name	Partner Full Name
1	A-D	AIRBUS OPERATIONS GMBH
2	A-E	AIRBUS OPERATIONS SL
3	AER	AEROSTACK GMBH
4	CNRS	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE
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9	NLR	STICHTING KONINKLIJK NEDERLANDS LUCHT – EN RUIMTEVAARTCENTRUM
10	SOL	SOLVAY SPECIALTY POLYMERS ITALY SPA
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11	TUB	TECHNISCHE UNIVERSITAT BERLIN

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101101409. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Clean Hydrogen Joint Undertaking. Neither the European Union nor the granting authority can be held responsible for them.

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