

Fuel Cell Auxiliary Power Units for Heavy Duty Truck Anti-Idling

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ABSTRACT

The DESTA project, funded by the European Commission under the FCH JU program, is a collaborative effort of AVL List GmbH, Eberspächer Climate Control Systems, Topsoe Fuel Cell (TOFC), Volvo and Forschungszentrum Jülich to bring fuel cell based auxiliary power units (APU) for heavy duty truck idling elimination closer to the market. Within this project Solid Oxide Fuel Cell (SOFC) technology is used, which enables the use of conventional diesel fuel. During the project the technology is significantly optimized and around 10 APU systems are thoroughly tested. In 2014 a vehicle demonstration on board of a US type Volvo class 8 truck will be performed.

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INTRODUCTION

Idling of heavy duty truck engines causes significant costs and emissions. Nevertheless electrical energy for driver comfort functions (climatisation, TV, PC, microwave, refrigerator,..) is required. Fuel Cell APUs will bring significant advantages by reducing idling costs. Additionally the emissions of trucks can be reduced significantly and the noise of idling engines nearly eliminated. Based on literature surveys the idling time of US class 8 trucks is somewhere in the range of 1,500 to 2,500 hours per year. This causes fuel costs of 5,000 up to 9,000 US\$ per year. By the use of SOFC APUs developed in DESTA the fuel consumption can be reduced by ~85%. Compared to commercial available and diesel driven APUs with internal combustion engine (ICE APU) the fuel consumption can be reduced by ~45%. Hence

SOFC APUs promise a very convincing business case to truck owners and operators with very short amortization periods (~1-1.5 years).

Due to the promising business outlook AVL and Eberspächer developed SOFC APU technology for around 10 years. Especially the last year tremendous progress has been achieved with complete stand-alone prototype systems performing extremely well. During the last year system tests on ultra low sulfur diesel (ULSD) proved electrical efficiencies of around 30% and net power outputs of ~3kW.

In the current DESTA phase 6 APU systems (3 from AVL, 3 from Eberspächer) are thoroughly tested and compared. After this benchmark test the superior features of both systems will be merged to an optimized DESTA APU.

This DESTA APU will then be used for the Volvo truck demonstration.

THE EBERSPÄCHER SOFC APU

There are several APU products for power generation on the market, mostly diesel operated ICE APUs. Despite of the fact that they are working more efficient than the main engine of a commercial vehicle in stationary operation, they do not exceed an electrical efficiency of about 22%. Furthermore a Diesel-APU is everything but silent and emits a lot of soot.

With a diesel operated fuel cell system, an efficiency of 30% shall be achieved at a performance level of about 3 kW - and this with extremely low exhaust emissions.

In the reformer, diesel and ambient air are converted into a synthesis gas, containing hydrogen and carbon monoxide, by means of catalytical partial oxidation (Figure 1: SOFC APU). Electrical power is generated in the SOFC due to the chemical reaction of gaseous fuel and air/oxygen. This process runs with a theoretical efficiency of more than 35% at temperatures of more than 800°C. An unembodied start up-burner module made of a start-up burner and heat exchanger provides the careful heating of the fuel cell.

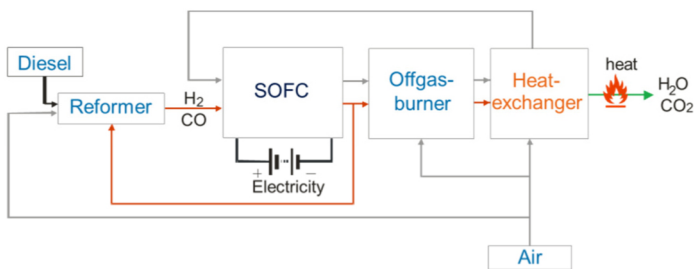


Figure 1. SOFC APU block diagram

As the fuel cell does not convert all the gaseous fuel, an off-gasburner uses the remaining hydrogen and carbon monoxide containing ingredients of the fuel cell exhaust gas. This waste heat conditions the cathode air for the fuel cell. It could also be used for auxiliary heating purposes in the vehicle cabin. A part of the unconverted fuel cell exhaust gas is passed back into the reformer in order to cool and to improve the process, similar to the exhaust gas recirculation in combustion engines.

In comparison to an ICE APU, emissions are up to 60 times lower and especially dangerous soot particles are not detectable at all.

SOFC APU from Eberspächer in project "DESTA"

In Figure 1 an outside view of the first SOFC APU from Eberspächer is given, which was operated with a diesel reformer.



Figure 1. SOFC APU from Eberspächer in project "DESTA"

Within the first tests with an autarkic fuel cell system, an electrical gross output of 2.1 kW and an electrical net output of 1.7 kW at a diesel input of 8 kW have been demonstrated. The system was operated with sulfur-free, synthetic diesel.

In Figure 3, SOFC APU performance is shown at various diesel fuel inputs of 8 kW, 6 kW and 5 kW_{therm}. The corresponding electrical gross power, electrical net power and the electrical net efficiency are displayed. The efficiency ranges between 18% and 22%, depending on the diesel input into the reformer.

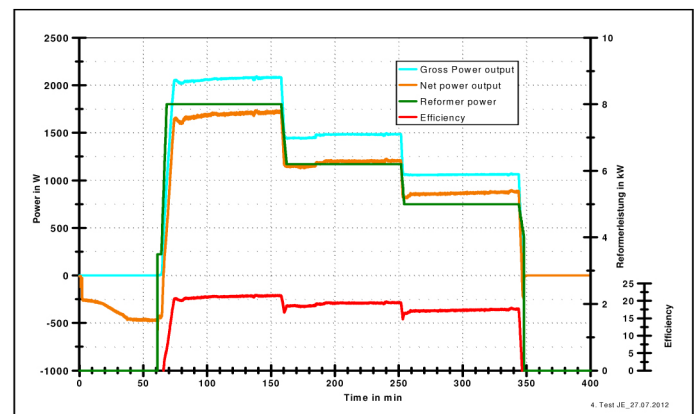


Figure 3. first test results of SOFC APU from Eberspächer

In Figure 4 a weekly APU load profile is shown. The APU is activated by the truck driver and provides electrical power for electrical cooling, heating, refrigerator, lights, radio, PC, & TV. The daily cycle including two short breaks and a long overnight run, is typically repeated five times a week. The system needs a diesel start-up burner at the beginning of the weekly cycle. A complete shut-down only occurs at the end of the weekly cycle.

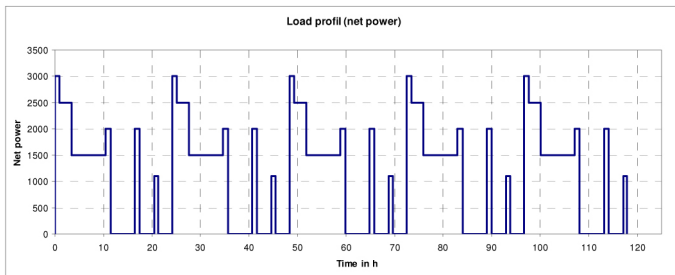


Figure 4. weekly load profile of a SOFC APU

THE AVL SOFC APU

AVL started the development of SOFC APUs in 2002. The first step was a technical feasibility study which resulted in a successful 1 kW proof-of-concept subsystem in 2004. In the years 2005 to 2008 all required sub-components and sub-systems (diesel reformer, media supply, anode recirculation system & burner system) for this product were developed. In 2009 a prototype development program was initiated and the first AVL SOFC APU Gen I was demonstrated in end of 2011 (Figure 5) [2].



Figure 5. AVL SOFC APU Gen I

With this system the first successful tests with sulfur free diesel fuel was performed. Around 1 kW of electrical power and ~23% electrical efficiency was reached.

The AVL SOFC APU system is characterized by an auto-thermal diesel reforming process, a hot anode recirculation system, highly efficient radial blowers for media supply and an aggressively small and light packaging approach. The hot anode recirculation system is a similar process like EGR in IC engines. Exhaust gas of the SOFC anode is recirculated into the fuel processor. This approach significantly improves the reforming reaction, because product water (from electrochemical reactions in the fuel cell) is recirculated back into the reformer. The water addition to the fuel reformer suppresses carbon formation and reduces the operating temperature, both leading to an extension of useful reformer product life. For this recirculation process a hot gas anode blower is required. This component was developed by AVL and is capable of supplying hydrogen containing gases up to 600°C. AVL has put tremendous efforts into a small and light package, because packaging space is a limited resource in a

lot of applications. Having a small overall package the AVL system complies with a lot of different application requirements (truck, marine, leisure, defense,...).

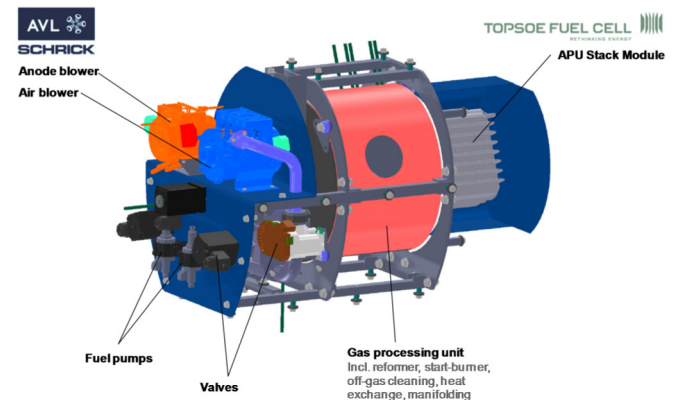


Figure 6. Design of the AVL APU system

The system design (Figure 6) consists of 3 sections. On the left side is the media supply unit with 2 blowers (air blower and anode recirculation blower), 3 valves and 2 fuel pumps. On the right hand side, the TOFC stack module (with one or two stacks) is located. The stack module is screwed to the rest of the system which makes it easily exchangeable (if required). The middle part of the system is called gas processing unit. This part is a completely integrated unit of diesel reformer, start-up burner and afterburner (to oxidize residual H_2 and CO from the fuel cell). The different components are integrated in a way, that the heat flow between the different processes creates a significant benefit. Apart from the system shown in Figure 6 only power electronics (DC/DC converter) and a system controller are additionally required. For start-up power energy from a battery is required.

In the meantime AVL has made Gen I.I available, which is the first AVL APU system which can be integrated into vehicles. It is equipped with all necessary power electronics and an electrical anode oxidation protection system (EAP). This EAP system is needed to protect the Ni based fuel cell anode from oxidation when no fuel supply is possible (start-up and shutdown). The Gen I.I system has also undergone significant optimization towards mechanical stability (for vibration and shock loads). The complete system was analyzed and improved by CFD and FE methods. In Figure 7 a picture from a vibration test is shown, which has been performed with a Gen I.I system. During this test the system went through a 6 weeks vibration test based on an accelerated truck vibration profile. For the first 3 weeks the system has been tested cold and for the final 3 weeks hot (that means in operation).