KABINENTECHNOLOGIE UND MULTIFUNKTIONALE BRENNSTOFFZELLE

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Zusammenfassung

Im Leuchtturmprojekt „Kabinentechnologie und multifunktionale Brennstoffzelle" des Spitzenclusters Hamburg Aviation wird die Anwendung der Brennstoffzelle und der damit verbundenen Innovationen für die Kabinentechnologien im Verkehrsflugzeug vorbereitet. Im Arbeitsanteil zur multifunktionalen Brennstoffzelle erfolgt die Integration des Gesamtsystems in eine Flugzeugsystemarchitektur im Labor, wo sie nach Flugzeuganforderungen getestet wird. Im zweiten Arbeitsanteil werden ausgewählte Kabinensysteme und deren Schnittstellen zu dem Brennstoffzellensystem bearbeitet. Hierbei werden neue Systemarchitekturen für die Brennstoffzellenprodukte Elektrizität und Wasser sowie Filter für einen erhöhten Umluftanteil an Bord von Verkehrsflugzeugen untersucht. Auf die letztgenannten Aktivitäten wird hier näher eingegangen.

Ein wesentlicher Inhalt des Teilprojekts ‚Energieoptimierte Kabinensysteme', ist die Untersuchung neuer Architekturen im Bereich der elektrischen Systeme, die nicht-flugrelevante Lasten mit elektrischer Leistung versorgen. Drei Aspekte wurden dabei untersucht, 115 VAC dezentrale Netzwerke, höhere Spannungen und Leistungsmanagement. Dabei wurden dezentrale Architekturen als gewichtsersparend auch auf Short-Range Flugzeugen identifiziert. Auch wurden höhere als die heute auf Flugzeugen typischerweise eingesetzten Spannungen, als der wesentliche Hebel für Gewichtsersparnisse identifiziert. Der letzte Aspekt, der zur Untersuchung in diesem Projekt ansteht, ist das Last-/Power Management und stellt ebenfalls einen wesentlicher Pfeiler zur Gewichtsersparniss bei. Diese Funktion kann auf bereits existierenden Flugzeugen nachgerüstet werden. Ein anderer Weg zur Energieeinsparung und zur Verbesserung des Kabinenkomforts von zukünftigen Flugzeugen ist die Erhöhung des Anteils der Rezirkulationsluft. Die Erhöhung des Anteils erfordert allerdings die Abtrennung des von den Menschen produzierten CO_2 aus der Luft. Die Benutzung von Feststoffadsorbern hat sich als erfolgsversprechend erwiesen, da sie leicht, kompakt und energiesparend sein könnten. Das neu entwickelte amino funktionalisierte Silica Aerogel erreicht selbst in Gegenwart von Feuchte und niedrigen CO_2 Konzentrationen hohe Adsorptionsbeladungen (0,047 g/g), wobei es auch Wasser und Ethanol abscheiden kann. Darüber hinaus verringert seine Fähigkeit auch bei niedrigen Temperaturen und leichtem Unterdruck zu renerieren, den notwendigen Energieverbrauch des Flugzeuges.

Summary

In the light tower project 'cabin technologies and multi functional fuel cell' in the frame of the Hamburg Aviation Cluster, the application of a fuel cell and the connected innovations for cabin technologies are investigated for use in an aircraft. For the multi functional fuel cell the integration of the system in an aircraft environment is done in a lab where it is tested according to airborne requirements. In the second part of the project selected cabin systems and their interfaces to the fuel cell system are under investigation. New system architectures for use of the fuel cell products water and power and also air filters for the application of higher air circulation rates are developed. On this later part this paper will focus on.

The project Energy optimized Cabin Systems deals with three aspects to reduce mass of the electrical system, to foster aircraft efficiency. These aspects are new 115 VAC architectures on future smaller civil aircraft, higher voltages and power management. In the scope of the project a wide set of architectures were analyzed and results showed, that in many cases decentralized architectures are lighter and more flexible on small aircraft than conventional centralized implementations. Analysis on higher voltages unveiled the promising HVDC approach, which allows weight savings not just in wiring but also in equipment. Power management, which shall permit (nearly) full usage of every wire, has the advantage of being installable on flying aircraft, was the last aspect investigated for weight savings in the electrical system. Another way to enhance the energy efficiency and cabin comfort of future aircraft is to increase the amount of recirculation air in the environmental control system. However, high rates of recirculation air demand for the separation of accumulating CO_2 emitted by the passengers and crew. Among several options the most promising way to realize a CO_2 separation unit successfully is using a solid adsorber, as a lightweight, simple separation unit with low overall energy consumption. The newly developed aerogel adsorbent, which is a amino functionalised silica aerogel, possesses a very high adsorption capacity at low CO_2 concentrations (0.047 g/g) even in the presence of moisture, whereas it also able to remove not only CO_2 but also water and ethanol. Finally, the ability to be regenerated at mild conditions will lower the energy consumption of an aircraft.

1. OVERVIEW ON THE LIGHT TOWER PROJECT ONE OF THE HAMBURG AVIATION CLUSTER

The Cluster Initiative was original initiated by the BMBF in 2008. The Hamburg Aviation Cluster was one of the first funded clusters with three light tower projects, which were granted from 2009 until 2013. The light tower project one 'cabin technologies and multi functional fuel cell' gathers in the area of aviation the regional competences of selected partners and subcontractors in Hamburg and focuses on innovative system concepts. Thereby the project concentrates on the application of a fuel cell for use in an aircraft and the connected innovation for the cabin technologies. In the part of the multi functional fuel cell the integration of the system in the lab according the airborne requirements are done. In the lab the system will be integrated into the aircraft architecture and tested. In the second part the cabin systems and there interfaces to the fuel cell system are investigated. For this work new system architectures for the use of the fuel cell products water and electrician and on technology for the use of higher air circulation rates are investigated. On this later part this paper will focus on.

1.1. The Global Goal of the Project

The international Air traffic is growing. The prognostic of grow is around 5% each year, which is demanding for new emission decreasing developments, like high efficient electrical Systems. Fuel cell technology as an electrical power supply for those systems has the great benefit of being an environment friendly energy generation. On one side the parasitic energy use from the engine for the bleed air can be avoided, on the other side an independent usage of the cabin systems on the ground can be realized. This directly leads to a reduction of the emission and noise on the airports. The goal for the future are civil aircrafts, which fulfil the vision of ACARE2020 with lowering those side effects by 80%.

1.2. Work Breakdown Structure of the Project

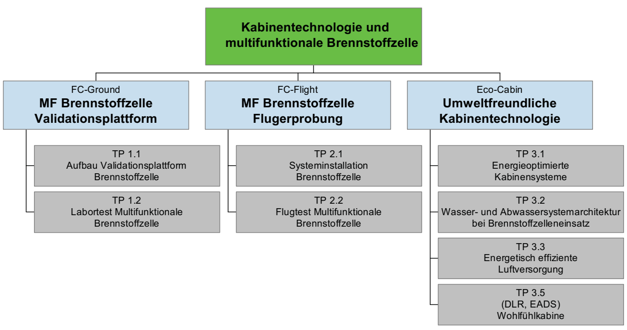

Figure 1: WBS of the Light Tower Project ONE

In Figure 1 the work break down structure of the project is shown. The light tower project Cabin Technology and Multi Functional Fuel Cell is divided in three sub projects, the 'multi functional fuel cell validation platform', the 'multi functional fuel cell flight test' and the 'environmental cabin technologies'. This sub projects consists of further sub projects, like 'energy optimized cabin systems', 'water and waste water systems for fuel cell application', 'energy efficient air supply' and at last the EADS-IW and DLR leaded sub project 'high comfortable cabin'.

1.3. The Multi Functional Fuel Cell

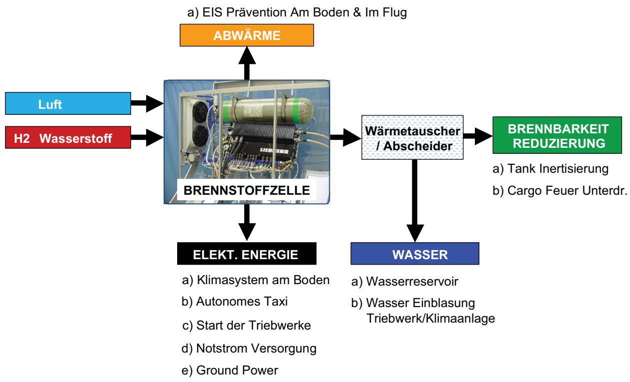

Figure 2: Architecture of a multi functional fuel cell

The vision of Airbus is to replace the Auxiliary Power Unit (APU) in a future aircraft by a fuel cell system. This initial step would lead directly to emission-free and noiseless ground operations and provide a significant ecological impact. The new concept for the ecological-efficient use of fuel cells in aircrafts, lead by airbus, lies in the multi functionality. This means that apart from the supply of the consumers in the airplane with electricity also the by-products of the hydrogen, the water as industrial water and the exhaust gas for the reduction of the fire risk can be used. Thus on the one side the fresh water need reduces and on the other side the installation of a so-called inerting system can be replaced or adopted. If the entire advantages of this multi functionality concept are used at the same economical impact, the weight reduction of the airplane leads to additional fuel savings.

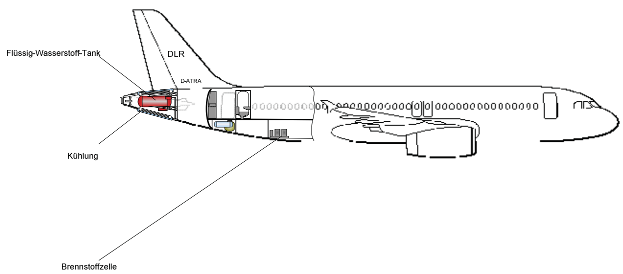

Figure 3: Installation of a multi functional fuel cell

In TP1 and TP2 of the project the lab and flight tests are prepared. As basis for the future flight tests with a multi-functional fuel cell system two substantial requirements in the project are worked on. The function of the system must be representative as well as the installation of such a system has to be to a certain extent aircraft like (see Figure 3). Apart from a fixed installation of the system, the fuel cell, its controllers and DC/DC converters might also be installed on a pallet within the cargo area. In this case other safety-relevant components of the system, like the tank for the liquid hydrogen must be installed outside of the pressurized area in the former APU compartment. This installation cannot provisionally taking place, but must happen according to the necessary technical permission for the test aircraft, i.e. all necessary safety guidelines must be obeyed. These installation works are advanced parallel to the test activities on the test stand.

1.4. Water and Waste systems for fuel cell use

The goal in TP3.2 of the project is well connected to the fuel cell use. Here the water from the fuel cell exhaust gas should be used for the supply of the fresh water system in the airplane. The content of the work is the definition of a System concept and architecture for a water generation system as well as the development of the system components (condenser, water trap, water purification). For use of the fuel cell water adjustments to the fresh water system have to be investigated, e.g. an additional mineralization function to use this water on an airplane. The benefits of weight reduction by a smaller water tank have to be analyzed for different aircraft architectures as well as the design savings in simplifying the requirements to develop the water system only for one water quality and not have to take anymore into account the water quality of regions from all over the world.

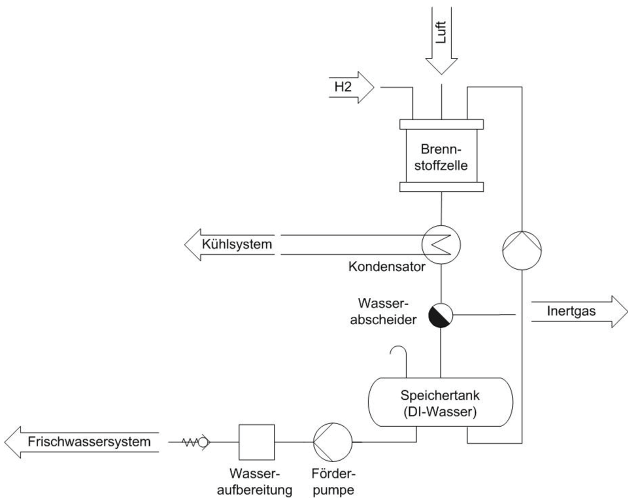

Figure 4: Architecture of a fuel cell water system

In the TP3.4 the work of the DLR and EADS-IW concentrates on the improvement of the cabin comfort by first acquiring data from questionnaires of passengers in virtual flights and by adapting at the same time the environmental condition in such an aircraft.

2. ENERGY OPTIMIZED CABIN SYSTEMS

The sub-project TP3.1 energy optimized cabin system has aimed at the optimization of that part of the electrical system, which supplies non-flight relevant systems. This part of the electrical system shall be referred to as Cabin and Cargo distribution system and the non-flight relevant loads shall be referred to as Cabin and Cargo loads in the following.

Figure 5 shows a schematic of the electrical system on large modern civil aircraft. Generators in the main engines produce electrical power. The power is always transmitted to the forward of the aircraft first (PEPDC). From there it is, among others, conducted to the so-called Secondary Power Distribution Boxes (SPDBs), which supply, as last instance of the electrical system, the Cabin and Cargo loads, which locally require below 15 A at nominal voltage. Hence, the SPDBs are responsible to supply the low power loads on the Cabin and Cargo perimeter. The SPDBs and the lines from the main power bay in the forward of the aircraft to the SPDBs are understood to be the Cabin and Cargo distribution system. In some cases, also the lines downstream the SPDBs will be considered to be part of this network in the following descriptions.

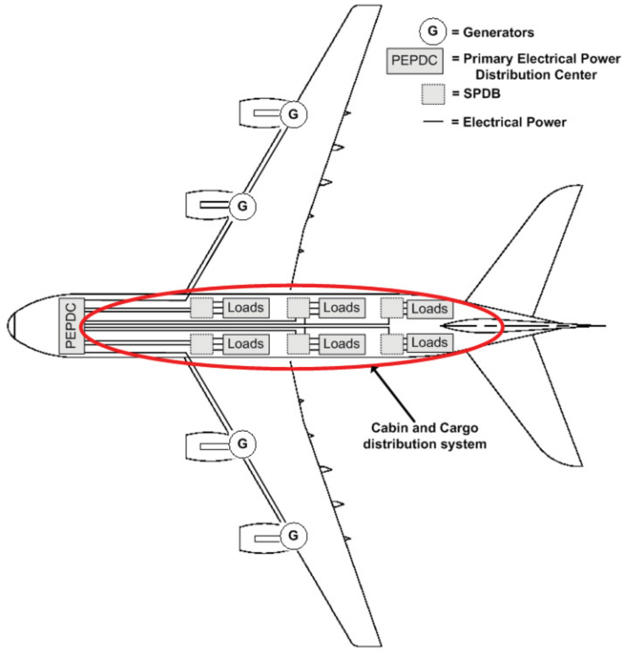

Figure 5: Architecture of the electrical system on large modern civil aircraft [1]

The investigations in the project concentrated on three, most promising aspects, which are:

1. architectures,
2. higher voltage supplies and
3. power management.

Each of these aspects is able to reduce the weight of the electrical system and thus significantly contribute to energy efficiency of the aviation industry. Furthermore, all three research streams are able to support the introduction of the fuel cell on aircraft.

2.1. Architectures

On modern civil aircraft, decentralized architectures in the electrical system based on semi-conductor technology, turned out to be best suited to reduce the weight of the electrical system compared to legacy aircraft. Decentralized architectures require more equipment, e.g. the SPDBs, as already displayed in Figure 5, than centralized architectures. More equipment means more equipment weight. In order to still be beneficial, such architectures must over-compensate the higher equipment weight by significantly less wiring weight. On large aircraft this is easily achievable, due to the long wiring lengths and thus heavy wiring. On smaller aircraft, with less wiring, it needed to be analyzed whether decentralized architectures are suitable. Results showed that also on smaller aircraft, the decentralized concept will be beneficial most of the time. Figure 6 summarizes the results. It shows the weight for several options. The reference architecture, as it can be found on existing legacy aircraft, has the highest weight (red line). A centralized supply (star), is heavier than most of the decentralized versions expect for the one with 16 SPDBs. The optimum shows at 6 SPDBs. For aircraft with slightly similar dimensions as for the one, to which the results refer, the optimum is not at 6 SPDBs but remains in that area. This shows that also on smaller aircraft, the decentralized architecture is most beneficial. This also supports the fuel cell approach. It allows detailed access to loads and thus detailed power control of them regarding power load fluctuations.

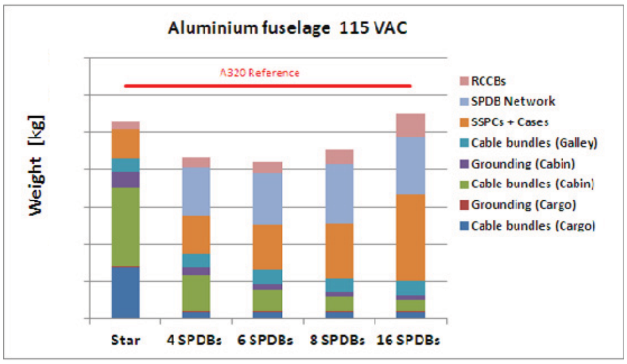

Figure 6: Results of the analysis on 115 VAC architectures

2.2. Higher Voltage Supplies

A plain way to reduce the mass of the electrical system is to increase the supply voltage. Provided the nominal power *P* demand of all electrical consumers remains constant, and the supply voltage *U* is doubled, the supply current *I* can be halved, see also Equation (1).

$$P = U \cdot I = 2 \cdot U \cdot \frac{1}{2} \cdot I = const \qquad (1)$$

The reduction of the nominal current typically allows reducing the wiring cross-section, which in turn saves weight. Harvesting the potential weight reduction means to consider and master three subjects:

1. Technical feasibility,
2. Human body protection, and
3. Commercial views.

Commercial views are e.g. airport readiness for aircraft with higher voltages. Depending on the final architecture of the electrical system, with which higher voltages are introduced, airports would have to update their ground power units, and service devices, such as vacuum cleaners, to provide the supply voltage. This is technically feasible, but requires investments. Furthermore, airline acceptance will be a major driver for or against the introduction of higher voltages. Depending on the solution, airlines would face the challenge of equipment only being capable to run on 115VAC aircraft and other equipment only being able to run on higher voltage aircraft. A third party will be system suppliers having the tendency to minimize investments for equipment on new aircraft. Nevertheless, technical solutions, which can make airports stay with their current equipment and airlines use one type of equipment on both 115VAC and 230VAC aircraft is possible. However, dual-voltage solutions, in most cases, will not provide the most efficient implementation and tend to be compromises only.

Research in this project concentrated on the technical feasibility of introducing higher voltages, which covered studies of both single-voltage and dual voltage type on the one hand, and the subject human body protection on the other hand. Currently under investigation for use on aircraft is the well known voltage level 230 VAC level, which is wide-spread all over the world, and partly implemented on aircraft already, as well as High Voltage Direct Current (HVDC) approaches.

The latter became focus in the studies due to the fact, that 230 VAC can be considered to be technically mature for civil aircraft and requires no intensive long-term research anymore. However, HVDC approaches still require further development to make it mature for future civil aircraft, and turned out to be much more promising regarding aircraft weight reduction, and thus more energy efficiency than an alternating current (AC) approach with comparable voltage level. Both types of voltages basically allow decreasing wiring weight. Furthermore, HVDC approaches will make it possible to optimize the electrical equipment in many cases, such that weight savings of wiring and equipment add up.

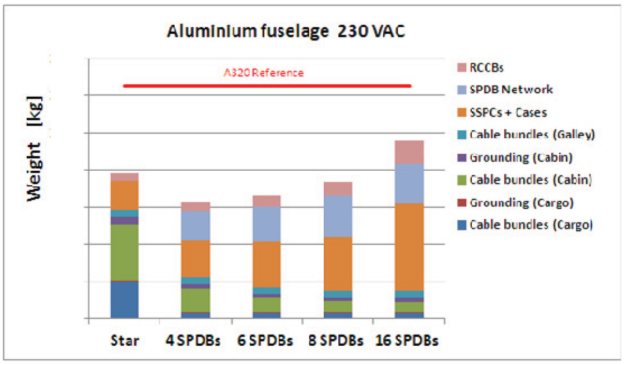

Figure 7: Results of the analysis on 230 VAC architectures

Figure 7 and Figure 8 some results out of a wide spread catalogue of analyses, that have been performed so far on this subject. Besides the fact, that the absolute weight of the electrical Cabin and Cargo distribution system has dropped, which could lead to a reduction of >20 % of the considered part, again decentralized architectures were identified to be most beneficial. Furthermore, HVDC architectures meet the application of fuel cell on aircraft as their output voltage is DC, too. A full HVDC network might allow doing without inverters or at least reduce the mass of inverters as the need for AC supply would go down or disappear as whole.

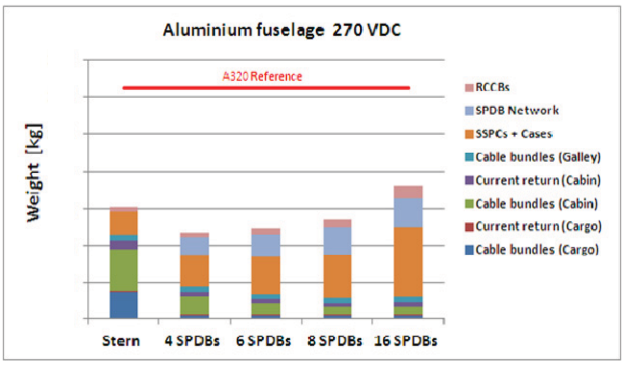

Figure 8: Results of the analysis on 270 HVDC architectures

2.3. Power Management

Sizing the electrical system requires an Electrical Load Analysis (ELA) to be performed first. Such an ELA has the shape as described in Table 1. For every system, which will be connected to the generators or a wire, the maximum power or current values are collected and summed up per flight phase (FP). In the example in Table 1, the maximum current demand shows in FP 2 and requires to the respective wire to have the capacity of 35 A, taking voltage fluctuations in the network into account.

Measurements have shown, that this kind of approach leads to low usage of the distribution network wiring, as can be seen in Figure 9.

Table 1: Simplified example for an Electrical Load Analysis (ELA)

System	FP 1	FP 2	FP 3
1	7.5 A	10.5 A	2.5 A
2	2.2 A	5.6 A	3.2 A
3	12.5 A	8 A	4 A
…			
n	5 A	6.35 A	1 A
Sum	**27.2 A**	**30.45 A**	**10.7 A**
Wire size	**35 A**		

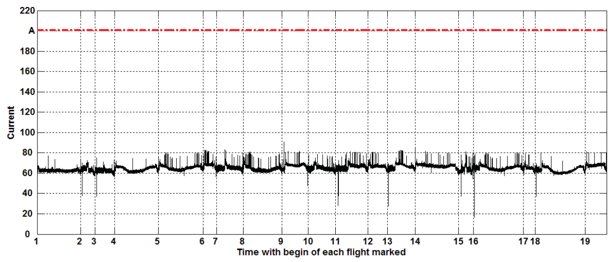

Figure 9: Current demand of the seat power supply system

The Figure shows the current demand of the seat power supply system (SPSS), over different flights. SPSS provides power to in-seat screens and passenger electronic devices. The red line in the figure is the initially expected maximum power demand, the black line the actual demand. One can see the gap between the actual demand of the and the maximum value. This gap represents unnecessary weight the aircraft carries with it. On large aircraft large weights can be saved, which are sometimes about 20 % of the mass of that part of the electrical system considered for the power management approach described in this section. In turn, unnecessary weight reflects in fuel consumption and CO2 dissipation that could have been avoided. However, it could have been avoided by use of a power management (PM) function only.

Today, such a function is not yet available in full scale throughout the whole Cabin and Cargo distribution system. The SPSS already uses power management, which clearly indicated, that this kind of function is certifiable. Nevertheless, extension to all Cabin and Cargo systems required further investigations. It was to investigate how to cover the broad set of different electrical characteristics and how to provide a stable function. It was to make sure that power management and the fact that capacities would not be able to supply all loads at maximum power at the same time in a flight phase anymore will not be perceived by neither cabin crew nor passengers.

Basically power management can be subdivided into three approaches, as described in Figure 10.

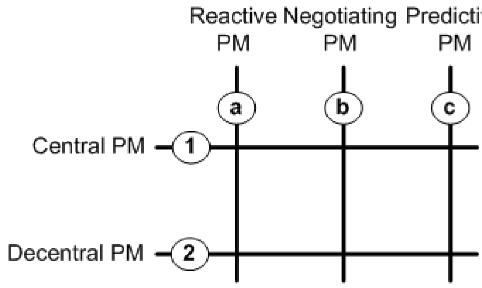

Figure 10: Power management concepts [2]

A reactive power management function does respond and clear overloads, if an overload has occurred. A negotiating PM function would e.g. receive requests of an electrical system asking for permission to go on-line. If enough margin is available, the system would be granted permission to do so. Predictive versions are e.g. those, which collect information about load characteristics and can learn and adapt during operation. Decentralized and centralized are defined by the location of each power management function. Predictive versions often use artificial intelligence techniques such as neural networks. These techniques contain nondeterministic steps, see also [3], [4]. Though [3] and [5] explain these techniques to be well capable of dealing with cases of fuzzy knowledge or complex non-linear behavior, the use of adaptive software tends to impose significant difficulties with certification. The negotiating PM requires bidirectional communication between the PM function and loads usable for load reduction. All loads must be able to receive and send PM signals. Provided, this was a prerequisite for a system to be includable in the PM algorithm, this would mean not just technical modifications in the electrical system but also in all other PM-included systems, which would reduce the option for retrofit solutions. The above given reasons lead to a important results in the project, thus, to use a reactive power management function.

2.3.1. Integration of Power Management on Aircraft

Figure 11 displays how to integrate a power management function on the aircraft. Given instances in the electrical system were identified to be suitable for the inclusion of such a function. Input data, such as currents of different distributions level, a power management functions needs are available. Computation units permit to run the actual power management algorithm, communication infrastructure and switches are usable and usable by the power management, respectively. Depending on the tuning of the communication infrastructure, which is a major driver for response times, this power management function can also be run with the fuel cell as electrical source.

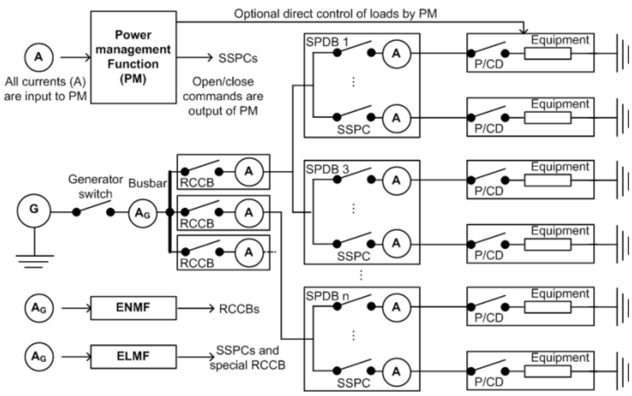

Figure 11: Potential structure of power management on aircraft [6]

3. ENERGY EFFICIENT CABIN AIR SUPPLY

3.1. Introduction

The environmental control system is the one of the biggest secondary power consumers on board of an aircraft and is therefore investigated in TP3.3. One way to increase the aircrafts efficiency could be the reduction of energy needed for cabin pressurization at cruise altitude by reducing the amount of outside air. However, the CO_2 concentration should not exceed approximately 0.25% (250 Pa), which is half of the current limit defined by the United States Department of Labour. Therefore, a separation of accumulating CO_2 emitted by the passengers and crew must be considered. The CO_2 together with parts of the moisture and volatile organic compounds (VOC) should be separated from the recirculated cabin air by a lightweight, simple separation unit with low overall energy consumption.

The introduction of a solid adsorber seems the most promising way to design an efficient CO_2 separation unit in the environmental control system. If a regenerable adsorbent is used, desorption conditions should be mild (low temperature and mild vacuum) to minimize the energy consumption of the system. Early CO_2 removal systems in spaceships used non-regenerative chemical adsorbents for the removal of the human emitted CO_2 [7]. Applying these systems to an aircraft would lead to unacceptable high maintenance costs due to the demand of regular exchanges of the adsorber in period of hours or days.

Hence, CO_2 separation systems using "in situ" regeneration of the adsorbent have to be used, because they allow to be checked within aviation specific maintenance cycles. These systems are more complex, due to the demand for at least one bed for desorption respectively adsorption, as displayed in Figure 12. Regeneration of the adsorber can be achieved by temperature and pressure swing adsorption.

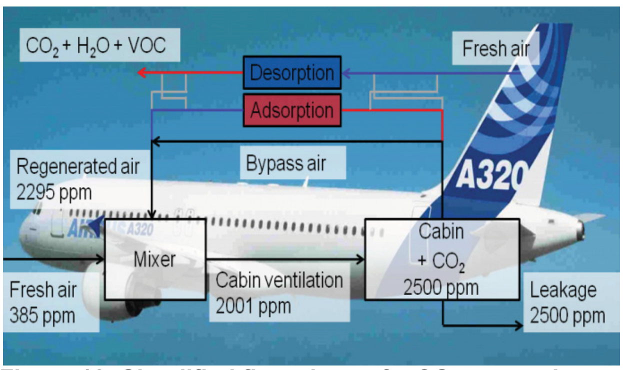

Figure 12: Simplified flow sheet of a CO_2 separation unit using a regenerable adsorbent.

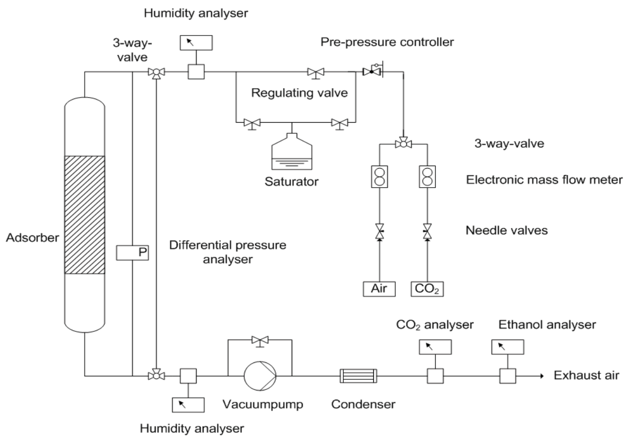

Figure 13: Experimental set up for adsorption from gas mixtures

The two established materials for the separation of human emitted CO_2 from air are zeolites and solid amine sorbents, possessing advantages and disadvantages. Zeolites have got a high adsorption capacity and a long life time, but demand additional drying beds due to limitations in the adsorption of CO_2 from humid air. Materials consisting of a solid support being impregnated with liquid amines are called solid amine sorbents and do not demand for the separation of humidity from the recirculation air. But an undesirable loss of the amines into the regenerated air may occur, since the amines are not covalently bound to the surface of the support. Using “in situ” adsorbent regeneration has been established up to now only in vessels with an absolute necessity for a CO_2 removal unit, due to the absence of breathable air in the operation environment (e.g. submarines and spacecrafts). Hence, the established materials used for CO_2 adsorption could be applied in spite of the above mentioned limitations. However, the successful application of a CO_2 removal unit to an aircraft requires an adsorber with none of these drawbacks.

In this work a novel amino functionalized silica aerogel adsorbent has been developed for the utilization in a CO_2 separation unit for the realization of an energy efficient cabin air supply [8]. Silica aerogel possessing a low density, an open pore structure and a high surface area are ideally suited for use as an adsorbent [9]. Furthermore, they can be easily functionalized to specifically improve their adsorption capabilities for the requirements of CO_2 separation in an aircraft.

3.2. Materials and Methods

The aerogels were produced as described in Wörmeyer et al. (2012) [8]. The pure CO_2 adsorption isotherms were measured with a Quantachrome Nova 3200e at 0°C. The experimental device is a fixed bed adsorber, being illustrated in Figure 13. The fixed bed has got a diameter of 0.025 m and flow capacities of 0-2 NL/min. The temperature can be changed from ambient to 300°C and the pressure from 0.1 – 1 bar.

3.3. Results and Discussion

3.3.1. Comparison of adsorbents by pure CO_2 adsorption

The results (Figure 14) show that in a pure CO_2 environment the newly developed adsorbent is able to adsorb more CO_2 (0.047 $g_{CO2}/g_{Adsorbent}$) than the commercial adsorbents zeolite 13X (0.023 $g_{CO2}/g_{Adsorbent}$), HSC+ (solid amine sorbent) (0.037 $g_{CO2}/g_{Adsorbent}$ at 2000 Pa) and an enhanced activated carbon (0.01 $g_{CO2}/g_{Adsorbent}$) at the relevant partial pressure. This renders the adsorbent very useful for the removal of CO_2.

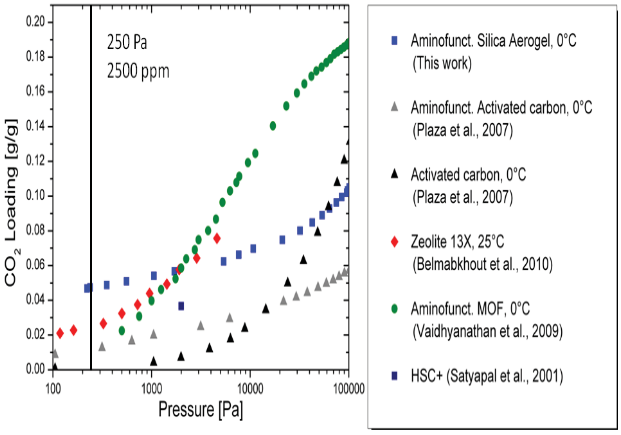

Figure 14: Pure CO_2 adsorption isotherms of state of the art adsorbents and amino functionalised silica aerogels. Black line represents the partial pressure at the relevant CO_2 concentration of 2500 ppm [11].

3.3.2. Breaktrough curves and adsorption capacity

In addition to CO_2, water and VOC´s should also be removed from the recirculated cabin air by the aerogel adsorbent. Ethanol was used to represent the VOC´s, since it is the VOC with the highest concentration in aircraft cabin air [10] with apparent values in the range of 2 ppm. Figure 15 shows that order of breakthrough is water, ethanol and CO_2. Hence, in a CO_2 removal unit some of the emitted moisture and nearly all of the ethanol will be separated from the recirculation air.

Conditions	
Temperature	22°C
Pressure	1 bar
Flow	1.25 Nl/min
$C_{CO_2,in}$	2500 ppm
rH_{ein}	30 % rel.
$C_{ethanol,in}$	10 ppm
$X_{CO_2,BT}$ [g/g]	$3,4 * 10^{-2}$
$X_{H_2O,BT}$ [g/g]	$2,6 * 10^{-2}$
$X_{Ethanol,BT}$ [g/g]	$1,2 * 10^{-4}$

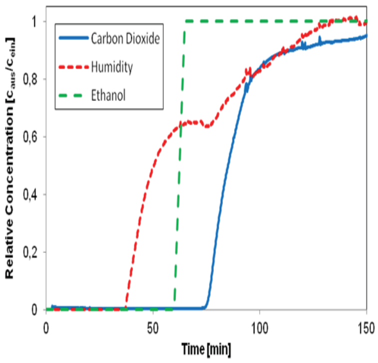

Figure 15: Separation of CO_2, H_2O and Ethanol from aircraft cabin air by amino functionalised aerogel. Bed length 0.095 m. The concentrations of the species in the incoming air reproduce aircraft cabin air with an elevated moisture content.

3.3.3. Desorption and regeneration mode

Since the adsorbent should also be regenerated during aircraft operation, the evaluation of the desorption conditions is also valid. For this purpose the adsorbent was regenerated at 70°C and 250 mbar (outside pressure at cruise altitude) with air. The adsorption cycle (0.25% CO_2 and 30% rel. humidity at 23°C) took as long as the desorption cycle. Figure 16 shows that the adsorbent can be successfully regenerated at moderate temperatures. The constant adsorption capacity indicates a complete desorption of the adsorbed CO_2 and water. The observation that the adsorption takes as long as the desorption leads to the fact that just two beds are needed. One bed will regenerate the recirculation air while in the other bed the adsorbed CO_2 will be vented to the outside.

Conditions	
Temperature	20°C
Pressure	1 bar
Flow	1.25 Nl/min
$C_{CO_2,in}$	2500 ppm
T_{des}	70°C
P_{des}	250 mbar
$t_{ads} = t_{Des}$	
$rH_{ein,ads}$	30 %
$rH_{ein,des}$	0 %

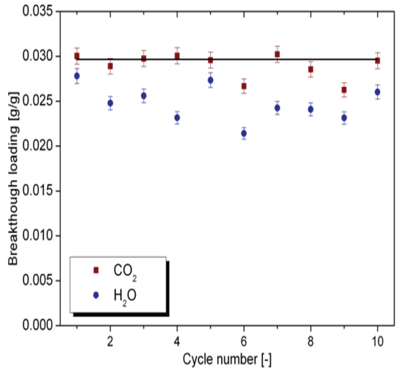

Figure 16: Breakthrough loading of amino functionalised aerogel after several adsorption and desorption cycles shows complete desorption at 70°C and 250 mbar desorption conditions. Adsorbent bed length 0.125 m.

3.4. Conclusion

The newly developed aerogel adsorbent promises the successful integration of a CO_2 removal unit in an aircraft. The amino functionalised silica aerogel possesses a very high adsorption capacity at low CO_2 concentrations (0.047 g/g) even in the presence of moisture. It is not only able to remove CO_2 but also water and ethanol from the simulated recirculation air. Finally, the ability of the newly developed aerogel adsorbent to be regenerated at mild conditions will lower the energy consumption of an aircraft.

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