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Inhouse4000 – experience with a PEM fuel cell system for stationary applications in buildings

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Object of the R&D activities of the last 2 years was the development of the new generation of a stationary low temperature PEM fuel cell system (operating temperature max. 80°C) with the following features

- 5 kW electrical power
- 10 T€ / kW electrical power
- robust continuous operation
- lifetime greater than 10.000 h
- system volume less than 1000 dm³.

This new system is a pre-stage for a market suitable system. With some modifications it also allows an upgrade to a middle temperature system (operating temperature max. 120°C). The accomplished R&D activities are essentially based upon simulations, the development of several versions, experimental analysis in several test systems and a two years lasting field test. The system was integrated into the supply system (heat and electrical power) of a botanical garden. In summary of these activities we could build up a new prototype system which accomplishes all requirements mentioned above. We achieved research results, which allow us the development of a market-driven system suitable for low and middle temperature applications within the next 2 -3 years.

INTRODUCTION

Important international companies, which are developing and producing PEM fuel cell systems, changed their development focus from low temperature PEM fuel cells to high temperature fuel cells (operating temperature up to 200°C, Plug Power/ Vaillant).This new membrane technology is very CO tolerant and needs no water during operation. Due to these advantages it seems that a high temperature system will be much smaller and cheaper than a low or middle temperature system. But in the present project we demonstrate that proceedings in the R&D of low and middle temperature fuel cells systems have enough innovation potential to be competitive in certain applications. Main reasons for it are small reformers with carbon monoxide content less than 10 ppm and the high power density of low temperature PEM fuel cells. An increasing of the lifetime and a significant cost reduction for low temperature membranes, the ongoing material and procedural change-over from low temperature membranes to middle temperature membranes are other reasons for it. At least new developments in the nano-technology create new chances for low and middle temperature membranes.

METHODS

We tried to combine theoretical methods and practical tests to get significant results within an acceptable time. One of the central issues is the degradation of the cell. The degradation can be divided into a reversible and an irreversible degradation. Reversible degradation means a degradation of the cell voltage resulting of bad operating conditions (temperature, humidity, mass flow of reactants, pressure), inefficient or inhomogeneous fluid allocation and others. Irreversible degradation means a degradation of the cell voltage resulting of an alteration of the components of the fuel cell. This includes an alteration and loss of catalysts, carbon corrosion and a disintegration of the membrane caused by radicals. Together with a partner from Hochschule Anhalt we developed a simulation system for low temperature PEM fuel cells. This is an universal mathematical 3 D model and allows the evaluation of physical conditions in a single cell.

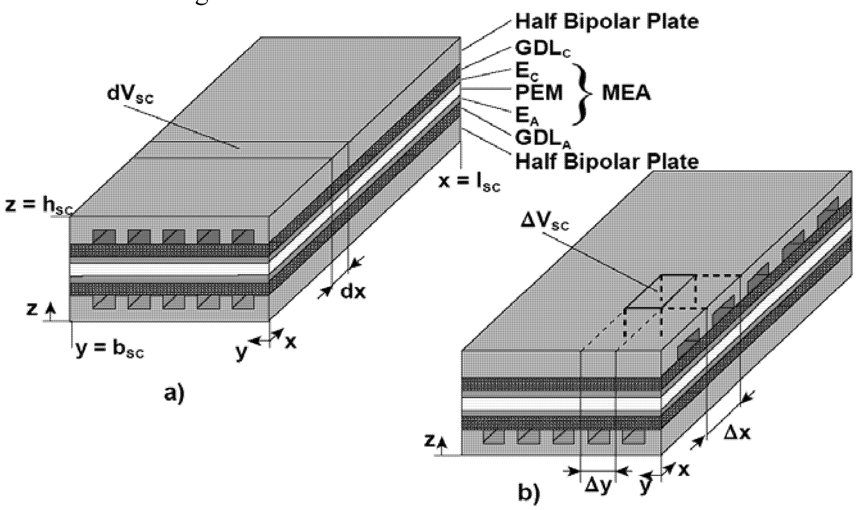


Fig.1: illustration of the simulation elements in a cell (Karwoth, 2005)

The design of the cell and the bipolar plates will be deposited in the simulation. The deposited bipolar plate design will be divided into several simulation elements. One element includes one channel and a half land on each side of the channel. One simulation element includes all layers beginning with the cathode bipolar plate through the gas diffusion layer and the MEA to the anode bipolar plate. The number of modelling elements is selectable. The maximal solution for a single cell is 93 x 93 modelling elements. Each modelling element delivers 50 parameters, which can be analyzed to evaluate the cell.

Most important aim of the simulation was to create a very homogeneous allocation of the fluids, the temperature and the current density. To reach this we diversified the operating conditions (temperature, humidity, pressure, mass flow of reactants) and the structure of the bipolar plates. Another aim was to reach parameters which allow a reduction of costs.

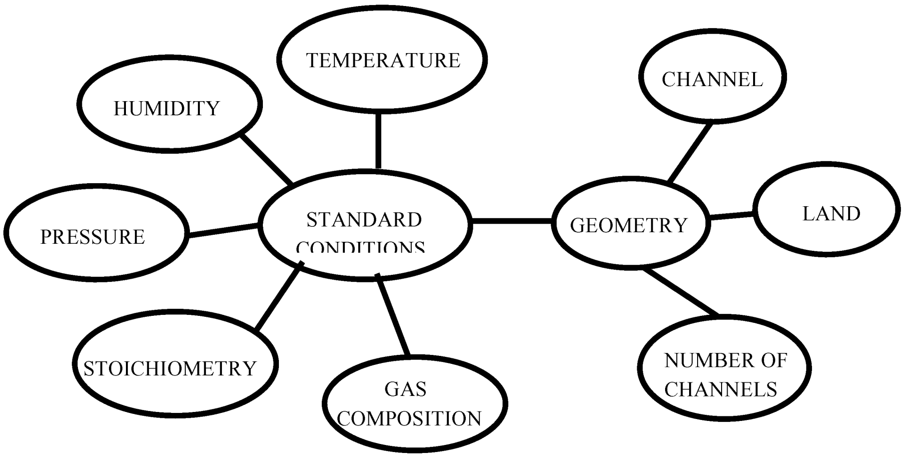


Fig.2: variation of parameters for simulation

Another important parameter was the flow direction. All simulations were made with co flow of the fluids and counter flow of the fluids. After the simulation we obtained statements concerning the optimal operating conditions in connexion with the best bipolar plate structure. We could see as shown in fig. 3 the homogeneity of the current density and its changes by differing the operation conditions or flow direction of the fluids.

Due to the simulation conclusions we developed several designs for bipolar plates. At first we made some pre-tests. That means we evaluated physical parameters like contact pressures, materials and tolerances. But we also evaluated economical parameters like production costs now and later (mass production). Passing these tests the bipolar plates were integrated into short stacks (300 – 500 W). These stacks were operated several hundred hours. These test results where compared to the simulation results. We obtained a very good consistence between test and simulation. The best short stack/ bipolar plate design was chosen and operated for several thousand hours. The tests with the other designs were terminated.

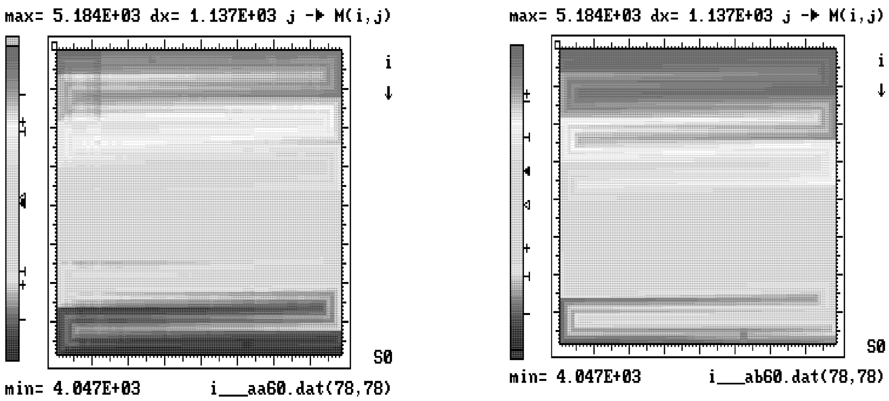


Fig. 3: simulation result of a bipolar plate design with different operating conditions (Beckmann, 2005)

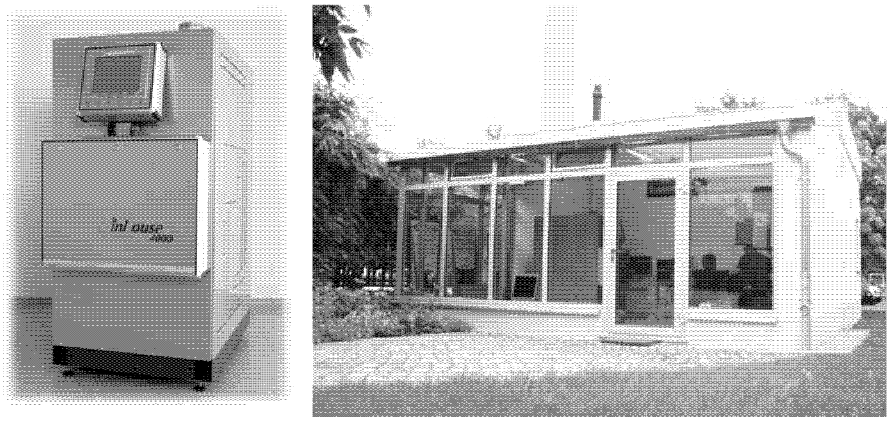


Fig.4: inhouse4000 system at the botanical garden of the city of Chemnitz (Foto: RBZ)

We had to iterate this process to find the best operating conditions and the best bipolar plate design. After all these tests we adjusted the design of our existing stacks for field test systems. The test of larger stacks (4 kW) with this new design and operation conditions is still running in our field test systems inhouse4000 (Fig. 4).
Based on these new stacks and our experiences with our field tests systems we also had new conditions for the peripheral devices which required a modification or adjustment of the devices and the process. The air supply system has been reduced about 50% in size and power consumption. The humidification system was radically modified and does not need any auxiliary power. The new air supply system and the humidification system have been running since 10000 hours in one of our field test systems. The reformat conditioning follows a complete new concept. It is a self regulating system with no auxiliary power consumption. The fuel cell operating has been stabilized and its sensitivity against outside influences has been strongly reduced.

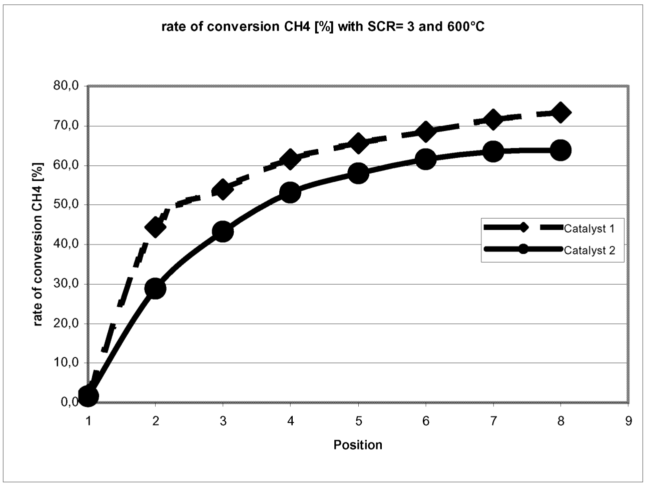


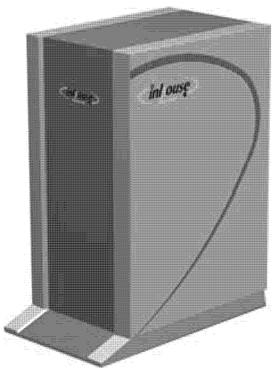
Fig.5: catalyst screening (CH_4 rate of conversion) on a test facility with 8 catalyst carriers connected in series (Nitzsche, 2006)

The reformer of the inhouse4000 system was revised last year, concerning efficiency, achievable gas quality and size. Size and thermal mass of a reformer can be reduced by improved catalysts. Hence first of all a catalysts screening was carried out, to take into account the advances of catalyst manufacturers. (Fig. 5)
For the steam reforming process two catalysts could be identified, which enabled us to reduce the reforming temperature by 50 K. Furthermore catalyst mass and heat exchange surface could be reduced by 20%. For the new inhouse system his led to a reformer with a performance enhanced by 25% and a simultaneous reduction in size by 20%. A similar result could be achieved within the gas-cleaning stages. Here the CO concentration in the reformat gas after the reformer could be reduced by 20%.
It can be shown that the gas quality and especially the CO concentration are stable during load changes. Another advantage could be gained by using catalytic active heat exchangers. An important aspect to improve the energy efficiency of the entire system was to reduce the heat losses to a minimum. Compared to the new, the old design showed a number of heat bridges, which were eliminated completely. Furthermore a new isolation, which features a heat transfer coefficient that is only 25% of the original value. Therefore the heat losses of the reformer and temperatures inside the housing of the system could be reduced essentially. For example the temperature of the external wall of the reformer could be reduced from 90°C to 45°C. Durability and stability of the reformer through 10.000 h of operation under difficult conditions were already shown by the old design. Because of the modified catalyst the new reformer can also reform biogas. A first prototype is already built and is tested extensively at the moment. The first test shows that the reformer is applicable with biogas with CO_2 content from 25% to 55%.
A network of field test systems (inhouse4000 and older types) installed in our labs and at cooperation partners secures a lot of experiences and measure data. Due to the fact that these systems are operated under real application conditions we could eliminate a lot of construction failures and we learnt a lot about failures occurring under real applications.
Taking all experiences from field tests and our new developments we created a new generation of the inhouse system – the inhouse5000. This system is suitable for energy production in multi family residences, hotels or wellness centres, public buildings and small and medium sized enterprises.
The inhouse5000 system produces electrical and thermal power to deliver the minimum and medium load of the mentioned objects. The system is designed for a grid connected operation. It has a modular design and can be adjusted to the customer needs. Ongoing tests with biogas extend the range of applications. Cluster of inhouse systems can be installed on farms to use biogas and produce electrical power and heat for the farm.

CONCLUSIONS

With the new system inhouse5000 we solved a lot of problems. The reformer size was reduced by 20 % by increasing the reformer performance by 25 %. The energy consumption (natural gas) of the system was reduced by optimising the isolation of the reformer and reducing the anode stoichiometry. New catalyst screening helped us to reduce the carbon monoxide. The carbon monoxide part is less than 10 ppm. According to the new operating conditions of the stack and the reformer we optimised and adjusted our peripheral devices. The electrical energy consumption for peripheral devices was reduced by nearly 50 %. New materials and the optimised construction of reformer and fuel cell stack led to a significant increasing of the lifetime of stack, reformer and system. As already mentioned one inhouse4000 system is running for 10000 hours and the test is going on. Surely we can not operate a fuel cell for such a long time. But currently we can operate a stack 4000 – 5000 hours in our inhouse4000 system. Saving

of primary energy (natural gas) resulted in a reduction of carbon dioxide production. Comparing to conventional systems we produce with our fuel cell system approximately 75% of carbon dioxide. If we are using biogas we have a closed carbon dioxide cycle.
Sufficient innovation potentials have been revealed with the mentioned methods. It is possible to develop through intensive R&D competitive products within the next 3 – 4 years. Inhouse5000 is the next step to a competitive product for the market. Already today we can demonstrate the potential of fuel cell systems.



basic principle	
fuel generation	natural gas steam reforming
fuel cell type	PEM fuel cell
nominal power	
electric	1 - 5 kW
thermal	2 - 10 kW
natural gas consumption	0,5 – 1,5 m^3/h
temp. of heating circuit	50 / 70°C
cold start time	1 h
load change (30-100%)	15 min
current efficiency	25 – 30 %
total efficiency	60 – 90 %
dimensions(WxHxD)	700x1500x1000 mm^3

Fig. 6: inhouse5000-system (RBZ, 2007)

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