Hydrogen is considered to be the energy source of the future and will, at some time, replace the ever-dwindling stocks of petroleum and natural gas. Motor vehicles will then be able to operate with fuel cells, a field in which W. L. Gore & Associates, as producer of high-tech membranes, is working as well. The following article describes the resulting challenges from the point of view of a component manufacturer in the fuel cell technology environment.

1 PEM Fuel Cells for Automotive Applications

The proton exchange membrane (PEM) fuel cells are the most likely candidates for operating motor vehicles. They run at moderate temperatures, but also have a wide operating range (ideally from −40 °C to 120 °C). The assembly is shown in Figure 1. A thin polymer membrane prevents direct contact between the gases but facilitates the flow of protons (H+) from the anode to the cathode side, where water is produced. A specific catalyst coating ensures that hydrogen is oxidised into protons and electrons on the anode side and atmospheric oxygen to be reduced on the cathode side. This composite construction is known as a Membrane Electrode Assembly (MEA).

2 Applications in Motor Vehicles

Basically, work is being carried out on two different applications for motor vehicles: traction power, as a direct alternative to the well-known internal combustion engine and the APU, the on-board auxiliary power unit, as a supplement to, or replacement for, the conventional battery system. Hybrid systems are also conceivable, for example, combining it with a new type of energy storage device (supercapacitors). The demands vary, depending on the operating requirements. As expected, traction power represents the biggest challenges to the MEA manufacturers because of the extremely high performance requirements and the need for cost-effectiveness. In fact, each vehicle (100 kW) would probably need about 10 m² of membrane.

3 Gore and Fuel Cells

The proton conductivity under real operating conditions is essential to the power density of the fuel cell. The thickness and the specific conductivity of the ionomer (ion-conducting polymer) play an important role. For Gore, as a polymer and membrane specialist, this was a determining factor in their decision to work on fuel cells.

By Peter Hertel
1 PEM Fuel Cells for Automotive Applications

Whereas Gore’s existing products in headlamps, electronic casings, sensors, batteries and bearings were already well-known in the automotive industry, this meant opening up a completely new market segment.

Based on over 40 years of experience in the manufacture of the thinnest ePTFE (expanded Polytetrafluoroethylene) membranes, a composite membrane was developed, possessing qualities hitherto unknown in fuel cell technology. It is the core of the membrane electrode assembly, which is marketed under the brand name Gore Primea MEA, Figure 2. Here, a thin, highly porous PTFE matrix acts as a mechanically and chemically stable backbone for high performance ionomers which fill the pores for each application. In this way even mechanically unstable ionomers can be used to make stable membranes, which was not previously possible, with low thickness membranes (Gore membranes for automotive applications are usually thinner than 20μm).

4 Challenges for the Component Manufacturer

The demands placed on the MEA can be summarised in three key words:
- performance
- reliability,
- cost-effectiveness (cost reducing effect on the entire system).

The performance characterisation of an MEA follows a polarisation curve, as shown in Figure 3. In particular, where the membrane is used in vehicles the specific operating conditions always have to be taken into account. Constant load changes and changes in the environmental conditions provide the biggest challenges to the stability of the fuel cells compared to other applications. Here the performance / power density targets (10KW/m²) seem to be more easily achievable than targets in terms of durability. Gore MEAs have already been run in the laboratory for 30,000 hours under stationary conditions. However, the 5,000 to 7,000 hours that need to be achieved in a cell stack under automotive operating conditions are a somewhat more complex matter. Cycling, start-stop, cold start, changing temperatures and humidity, all make enormous demands on the system and its component parts.

The challenge for the manufacturer is to identify and understand the wide variety of mechanical and (electro)chemical types of phenomena which occur and then either exploit them or avoid them from the point of view of system engineering or materials. A hole in the membrane, for example, does not immediately result in the collapse of the entire system, but it could lead to more extensive damage. There could be various causes for such a pinhole. In the simplest case a fibre from the gas diffusion media could pierce the membrane, whilst in the worst case the membrane could become chemically decomposed. Under certain conditions, e.g. caused by non-uniform gas distribution in the channels, not only is water synthesised in the presence of the catalyst, but also unwanted by-products such as hydrogen peroxide and free radicals. The presence of metal ions which have originated from an unclean environment can make this effect even worse. Moreover, mechanical effects, caused by repeated swelling and shrinking of the ionomer as a consequence of load changes can damage the membrane. Unfavourable potential distributions in the cells can cause damage to the electrodes and thereby break up their structures. The result is a measurable loss of performance which represents an irreversible degradation of the cell.

Much of this type of damage only starts becoming measurable after hundreds, if not thousands of hours, which makes it more difficult to develop counter-measures quickly. Once the damage has been determined, the next step would be to conduct a post-mortem analysis in order to ascertain the true cause of the failure and understand why it happened. There are a wide range of optical, mechanical, electrical and electrochemical procedures available (SEM, permeation and resistance measurements, cyclic voltametry) to analyse changes in the membrane, in the ionomer or in the electrolytes. Gore has invested many millions of euros in a testing infrastructure, in order to carry out analysis requests. This testing infrastructure comprises more than sixty testing stations which are run by an equally large number of scientific personnel.

If the factors (load, temperature, pressure) which speed up any specific material degradation are known it is then possible to develop test procedures to predict potential damage earlier and to considerably reduce the development time of new materials. Figure 4 shows a test procedure which permits membrane failure to be demonstrated about 10 times faster than under actual conditions.

Obviously, the knowledge gained from this must subsequently be translated into improvements to the materials and the system or to the operating strategy. Mathematical modelling (using simulation programmes) is becoming increasingly important in this context. It provides an insight into the processes inside the fuel cell and helps to assess the influence of material and structural properties on the overall performance. As the performance of a PEM fuel cell is dependent on electrochemical kinetics, proton conductance through the ionomeric material and mass transport limitations, a huge number of experiments would be necessary to measure the influence of each component. What is more, the real conditions in a sealed operating cell, such as temperature and humidity distribution along the flow channels are difficult