Fuel cells: evolution in design

Andrey Muntyan
Tavria State Agro Technical academy, Melitopol, Ukraine

The history of the fuel cell can be traced back to the 20th Century, yet in spite I of this fact and several decades of intense development, fuel cell technology still seems a long way from commercialization. Fuel cell manufacturers believed that 2003-2005 would be when commercial production of their units for various applications would start, but the latter half of the decade is a more realistic prospect.

Nevertheless, development continues because fuel cells have considerable potential in a wide range of applications. In the power industry, their efficiency and emissions-free characteristics make them suitable for a wide range of applications: combined heat and power, distributed generation, storage and back-up applications, and powering the home. Their widespread commercial use is held back by two key factors: cost and reliability.

An innovation by a UK-based company promises to help overcome these obstacles, however. Morgan Fuel Cells (MFC) has announced a technology breakthrough that will boost the power output of fuel cells and at the same time cut manufacturing costs. The development brings forward the day when fuel cells will be commercially viable for mass-market automotive and general power applications.

The breakthrough is in the design of the bipolar plates that are a key component of fuel cells. Drawing its inspiration from the natural world, MFC has developed a 'bio-mimetic' bipolar plate, the design of which mimics the structures seen in plant tissues and animal lungs. The design results in more efficient and even distribution of gases, resulting in greater efficiencies, higher power outputs and greater reliability than ever seen before in fuel cells. MFC says that it has already achieved increased power outputs of 16 per cent, and believes that more can be achieved.

Fuel cells generate electricity through a simple electrochemical reaction between the fuel - hydrogen - and oxygen from the atmosphere. Heat and water are the only byproducts. There are several different types of fuel cell but they are all based around the same basic design consisting of two electrodes separated by a solid or liquid electrolyte. A proton exchange membrane (PEM) cell typically used in power generation and vehicle applications uses a polymeric membrane as the electrolyte with carbon supported platinum electrodes. A single cell produces between 0.6 and 0.7 V, so a fuel cell 'engine' for a stationary power plant has to be built up from several hundred PEM cells stacked together.

Bipolar plates have two key roles in fuel cells. Firstly they are the method of introducing the gases into the fuel cell and ensuring that the electrodes are adequately supplied with reactants. On the cathode (positive electrode) side they supply air (or oxygen) and on the anode (negative electrode) side they provide the delivery of hydrogen (or fuel). The second function they play is to act as a conductor for the electrical energy, thereby allowing the current to flow from cell to cell through the stack.

The thing about bipolar plates is that they have to be resilient to any of the chemical reactions that are going on. So you have a very strong oxidising side of the plate and a very strong reducing side. You therefore need a material that is good in both of those areas.

Because of the way that operates, the machine likes to have long, straight tracks and you therefore end up with a serpentine design, i.e. a long straight track going up one side of the plate, then turning and going back down again. It's like a snake twisted over the full width of the plate to deliver the gas uniformly across the plate.

Although widely used in the fuel cell industry, this design brings a number of problems. A great deal of pressure is needed to blow the gas through the flow field channels because it has to travel anywhere from eight to 20 times the length of the plate, depending on how many turns there are. This high backpressure is achieved through the use of fans. In addition, because the gas travels such a long way, there can be a significant reduction in gas concentration from the inlet to the outlet.

The Oxford English Dictionary defines 'biomimetic' as "mimicking a biochemical process". In addressing the problems associated with serpentine designs, MFC took its lead from nature, which provides a perfect example through animal lungs and plant leaves.

A biomimetic plate is a flow field design that uses biological principles to diffuse the gas. If you look at any natural system, the way that gases or reactants are distributed over a large area is via a large central channel which then branches off into smaller and smaller vessels. That is a very efficient way of designing a gas delivery system and those are the types of designs that we have been able to develop and fabricate. MFC's biomimetic design is much more complex than the standard serpentine design. The key advantage of the biomimetic plates is that the gas has to travel a much shorter distance and the pressures required are therefore lower. We can reduce the backpressure. a shorter distance across the plate. Nature doesn't use any pumps or compressors to distribute gas, so it's a very efficient way of delivering the gas.

If you reduce the back pressure you reduce the fan power requirements so your parasitic load is lower and you get more power out of the stack. There is a knock-on effect of having a very efficient gas delivery system and that is that you don't need as much balance of plant to get the fuel cell to run. This improvement in efficiency and power output was a key selling point.

The fact that the gases have to travel shorter distances in biomimetic plates compared to serpentine plates also results in more even gas distribution and therefore an even distribution of current across the plate. This in turn helps to eliminate cold and hot spots, which results in improved reliability in the fuel cell.

If you take away the mechanical failure mechanisms - for example these cells tend to be clamped very tightly together and can break - one of the biggest failure routes is the fact that you get this unevenness across the membrane which over time means that parts of the membrane cease to operate effectively and this gradually magnifies into complete failure. If the membrane is too hot it is prone to drying out and if it gets too dry it won't work. Similarly if the membrane gets too wet then it floods and it also won't work. So a fine balance must be achieved to keep the central membrane conductive and the fuel cell working.