Injection moulded low cost bipolar plates for PEM Fuel Cells

A. Heinzel [1,2], F. Mahlendorf [2] *, O. Niemzig [2], C. Kreuz [1]

[1] Zentrum für BrennstoffzellenTechnik (ZBT) GmbH, Carl-Benz-Straße 201, 47058 Duisburg, Germany;
[2] University Duisburg-Essen, Institut für Energie- und Umweltverfahrenstechnik, Lotharstraße 1, 47057 Duisburg, Germany

* Corresponding author
E-mail address: F.Mahlendorf@uni-duisburg.de

Abstract

The development of bipolar plates that can be produced by standard mass production techniques is a main issue for the commercialization of PEM fuel cells, as bipolar plates contribute significantly to the cost structure of PEM stacks. In the recent years, the University of Duisburg-Essen together with the Zentrum für BrennstoffzellenTechnik GmbH (ZBT) has identified a number of carbon-polymer composites with densities of 1,6 g/cm³, specific bulk conductivities between 5 and 150 S/cm and material prices between 2 and 10 €/kg. Standard composite mixtures consist of a thermoplast and a carbon compound mixture with additional additives to increase the conductivity of the compound material. The composites generally show high corrosion resistance in the PEM fuel cell environment. Composite material samples proved to be absolutely stable in immersion tests in sulphuric acid and deionized water under pure oxygen atmosphere for several thousand hours. ZBT has successfully demonstrated the production of bipolar plates by injection moulding with cycle times of 30 – 60 seconds. With the help of tailored moulds injection moulding of bipolar plates becomes price competitive even for comparatively small series in the range of several thousand plates. PEM stacks with injection moulded bipolar plates of 2,5 – 4 mm thickness and an electrical power of up to 200 W have been constructed and successfully operated.

1. Introduction

Beside the membrane-electrode-assemblies (MEA) and the gas-diffusion-layers (GDL) the bipolar plates constitute the most important element of a PEM. They have the function of a manifold for the reactant gases - e.g. hydrogen or reformate gas and air - and should distribute the reactant gases on each side over the whole active area of the MEA. Furthermore the bipolar plates have to be gas-tight to prevent mixing of the reactant gases.

To get each cell into electrical contact, the bipolar plates need to be electroconductive especially in the z-direction, i.e. orthogonal to the plate. Furthermore the thermal conductivity is also a very important demand on the bipolar plates, to control the stack temperature and to achieve a homogeneous temperature distribution in each cell and over the whole active area. Another demand on the bipolar plates material is the chemical resistance to the stack conditions. The material has to resist temperatures of about 80° C, high humidity, a steady electrical potential and a low pH-value.

To meet these demands ZBT has developed a number of compound mixtures for bipolar plate materials consisting of a commercially available thermoplast and graphite with additional additives to increase the conductivity of the compound material. The composites generally show high corrosion resistance in the PEM fuel cell environment. For example, a composite material with a bulk conductivity of 20 S/cm proved to be absolutely stable in immersion tests in sulphuric acid and distilled water under pure oxygen atmosphere at 60 °C for over 10.000 h.

Different bipolar plates production techniques like high performance drilling, compression moulding and injection moulding have been investigated at the ZBT [1,2]. ZBT has recently focused on injection moulding as a standard mass production technique to manufacture bipolar plates in a one-step process. Within the frame of ongoing R&D work, key production steps are optimised and preparations are made for small and medium series production.

2. Experimental

Thermoplastic materials were chosen as polymer matrix due to their low cost, high availability, high chemical resistance and good mechanical properties as well as being impermeable. Standard composite mixtures consist of a thermoplast and a carbon compound with additional additives to increase the conductivity of the compound. A variety of mixtures with regard to composition and ratio of electronically conducting and insulating compounds were prepared at temperatures between 200 °C and 250 °C in a kneader or an extruder, if larger quantities are required.

The bulk resistance, volume resistance and contact resistance were obtained simultaneously in a four-electrode DC-measurement. The DC resistance measurements were performed with a digital multimeter (Keithley 137) and a potentiostat used as galvanostat (WENKING 96-20). During the measurements the samples with an area of 2 cm^2 were contacted via two gas diffusion layers in a press with two gold-plated hobs of stainless steel and a pressure of 4,5 MPa (Fig. 1).

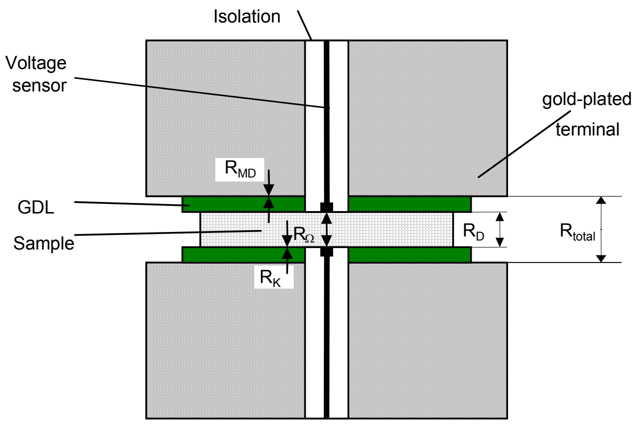

Fig. 1: Experimental setup for determination of specific bulk and contact resistivity. (R_Ω = bulk resistance, $R_D = R_\Omega + 2\,R_K$ = volume resistance, R_K = contact resistance bipolar plate / GDL)

3. Injection moulding of bipolar plates

From recent investigations it is known that thermoplasts with low additive loadings of 50 wt.% already achieve specific bulk conductivities of about 20 S/cm [3]. These compounds served as starting point for injection moulding experiments. Each test run of the injection moulding machine requires several kilograms of compound material. In a first step, filling materials (e.g. carbon compounds) are thoroughly mixed in an industry mixer, each batch yielding 5-7 kg of mixed components. The production of the compound material takes place in a twin screw extruder which is equipped with two gravimetrical metering units for the thermoplast and the premixed filling materials. The compound material coming out of the extruder nozzles is cut by an adjustable cutting device into granules of 4 mm diameter and 3-4 mm length (Fig. 2,3). The current output of the extruder is up to 5 kg/h, depending on the filling grade of the compound.

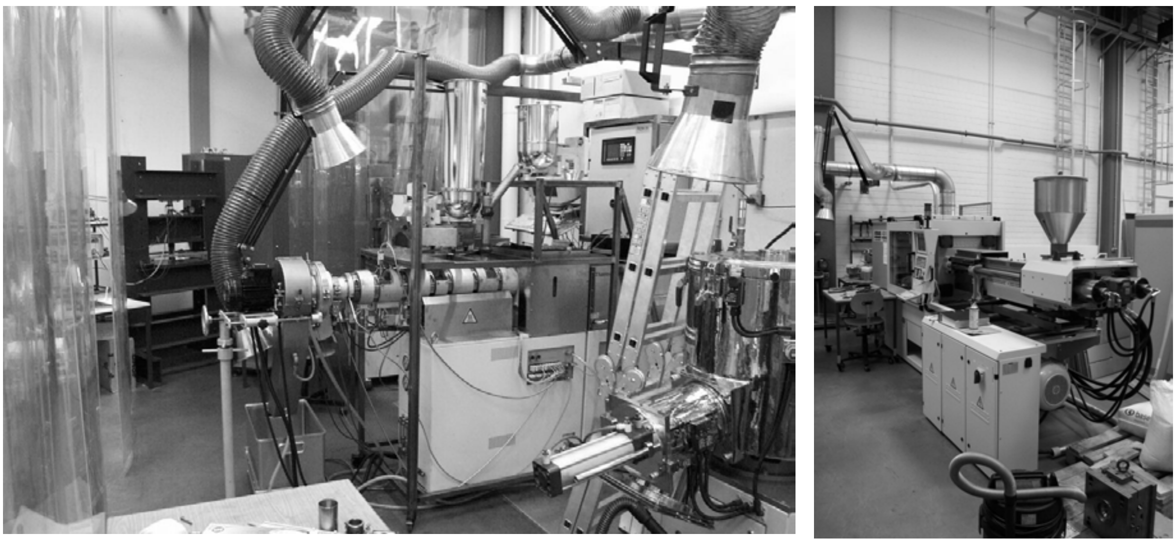

Fig. 2: Bipolar plates processing laboratory. The left photograph shows the extrusion machine (center) and the mixer (foreground), the right one depicts the injection moulding machine

After optimisations on the compound material, the injection moulding process (e.g. the process parameters) and the moulding tool, the injection moulding production of bipolar plates was built up. Structured and unstructured plates of 140 x 60 mm with a variable thickness between 2,5 – 4 mm were produced successfully by injection moulding, a mould for larger plates of 140 x 140 mm² is under construction and will soon be available. The process cycle time for each plate only takes between 30 – 60 seconds.

Fig. 3 depicts on the left side the compound granulate as it is used in the injection moulding machine and on the right side some injection moulded bipolar plates wrapped around a rod.

Fig. 3: Granulated compound material and injection moulded bipolar plates

A typical resistance measurement of a 4 mm thick injection moulded bipolar plate sample as a function of contacting pressure is depicted in Fig. 4. During the measurement the bipolar plate was sandwiched between two gas diffusion layers, as shown in Fig. 1. This arrangement allows the simultaneous determination of the

- bulk resistance R_Ω (through plane),
- volume resistance $R_D = R_\Omega + 2\ R_K$,
- contact resistance R_K.

The curves clearly show that the overall resistance of the bipolar plates sample is dominated by the contact resistance between the bipolar plate and the gas diffusion layers. At a contacting pressure of 30 bar the bulk resistance contributes only about 30 % to the overall sample resistance.

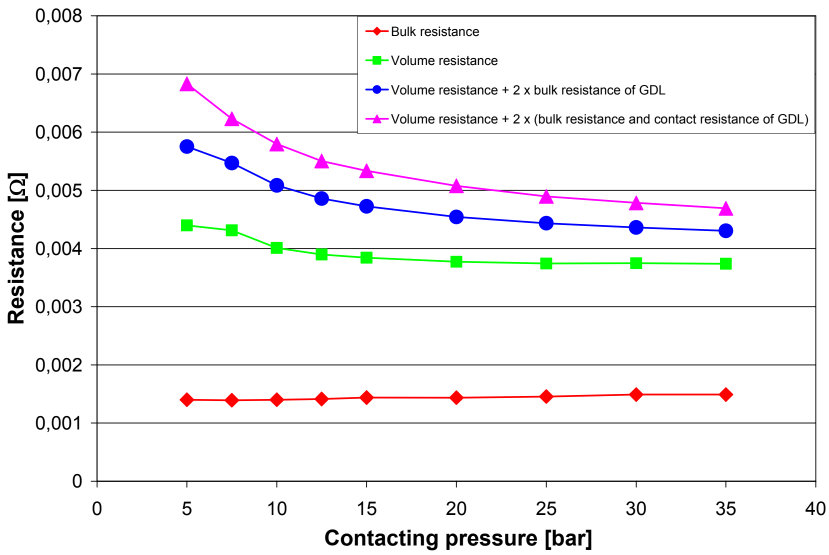

Fig. 4: Resistances of a standard 4 mm ZBT bipolar plate sample (20 x 20 mm²) produced by injection moulding as a function of contacting pressure

The performance of a highly conductive ZBT injection moulded bipolar plate is compared to some commercially available bipolar plates with respect to the volume resistance in Fig. 5 and the bulk resistance in Fig. 6. The commercial plates are produced by compression moulding of graphite filled thermosets. In addition the resistance of a purely graphitic sample was determined. Especially in the region of low contacting pressure the injection moulded ZBT sample as well as the compression moulded bipolar plates exhibit a volume resistance which is largely dominated by the contact resistance. Up to a contacting pressure of 20 bar the volume resistance decreases almost exponentially, whereas pressure increases above 20 bar do only deliver slightly better volume resistance values. Only the volume resistance of the graphitic sample does not show this behaviour. The bulk resistance is in contrast to the volume resistance almost independent of the contacting pressure, as could be expected (Fig. 5).

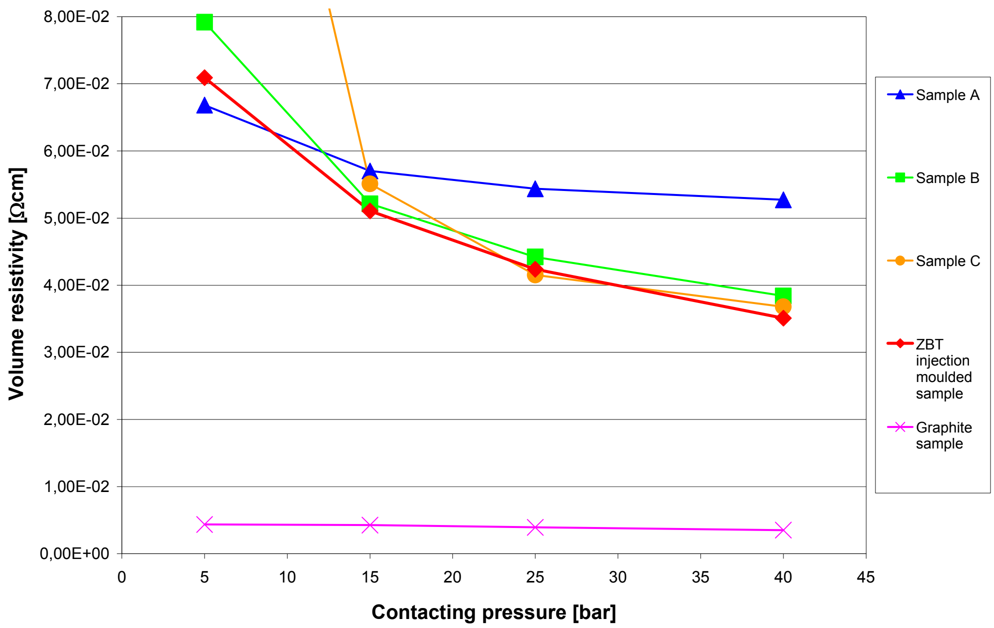

Fig. 5: Volume resistivities of different bipolar plates samples as a function of contacting pressure

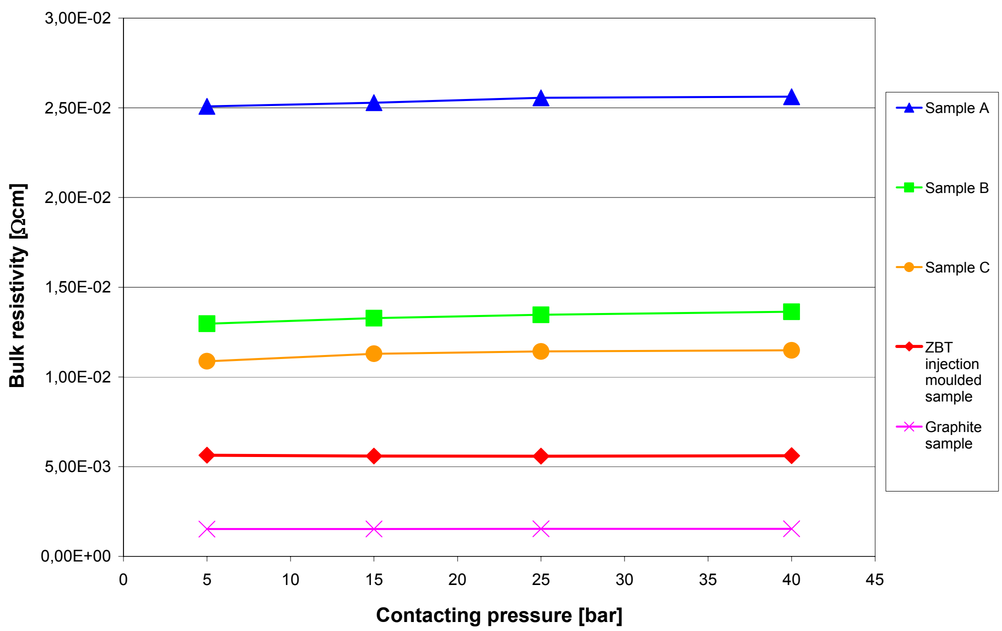

Fig. 6: Bulk resistivities of different bipolar plates samples as a function of contacting pressure

4. In-cell testing of injection moulded bipolar plates

In-cell testing of the injection moulded bipolar plates was performed successfully with several 20-cell PEM fuel cell stacks with an active area of 50 cm^2 and an electrical power of 100 to 200 W. Fig. 7 depicts the current-potential as well as power output curve of a 200 W PEM stack with injection moulded bipolar plates. The stack was operated with H_2 / air at ambient pressure and at a stack temperature between 25°- 30° C.

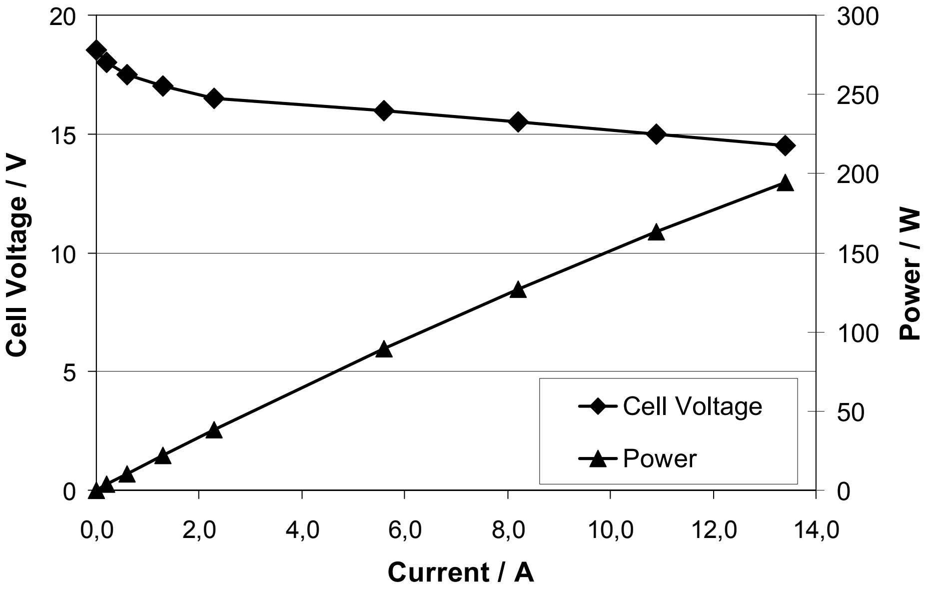

Fig. 7: Current-potential and power curve of 20-cell PEM stack with injection moulded bipolar plates; H_2 flow: 2,5 l/min; air flow: 9 l/min

A very interesting result is that in comparison to a similar 20-cell stack with compression moulded bipolar plates of the same material, the stack with injection moulded bipolar plates has a higher specific electrical output and lower resistance. An explanation for this could be seen in the small production tolerances of the injection moulded bipolar plates and the homogeneity of the material.

Two different 20-cell PEM-stacks, one equipped with injection moulded bipolar plates and one with compression moulded and high performance drilled bipolar plates were used to build up a 300 W hydrogen fuelled power generator providing 12 V DC and 230 V AC as depicted in Fig. 8. This PEM fuel cell system prototype is expandable to a power range of up to 1.000 W.

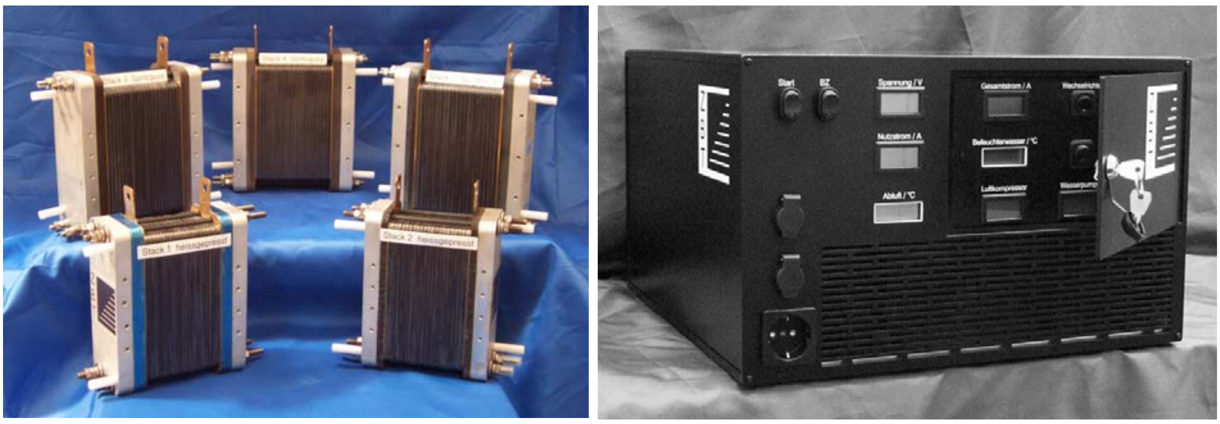

Fig. 8: ZBT`s air cooled PEM stacks in the power range of 100 to 200 W (left) and PEM fuel cell generator with an electrical power of about 300 W (right)

5. Economic perspectives of injection moulded bipolar plates

The assumption of a realistic cycle time of 30 seconds yields the following annual production capacity of a single injection moulding machine:

Number of plates:

- about 1.000 bipolar plates per eight-hour shift
- 300.000 plates / year in single 8-hour shift operation (80 % up-time of equipment)
- 900.000 plates / year in three 8-hour shift operation (80 % up-time of equipment)

Production capacity:

- assuming 10 W / plate (140 x 60 mm²) for portable applications would correspond to 3.000 kW - 9.000 kW PEM fuel cell power / year
- assuming 25 W / plate (140 x 140 mm²) would correspond to 7.500 kW - 22.500 kW PEM fuel cell power / year

To show the economic perspective of ZBT`s injection moulded bipolar plates, the cost for a representative plate of 100 cm² size with a thickness of 2,5 mm and an electrical bulk conductivity of 50 S/cm is depicted in Fig. 9 as a function of the associated series size. The cost model considers the price of the raw materials and the production costs which include machinery depreciation, labour, moulds and energy consumption.

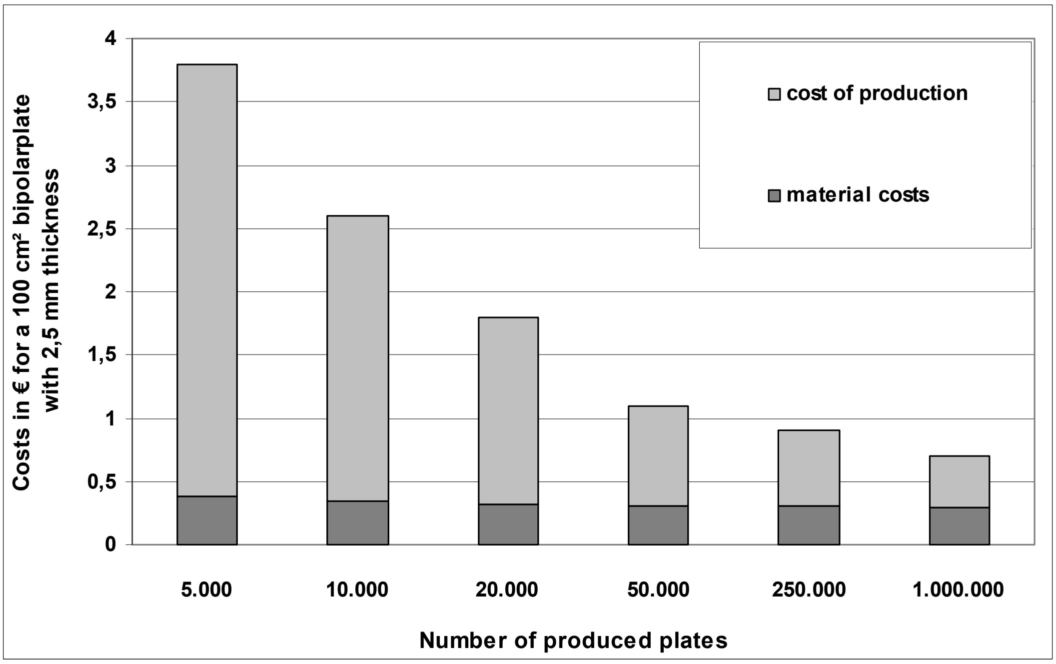

Fig. 9: Dependence of production related costs and material costs of injection moulded bipolar plates on production volume

Given a cycle time of 30 seconds, the maximum annual capacity of an injection moulding machine is approximately 900.000 to 1.000.000 plates. If a number of smaller series have to be produced (e.g. 10.000 plates) the total annual capacity that can be manufactured on a single injection moulding machine, will of course decrease, as for each job a new mould has to be installed, tested and machine parameters optimised. The cost model takes this fact into account.

It can be seen from Fig. 9 that above a number of about 300.000 plates the production related costs get into the region of the material costs, about 0,30 – 0,35 € per plate. But even for comparatively small series in the range of several thousand plates, ZBT`s bipolar plates are price competitive due to a flexible design of the mould.

6. Conclusions

Starting with the granulated compound material, injection moulding of thermoplastic bipolar plates is a straightforward one-step process that does not require any preform processes. A range of low-cost carbon-polymer compounds with specific bulk conductivities between 5 and 150 S/cm has been developed and a production line for bipolar plates by injection moulding has been set up.

Material prices between 2 and 10 €/kg translate into 0,8 to 4 €/kW, assuming a MEA power density of 7 kW/m². The optimisation of the injection moulding production process includes the identification of critical production steps and adaptation of all process parameters to the specific properties of carbon-polymer compounds. In injection moulding technology the design of the mould is of crucial importance. ZBT has developed tailored moulds to make injection moulded bipolar plates price competitive even for small series of several thousand plates. If smaller numbers are required for PEM fuel cell prototype development, flow fields can be machined into injection moulded blank plates (spindle speeds up to 80.000 rpm).

With demonstrated cycle times of 30-60 seconds, the capacity of the installed production machines allows an annual output in the range of several 100.000 plates, either blank or with flow-field. The next steps are the establishment of a quality control system and small series production for selected customers.

1. K. Ledjeff-Hey, T. Kalk, F. Mahlendorf, O. Niemzig, A. Trautmann, J. Roes, *Portable PEFC generator with propane as fuel*, J. Power Sources, **86** (2000), 166-172.
2. F. Mahlendorf, O. Niemzig, C. Kreuz, „*Low-cost bipolar plates for PEM Fuel Cells*“, 2000 Fuel Cell Seminar, Portland, Oregon, pp. 138-140, 2000.
3. A. Heinzel, H. Kraus, C. Kreuz, F. Mahlendorf, O. Niemzig „*Low-cost composite bipolar plates for PEM Fuel Cells*“, 2002 Fuel Cell Seminar, Palm Springs, California, pp. 153-1156, 2002.

Keywords: PEM Fuel Cell, Bipolar Plate, Electroconductive Compound, Injection Moulding