Conventional Designs for Bipolar Plates in PEM Fuel Cells: A review

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***Abstract*: The Polymer Electrolyte Membrane Fuel Cell (PEMFC) forms an important candidate for various applications, such as transport and stationary cogeneration applications due to enormous benefits. These include high efficiency, high power density coupled with its ability to operate at low temperatures. Bipolar plate forms an important component of PEMFC, which facilitates supply of reactants on cathode and anode sides and removal of waste products from the cathode side of the fuel cell. They also provide mechanical support to the fuel cell. The flow – field layouts in these bipolar plates play an important role in producing power as they influence reactant flow, pressure drops and water removal. Conventional flow-field design of these bipolar plates have been developed to achieve aforementioned functions efficiently so as to obtain high performance and economic advantages. The present paper presents a comprehensive review of different conventional flow-field designs for these bipolar plates with their pros and cons.**

***Index Terms*: PEMFC, Bipolar Plates, conventional, flow-fields.**

I. Introduction

Polymer Electrolyte Membrane Fuel Cells (PEMFC's) are energy converters which are expected to play an important role in the economy of this century and foreseeable future. It offers several advantages for transport and other applications with different requirements. Majority of automotive manufacturers are actively pursuing PEMFC research and development because of its modestly low operation temperature (< 100^0C), high power density, fast start-up, system robustness and low emissions [23, 25]. Bipolar plates account for 80% of total weight and 45% of stack cost of the PEMFC stack [25].

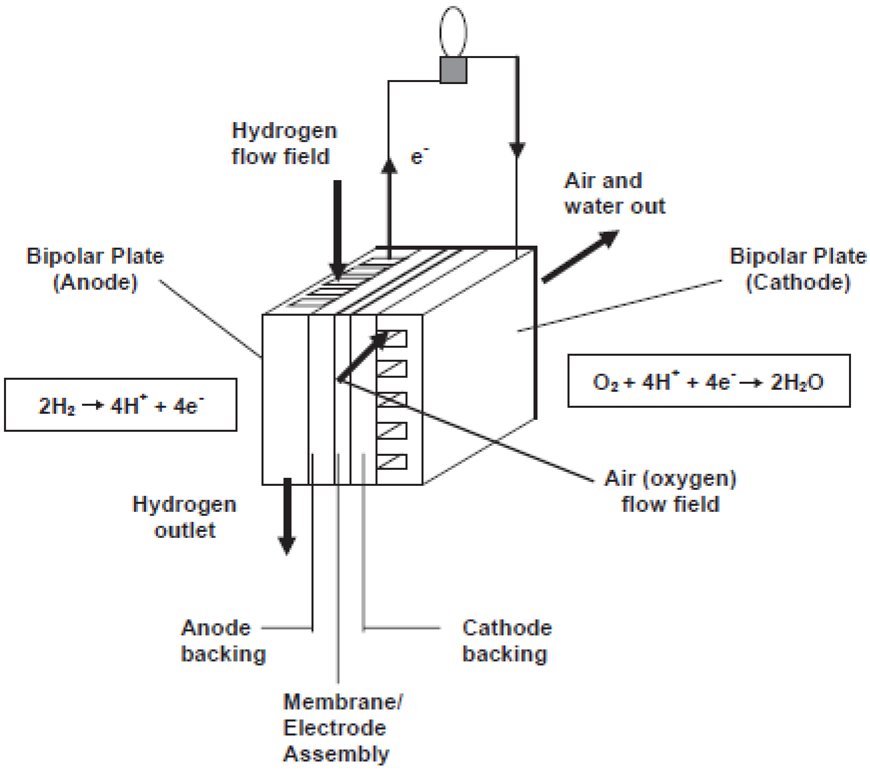

Fig 1. Schematic of a PEMFC [].

Bipolar plates account for maximum weight of the stack, thus making it necessary for producing bipolar plates with smallest possible dimensions. The US Department of Energy (DOE) recommends bipolar plates with smallest dimensions upto 3 mm thickness[]. The Membrane Electrode Assembly (MEA) is sandwiched in between the two bipolar plates which form as the anode and cathode side of the PEMFC stack for current collection. Bipolar plates accomplish may functions such as distribution of reactants in the active areas, carrying current from cell to cell and thereby providing a sealing to prevent leakage of reactants and coolants.

They also facilitate in water removal from the cell. They also enable heat management in the PEMFC in the absence of dedicated cooling plates. All these functions of bipolar plates are facilitated by appropriate design topologies and materials. These include conventional designs such as serpentine, parallel, interdigitated and pin type[23]. Apart from the aforementioned conventional designs, some other novel designs by ramos-alvarado et al. [6] and roshandel et al.[20] have successfully demonstrated improvement in PEMFC performance through their designs. The objective of this study is to provide a comprehensive review of different conventional flow field design for bipolar plates and their effect on different parameters of PEMFC performance. The principal conventional flow-field designs are as follows[23]:

- Pin Type Flow-Field.
- Parallel/Straight Flow-Field.
- Sepentine Flow-Field.
- Interdigitated Flow-Field.

II. PIN TYPE FLOW-FIELD

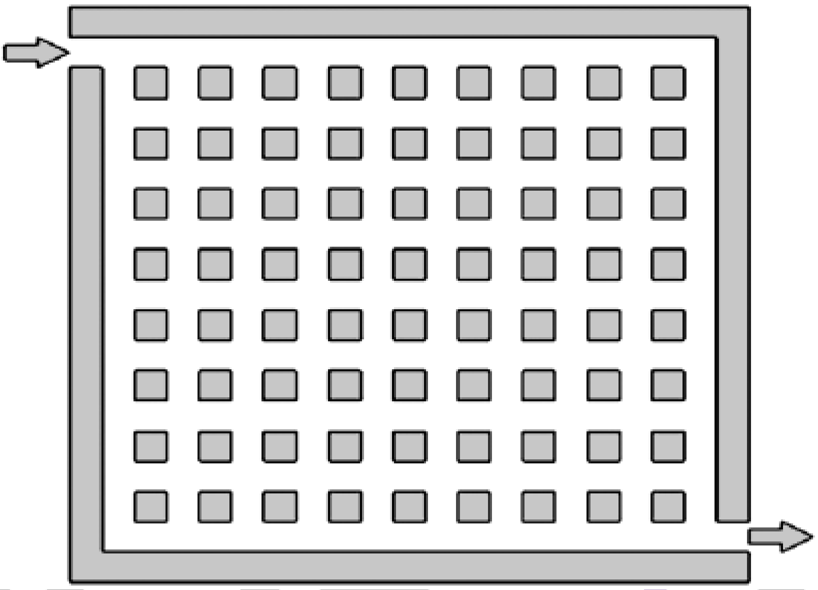

Fig 2.Pin Type Flow-Field [26]

This flow-field network is formed by an array of pins arranged in regular network. These pins cam be of any shape, although circular or cubical pins are mostly used in practice. These pins protrude from the plate surface thus allowing the reactants to flow through the intermediate grooves that are formed due to protrusion. The reactant gases flow in a network of series and parallel flow paths leading to low pressure drops. The flow in this network is based on the principle of least resistance. The reactant gases tend to follow the path of least resistance. This can lead to non uniform distribution of reactants and poor product water removal. This may further result in formation of stagnation areas leading to a reduction in fuel cell performance. Formation of stable recirculation zones may occur behind each pin due to slow reactant flow in small channels. These recirculation zones may decrease the reactant concentration thereby decreasing the fuel cell and stack performance. These drawbacks can create problems for certain pin geometries. However, this type of flow-field is suitable for high reactant flows with low utilization levels of fuel and oxygen.

III. PARALLEL/STRAIGHT FLOW-FIELD

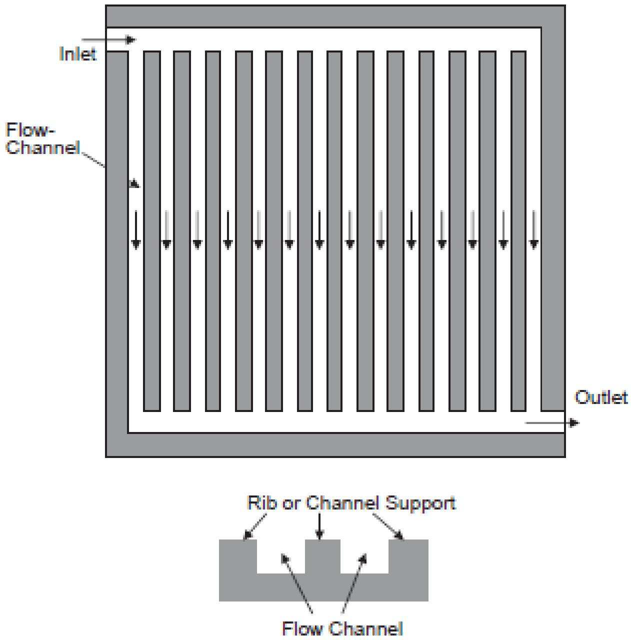

Fig 3. Parallel /Straight Flow-Field with channel cross-section [23].

This flow-field network is formed by channels that are parallel to the edge of the plates. The number of such parallel channels desired in the network depends on the requirements of the fuel cell. These parallel channels form a link between inlet and exhaust manifolds of the bipolar plate. Extended periods of operations by using air as an oxidant resulted in low and unstable cell voltages[23]. Due to continuous operation of the fuel cell, the water formed at cathode accumulates in the flow channels adjacent to the cathode. This leads to wetting of channels on its bottom and sides. The water droplets thus coalesce to form larger droplets. As a result, the amount of force required to drive the droplets out of the channel and cell increases with increase in size of droplets. As different parallel channels have different size and number of water droplets, the reactant gas follows the principle of least resistance. The reactant gas flows through the least obstructed flow path. Water accumulates in channels of least reactant flow thus resulting in formation of stagnation areas in the fuel cell. This results in poor cell performance due to inadequate water removal and poor gas flow distribution on cathode side. The solution to the above problem can be achieved by recirculating portion of the reactant gases and condensing excess product water outside of the fuel cell stack.

The straight and parallel channels are short in size and have no directional changes which lead to low pressure drops across the channel. In comparison, the pressure drop in the entire piping, manifold and distribution system is highly appreciable. This difference in pressure drop leads to uneven reactant distribution in the flow-field. The channels in proximity to inlet flow field have more reactant flow as compared to the channels that are farther away. One possible solution to this problem is to provide obstruction in the flow-fields at the inlet and exit which can increase the pressure drop, thus improving the uniformity of distribution of reactant gases. However, this affects the design and fabrication leading to complications in manufacturing thereby increasing the cost.

IV. SERPENTINE FLOW FIELD

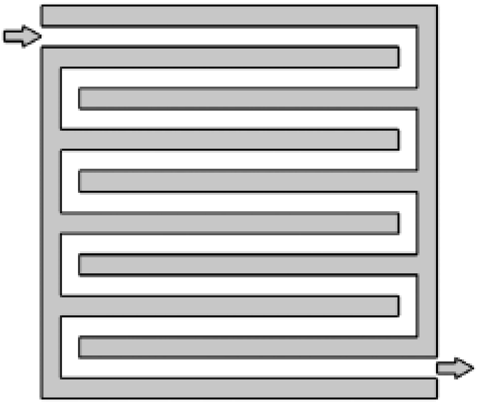

Fig 4. Serpentine Flow-Field [26].

This flow-field network is formed by channels that follow a continuous path from inlet to outlet in a well defined form serpentine. Thus a serpentine flow-field is a single serpentine channel with multiple turns of the same path from inlet to outlet. This flow-field solves the stagnation problem that predominantly occurs in straight flow-field and pin type flow-field. This flow-field allows the reactant to move through the entire active area of corresponding electrode thus eliminating the stagnant areas[23]. As the reactant covers the entire active area, this flow-field results in a relatively long reactant path leading to significant pressure drops. The oxygen concentration also depletes with increase in the length of path leading to formation of concentration gradients. This leads to decrease in current density along the channel.

Serpentine channels permit limited gas movement between adjacent legs of the same channel via the diffusion layer. This results in land portion of Membrane Electrode Assembly getting exposed to the reactant. Thus the reactant can flow across the land area from higher pressure leg of channel to a lower pressure leg channel through the diffusion layer. A longer channel can lead to excessive pressure drop between adjacent legs or at the end of the same channel. This can result in reactants flowing across the land area rather than following the requisite path through the flow-field. Hence, a serpentine flow-field should be developed as a compromise between pressure drop requirements and water removal aspects.

V. INTERDIGITATED FLOW-FIELD

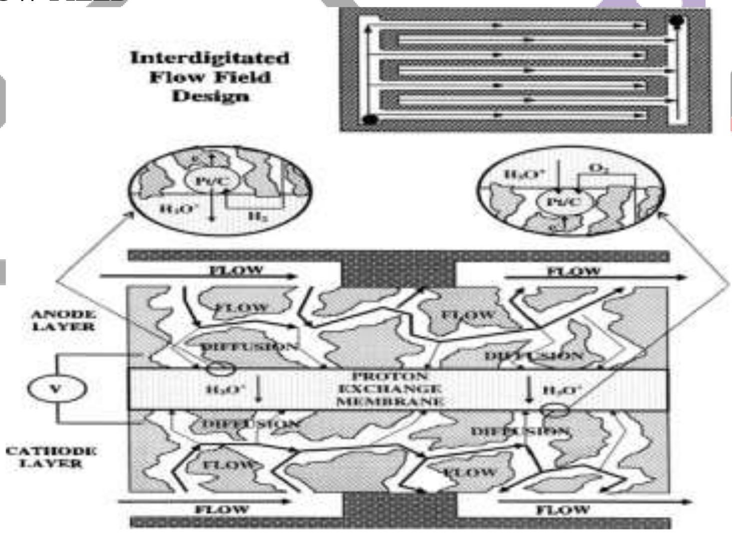

Fig 5. Interdigitated Flow-Field [23].

The flow-field in which the reactants are transferred from inlet to outlet by means of flow through dead end channels is called interdigitated flow-field. Here, the inlet and outlet of the channels are not directly connected to a single flow path. Rather, reactant transfer takes place through molecular diffusion from inlet to outlet. This results in development of convection velocity towards the catalyst layer. This phenomenon leads to effective water removal from the electrode structure eliminating the problem of water flooding and providing enhanced performance at high current density operation [23]. This flow-field design leads to high pressure losses on the oxidant air stream. High parasitic power is required for air compression, thus limiting the stack sizes [23].

In operation of this type of flow-field the linear region of cell potential versus current density is extended as the forced convection flow prevents flooding and reduces gas diffusion limitations. About one third of electrode surface area is utilized when high quantity of water accumulates at higher current densities[23]. This causes mass transport limitations in porous electrodes. In interdigitated flow-field this diffusive mass transfer mechanism is changed into forced convective mass transfer. This change in mechanism causes limiting current density and maximum power density to increase significantly [23]. Due to all these advantages, this design outperforms conventional flow-field design, especially on cathode side at high current densities [23].

VI. CONCLUSIONS

Bipolar plates form an important component of a PEMFC stack performing functions ranging from effective distribution of reactants across the active area of cell to mechanical support to Membrane Electrode Assembly as well as heat and water management. The design of bipolar plate is one of the key requirements of an effective PEMFC performance. The design of flow-fields form an important part of bipolar plate design. Thus, the design of flow-field becomes one of the most important criterion affecting the PEMFC performance. There are a variety of conventional designs including serpentine, straight/parallel, pin-type and interdigitated flow-field. Each conventional flow-field has their respective set of advantages and disadvantages depending upon type of applications required. Modifications and improvements in existing conventional flow-field designs can help in achieving performance improvement of PEMFC as well as their commercialization on a large scale.

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