

INTERDIGITATED FLOW-FIELD WITH TAILORED HEADER FOR UNIFORM DISTRIBUTION OF ELECTROLYTE IN REDOX FLOW BATTERIES

FIELD OF INVENTION

[0001] Redox flow batteries are designed to facilitate electrochemical reactions for converting electrical energy into chemical energy and back to electrical energy. One typical requirement in enabling electrochemical reactions with improved performance is to provide uniform distribution of electrolyte across the electrode, which is the reaction zone of the flow battery. The supply of electrolyte to the reaction zone can't be achieved without incurring pressure drop across the cell of a flow battery, thereby proportion of the electricity stored in the flow battery system consumed for pumping, which is called parasitic power loss. The associated parasitic power requirement in supplying the electrolyte to the reaction zone is an additional critical parameter in assessing efficiency of a charge-discharge life cycle of the flow battery.

PRIORITY CLAIM

[0002] This application claims priority to Singapore provisional patent application number 10202250224U filed 20 June 2022, the entire contents of which are incorporated by reference.

BACKGROUND

[0003] There has been a tremendous growth in the share of renewables, especially from solar and wind, in the energy generation space. In view of intermittency and seasonal variation in these sources, it requires suitable energy storage systems to stabilize the intermittence and fill the imbalance between supply and demand and therefore the demand for large-scale energy storage system has been growing. Most of the energy storage technology domain is being replaced by various chemical power sources which store electrical energy as redox active compounds. Among the diversity of chemical power sources, lithium-ion batteries, fuel cells, redox flow batteries appear especially relevant to large-scale

energy storage. Redox flow batteries have been emerging as promising sources for long-duration and large-scale duties attributed to their flexibility in designing the power and energy ratings independently, ease of expansion, long life, low levelized cost of electricity, high safety and low maintenance. Among all the redox flow batteries, the Vanadium Redox Flow Battery (“VRFB”) has the following advantages: technology maturation, wide range of applications, low maintenance cost, strong load balancing ability, negligible loss of redox species and long cycle life. However, the low energy density of VRFBs leads to high cost, which will severely restrict the development in the field of energy storage. Flow-field design and flow rate optimization is an effective way to improve battery performance with negligible changes in the cost of system.

[0004] A typical flow-field distributes electrolyte to the electrode region where electrochemical reaction occurs. The transport of electrolyte species from a reservoir to the cell reaction zone requires pumping and this introduces parasitic power consumption of pumps in the system. Low pressure losses in the transport of electrolyte, orderly supply of the active reactant to the electrochemical reaction zone and quick evacuation of product species from the reaction zone are essential features of a flow field. Non availability of active reactant on the reaction site leads to mass transport polarization and introduces energy losses. Non uniform distribution of the electrolyte results to reduction in electrode utilization and formation of dead zones (i.e. areas with less supply of fresh electrolyte) which lead to minimize the amount of energy that can store or deliver in a charge-discharge life cycle of flow battery. Therefore, a critical issue of a flow-field design is how to minimize the mass transport polarization with uniform distribution of electrolyte at a minimum pressure drop.

[0005] Example interdigitated flow-field channels are described in several patents like US6416892B1, US6485857B2, etc. While such inventions provide improvements in electrolyte distribution and performance, those skilled in that art are always striving to make further improvements.

[0006] In many of the above-mentioned inventions, the focus is on the configuration of flow-channels, ribs and restriction of flow between them using various techniques like partial blockage, thin ribs and wider ribs to obtain the

desired interdigitated flow. The distribution of electrolyte with desired pressure drop is also acquired by combining flow-through mode with interdigitation between the channels with single and multiple flow chambers in each inlet and outlet channels. Although the articulation of flow distribution is configured around flow- channels, the distribution of electrolyte uniformly across the reaction zone still depends on the mechanism of splitting the flow from inlet manifold or header of the interdigitated flow-field to inlet flow channels of the flow-field. Without having the desired split of electrolyte from the inlet header to the channels of flow-field, it is arduous to attain the desired distribution at required pressure drop. The present invention overcomes the aforesaid problems.

SUMMARY

[0007] The present invention relates to a design of flow-field for improved uniformity of electrolyte distribution across the reaction zone in a redox flow battery cell with low pressure drop. In particular, it solves the aforesaid problems by designing a tailored inlet header in the interdigitated flow-field with associated design of the flow-channel configuration to obtain desired distribution of electrolyte at minimal pressure drop.

[0008] It is therefore an object of the present invention is to design an interdigitated flow-field with tailored inlet header for uniform splitting of electrolyte from header to flow-channels. As the pressure drop incurred by the cell is largely associated with the flow in flow-channels and forced convection through the porous electrode under the rib, the dimension of the flow channel and rib is also a design variant in achieving the desired objective.

[0009] The present invention is related to the design of a flow-field using the concept of interdigitated distribution between the flow-channels. This interdigitated flow-field differs from conventional flow-field patterns by having inlet of fluid to entrance channel but the exit through the adjacent exit channel which is interdigitated with the entrance channel. The transport of fluid from entrance channel to exit channel occurs by forced convection through the electrode under a solid rib which exists between the entrance and exit channels. The entrance and exit channels are extended between a common supply manifold and common exhaust manifold or a common inlet header and common outlet header.

[0010] In conjunction with the accompanying drawings, the following thorough description of the invention will make the aforementioned objectives, features, and advantages of the invention more clearly apparent.

BRIEF DESCRIPTION OF DRAWINGS

[0011] The following description, along with the accompanying drawings, provides an illustrative example that can aid in obtaining a more comprehensive understanding.

[0012] FIG.1 illustrates an example embodiment of half-cell configuration of a flow battery with its major parts;

[0013] FIG. 2 illustrates an example embodiment schematic of interdigitated flow-field with inlet-outlet headers, inlet-outlet flow-channels and the corresponding ribs between the flow-channels; and

[0014] FIG. 3. illustrates an example embodiment design of the tailored rib inserted into the inlet header of flow-field.

DETAILED DESCRIPTION

[0015] FIG.1 (an example embodiment) describes components of a redox flow battery in half-cell assembly where in the porous electrode felt (cathode or anode) fill the place of flow channel area on the flow field plate. Leakage of electrolyte from pumping is arrested by the provision of a gasket. Electrolytes from an external reservoir pass through a piping manifold and enter a cell reaction zone (porous electrode) via flow frame and flow-channels of a flow-field plate. A membrane, which is placed after the gasket, separates the symmetry of half-cells thus leading to a full cell configuration.

[0016] The present invention describes the novel design of interdigitated flow-field for improving flow distribution, as illustrated in FIG.2. Flow-channels of the flow-field are extended between the inlet header (portion combining 102, 103 and 104) and outlet header (110). Electrolyte from the external manifold in the VRFB system enters the cell reaction zone via the designated entry (101) of the flow-field and leaves the reaction zone from the exit pathway (111). Inlet flow- channels (several numbers of the manner represented in 105 A, 106 A, 107 A) will receive

the electrolyte from the inlet header, allow it travel to the several outlet flow-channels (105 B, 106 B, 107 B and similar pathways) via the porous felt under the ribs (108 and 109 and similar embodiments), enters the outlet header (110) and leaves the cell from the exit section (111).

[0017] Computational simulations in conventional interdigitated flow-field having equal and constant widths of the flow-channels and ribs across the flow-field show that the middle flow-channels receive larger portion of electrolyte from the inlet header compared to the lateral flow-channels. In view of this, width of the flow-channels is transitioned from wider to narrow from the center of the flow-field towards both the lateral edges. This variation in channel width across the flow-field enables it to maintain equal velocity of electrolyte among the inlet flow-channels. Such design methodology is adapted to outlet flow-channels as well.

[0018] Another embodiment presented in this design is the thickness of solid rib wall between the flow-channels. In view of pressure difference between the adjacent flow-channels (combination of inlet-outlet channels), major portion of the electrolyte travelling in an inlet flow-channel enters the adjacent outlet flow-channel by forced cross-flow of electrolyte through the porous felt electrode under the solid rib wall in the direction of decreasing pressure and small portion will exchange with opposite side adjacent outlet flow-channel. The rib between first inlet flow-channel (105 A) and first outlet flow-channel (105 B) is made thicker (108) and the immediate adjacent rib between the first inlet flow-channel (105A) and second outlet flow-channel (106 B) is made thinner (109). Electrode felt under the rib (109 and similar) receive a marginal amount of electrolyte from the corresponding adjacent inlet channel and making it thin enable to reduce the dead zones (lack of fresh reactant in the reactive porous zone). Electrode felt under the rib (108 and similar) receive a surplus amount of electrolyte from the immediate inlet channel and making it thick enable it to have improved reaction kinetics and thus improved capacity and efficiency.

[0019] The embodiments herein describe the design of inlet header containing a single solid rib (102) of any shape vide trapezoid, rhombus, kite etc. as shown in FIG. 3. The inserted rib (102) splits the inlet electrolyte (101) into a first inlet fluid stream (103) and a second inlet fluid stream (104). The rib (102) also provides

tapered decreasing cross-section for the first inlet fluid stream to maintain constant velocity along its traverse length. Another embodiment of the inserted solid rib (102) is variation in the shape at the entry section of the electrolyte (102A) and at other extremes (102B) where the electrolyte takes opposite direction in the inlet header. The shape at 102A can be of any shape (straight wall perpendicular to the flow of inlet electrolyte, streamlined body, pin type etc.) and the shape at 102B is slightly curved to maintain streamlining of flowing fluid which avoids boundary layer separation with which the head loss of flow is reduced. The split of inlet electrolyte (101) into the first and second inlet fluid streams (102 and 103), the tapered cross-section in the first inlet fluid stream (103) and opposite directional movement of electrolyte (from 102A and 102B) enables the uniform splitting of electrolyte from inlet header to the inlet flow-channels which then takes the designated route to the cell outlet.

[0020] The embodiments described herein pertain to a bi-polar plate for a redox flow battery, the bi-polar plate being engraved with a flow field pattern, the flow field pattern being made using a plurality of factors, including an inlet header configured to be fluidically coupled to a liquid inlet for receiving an input electrolyte into the flow field adjacent to an upstream edge of the bi-polar plate, a rib portion which divides the inlet header into a first inlet stream and a second inlet stream, a plurality of inlet flow channels running from the inlet header portion, an outlet header configured to be fluidically coupled to a liquid outlet for receiving reacted electrolyte from the flow field adjacent to a downstream edge of the bi-polar plate opposite to the edge of the bi-polar plate, and a plurality of outlet flow channels running to the outlet head, the outlet flow channels being interdigitated with the inlet flow channels and separated from the inlet flow channels by a plurality of channel ribs.

[0021] The design of the bi-polar plate is such that width of the inlet flow channels varies between the lateral edges of the bi-polar plate such that inlet flow channels in a central region of the bi-polar plate have a greater width than inlet flow channels close to the lateral edges of the bi-polar plate.

[0022] In the bi-polar plate, the width of the channel rib is greater between a first inlet channel and a first outlet channel, between a second inlet channel and a

second outlet channel and so on. The width of the channel rib is lower between a first inlet channel and a second outlet channel, between a second inlet channel and a third outlet channel and so on.

[0023] The bi-polar plates' inlet header comprises a single solid rib which divides the input electrolyte into the first inlet fluid stream and the second inlet fluid stream. The said first inlet fluid stream comprises a tapered and decreasing cross-section towards the middle of the inlet header wherein it merges with the second inlet fluid stream moving in opposite direction to the first inlet fluid stream. Further, in the bi-polar plate, the said solid rib portion has slight curvature at the point where the second inlet fluid stream initiates the flow direction opposite to the first inlet fluid stream.

[0024] In the designs above, the rib portion design of the inlet header is substantially trapezoid, rhomboid or kite in shape.

[0025] A flow battery cell is created using the bi-polar plate as described above.

[0026] A redox flow battery is created using bi-polar plate as described above.

[0027] It would be apparent to a person skilled in the art that the present invention is not confined to specific inlet header but rather the combination to achieve a desired distribution of electrolyte in a cell / battery.

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CLAIMS

1. A unit cell for a redox flow battery comprising:

- an ion exchange membrane;

- electrode layers disposed respectively on both sides of the ion exchange membrane; and

- a bipolar plate disposed respectively on each side of the electrode layers opposite from the ion exchange membrane, wherein the bipolar plate comprises partition wall structures in the bipolar plate that define an interdigitated flow path suitable for passage of electrolyte solution, and a flow pattern is generated by having in the bi-polar plate:

- an inlet header configured to be fluidically coupled to a liquid inlet header for receiving an input electrolyte into a flow field adjacent to an upstream edge of the bi-polar plate;

- a rib portion which divides the inlet header into a first inlet stream and a second inlet stream;

- a plurality of inlet flow channels running from the inlet header portion;

- an outlet header configured to be fluidically coupled to a liquid outlet for receiving reacted electrolyte from the flow field adjacent to a downstream edge of the bi-polar plate opposite to the edge of the bi-polar plate; and

- a plurality of outlet flow channels running to the outlet head, the outlet flow channels being interdigitated with the inlet flow channels and separated from the inlet flow channels by a plurality of channel ribs.

2. The unit cell for the redox flow battery of claim 1, wherein in the bi-polar plate a width of the inlet flow channels varies between lateral edges of the bi-polar plate such that inlet flow channels in a central region of the bi-polar

plate have a greater width than inlet flow channels close to the lateral edges of the bi-polar plate.

3. The unit cell for the redox flow battery of claim 1, wherein in the bi-polar plate the width of channel rib is greater between a first inlet channel and a first outlet channel, between a second inlet channel and a second outlet channel and so on.

4. The unit cell for the redox flow battery of claim 1, wherein in the bi-polar plate the width of the channel rib is lower between a first inlet channel and a second outlet channel, between a second inlet channel and a third outlet channel and so on.

5. The unit cell for the redox flow battery of claim 1, wherein in the bi-polar plate the inlet header comprises a single solid rib which divides the input electrolyte into first inlet fluid stream and the second inlet fluid stream.

6. The unit cell for the redox flow battery of claim 5, wherein the first inlet fluid stream comprises a tapered and decreasing cross-section towards the middle of the inlet header wherein it merges with the second inlet fluid stream moving in opposite direction to the first inlet fluid stream.

7. The unit cell for the redox flow battery of claim 5, wherein the solid rib portion has slight curvature at point where the second inlet fluid stream initiates the flow direction opposite to the first inlet fluid stream.

8. The unit cell for the redox flow battery of claim 5, wherein the rib portion of the inlet header is substantially trapezoid, rhomboid or kite or of similar shape.

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