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DESIGN AND ASSEMBLY CONSIDERATIONS FOR REDOX CELLS AND STACKS

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SUMMARY

Single cell and multi-cell stacks of 929 cm^2 (1 ft^2) and 310 cm^2 (0.33 ft^2) active electrode area have been assembled and tested in the laboratory. A 1.0 kW preprototype system also has been evaluated. This system is comprised of four stacks of 310 cm^2 (0.33 ft^2) cells, each stack having 39 cells.

The mechanical design of a Redox stack is very critical to the system's performance and efficiency. The stack must be sealed internally and externally. Low density polyethylene frame gaskets, rubber gaskets and RTV silicone rubber sealant are used to prevent electrolyte leakage and mixing.

Shunt currents in the stack are reduced by using long, narrow flow ports. The electrolytes in the flow ports are insulated from the bipolar plate by polyethylene gaskets. The electrolytes circulating through the primary manifolds are insulated from the conducting membranes and bipolar plates by dielectric "washer" inserts. An improved design includes another polyethylene gasket which insulates the electrolytes in the flow ports from their adjacent membranes.

The stack design uses thin bipolar plates to reduce stack resistance. Thick terminal plates carry the load currents out of the stack without excessive I^2R losses.

INTRODUCTION

Individual Redox flow cells are assembled hydraulically in parallel and electrically in series as a single stack. External and internal electrolyte leakage, shunt currents and stack resistance are all factors which affect the system's performance and efficiency. Therefore, these problems must be considered as the stack is designed and assembled. This report will discuss how such factors as surface bonding, insulation of electrolyte from conductive surfaces, flow port sizing and proper design of bipolar plates can alleviate these problems.

STRUCTURE AND OPERATION OF A REDOX STACK

Figure 1 is a photograph of the 1.0 kW preprototype system. A schematic diagram, showing the major components in a full function, multicell Redox system, is presented in figure 2. For a more detailed discussion of system features and subsystem components, see reference 1. Acidified iron and chromium chloride solutions, stored separately in two external tanks, flow in a parallel fashion through a stack of cells. Two inlet manifolds distribute the electrolytes to each cell. A pair of porous, chemically inert electrodes in each cell provide surfaces on which the charge and discharge reactions can take place. The electrode on the chromium side is thermally plated with gold and electroplated with a trace amount of lead as a catalyst for the electrochemical reactions. Bipolar plates between adjacent cells conduct current from one cell to the next. Each cell contains an ion-selective membrane which keeps the iron and chromium cations separated, but allows chloride ions and protons to pass freely. The solutions leave the stack via the common outlet manifolds.

The parallel hydraulic arrangement of cells results in all the cells in the stack having the same electrolyte state of charge at any given time. Thus, the state of charge can be monitored by measuring the potential across the open circuit cell, which is electrically insulated from the rest of the stack.

Stacks having 929 cm^2 (1.0 ft^2) and 310 cm^2 (0.33 ft^2) active electrode area per cell are shown in figures 3 and 4, respectively. An exploded view of a single cell is presented in figure 5.

External Leakage

The Redox stack must be completely sealed to prevent both loss of electrolyte from the system and cross-mixing.

Each half-cell cavity is enclosed by a polyethylene frame, consisting of a "flow field" and gasket. Low density polyethylene was chosen for the frame material because it is soft enough to seal against mating surfaces without unacceptable cold flow and is resistant to attack by the chemical reactants. The gasket and flow field are cut from sheet stock using a steel rule die and a hydraulic press. These pieces are bonded together by applying a thin, uniform coat of contact cement to both faces and carefully pressing them together. The cement layer must be smooth and free of gaps and lumps or else the uneven surfaces may create leakage paths within the frame.

A silicon rubber adhesive sealant, RTV, is used to seal the polyethylene frame to the adjacent carbon or graphite bipolar plate. The frame is covered with an even coat of RTV, mated to the bipolar plate (see fig. 6) and allowed to cure under pressure at room temperature for at least one day. Metal guide pins inserted in each of the primary manifold holes are used to align these parts during assembly.

The gasket-flow field assembly surfaces must be smooth and free from scratches to avoid potential leakage paths.

Sealing the interface between the membrane and the gasket flow field assemblies depends upon maintaining the stack in compression. Threaded tie rods, as shown in figure 7, are carefully and evenly tightened sequentially to hold the stack pieces together. Steel plates at each end of the stack are used to distribute the compressive forces uniformly across the gasket sealing surfaces. Polyvinyl chloride plastic blocks serve as electrical insulators and protect the steel plates from the corrosive electrolyte fluids and provide non-conductive connections between the stack manifolds and external plumbing.

It is important that the faces of the graphite or carbon plates be flat (NASA uses a tolerance of ±0.001 in.) so that the mating faces will have an even pressure distribution. Uneven pressure could result in unsealed areas.

Neoprene rubber gaskets are placed between the plastic blocks and graphite terminal plates (see fig. 7) to seal around the primary manifolds. A rubber gasket is also used to electrically insulate the open circuit cell from the active cells in the stack. For both cases, a thin film of RTV is applied around the manifold holes to ensure a seal.

Internal Leakage

The system can lose capacity via internal leakage, that is, by positive fluid crossing over to the negative side of the cell, or vice versa, via leakage path between the cell cavities and the primary manifolds. The membranes, polyethylene gaskets and flow fields must form tight seals at these areas in the stack.

The membrane must be free of holes. Prior to stack assembly, each membrane is examined for holes by laying it on a sheet of white absorbent paper and applying methylene blue dye to the top surface. The dye stains the paper underneath to indicate holes.

After each stack is assembled, it is tested for internal leakage. The stack is attached with tubing to elevated reservoirs as shown in figure 8. The stack, tubing and reservoirs are then filled with water. The volume collected in the graduated cylinder is recorded over a period of time to determine the rate of internal leakage. The test is then repeated with the pressure head reversed. An acceptable leakage rate is 0.06 cm^3/hour per 929 cm^2 (1 ft^2) of active membrane area.

Shunt Current Losses

During operation, the electrolytes continuously circulate through the interconnecting flow channels and manifolds in the stack. Since these fluids are ionically conductive, current flow from one cell to another via the manifolds forms a secondary conductive loop or shunt current path which drains the system of electrical capacity. A mathematical analysis indicates that total shunt power loss increases exponentially with the number of cells in the stack by a power between two and three (ref. 2). The sum total of the shunt current losses can be determined experimentally by placing the system on charge at a constant voltage. As the system becomes fully charged, the current will gradually decrease until the charging rate equals the rate at which the solutions are discharging through the shunt loops.

To minimize the main shunt current path between cells via the flow channels and manifolds, the flow paths are restricted in cross-sectional area and increased in length. This reduces the shunt current but at the same time increases pumping power. Thus, an important design objective is to determine the optimum flow channel dimensions which will yield the minimum sum of losses due to shunt currents and pumping requirements. Reference 3 explains this optimization process in detail.

Other possible shunt paths in the stack such as paths from the electronically conductive bipolar plate or from the ionically conductive membrane to the fluids in the manifolds, have been eliminated. Dielectric inserts are placed in the manifold holes of the bipolar plates as shown in figure 5; likewise, washer-shaped polyethylene inserts are placed in the membrane manifold holes. The flow field gaskets also reduce shunt currents by insulating the fluids in the flow channels from the bipolar plates. The shunt current loss can be further reduced by cementing a second gasket to the flow field face to separate the flow channels from the membrane as in figure 9. This gasket has been incorporated into a 5 cell, 310 cm^2 (0.33 ft^2) stack, reducing the steady-state charging current from 30 to 12 mA. The predicted shunt current value for this stack is 8 mA based on a NASA generated shunt current model (ref. 3).

Contact between any two bipolar plates or membranes via the steel tie rods will cause a short circuit. The tie rods are, therefore, centered in their slots to clear the plates and membranes and, in addition, are covered with insulating shrink tubing.

Reducing Stack Resistance

To minimize the stack electrical resistance as well as its length, the bipolar plates are made as thin as their mechanical strength allows. The terminal plates, through which the load current enters and leaves the stack, must be thick enough to allow the load current to flow parallel to their faces without excessive I^2R losses. The take-off tabs on these plates are placed on two sides to decrease the current per tab and lower the resistive losses. These tabs are arranged in a staggered fashion to be accessible where the plates are close together. The bipolar plates and terminal plates are shown in figure 10.

The flow-through electrodes are porous carbon felt and thus allow excellent mass-transfer as well as permitting greater surface area for the oxidation and reduction reactions. The compression of the electrode in each cavity is, therefore, an important parameter. A certain minimum positive compression is required to ensure adequate electrical contact with the bipolar or terminal plates and also to ensure uniform fluid flow from the bottom edge to the top edge of the electrode. However, too much compression results in restricted electrolyte flow, high pressure drop across the cell and more difficult stack assembly.

CONCLUDING REMARKS

The design and assembly of a stack of redox cells must ensure the minimization of external and internal physical leakage of the circulating fluids, capacity loss caused by shunt currents and ohmic and ionic resistance losses within the cells and stack.

To minimize external and internal leakage, attention must be given to the design and assembly of the gaskets and flow fields enclosing the cell cavities. Both the contact cement and RTV adhesive sealant must be applied smoothly and carefully. The tie rods which compress the stack must all be tightened to the same torque. There must be no pinholes in the membranes which would allow electrolyte mixing.

Several design factors can reduce shunt losses. There is an optimum set of flow port dimensions resulting in a minimized sum of shunt and pumping power losses. The electrolytes in the manifolds and flow ports should be insulated from the adjacent bipolar plates and membranes. The tie rods must not short-circuit the bipolar plates or membranes.

To minimize stack resistance, the stacks are designed with thin bipolar plates. The terminal plates must be thick to handle the load current flowing across the plate. Proper compression assures good contact between electrodes and bipolar (or terminal) plates.

REFERENCES

1. Thaller, Lawrence H.: Redox Flow Cell Energy Storage Systems. DOE/NASA/1002-79/3, NASA TM-79143, 1979.
2. Prokopius, Paul R.: Model for Calculating Electrolytic Shunt Path Losses in Large Electrochemical Energy Conversion Systems. NASA TM X-3359, 1976.
3. Hagedorn, Norman H.; Hoberecht, Mark A.; and Thaller, Lawrence H.: Shunt Current, Pumping Power Cell Performance Trade-Offs in NASA-Redox Cell Stacks. NASA TM-82686, 1981.

Figure 1. - 1.0 kW pre-prototype Redox system.

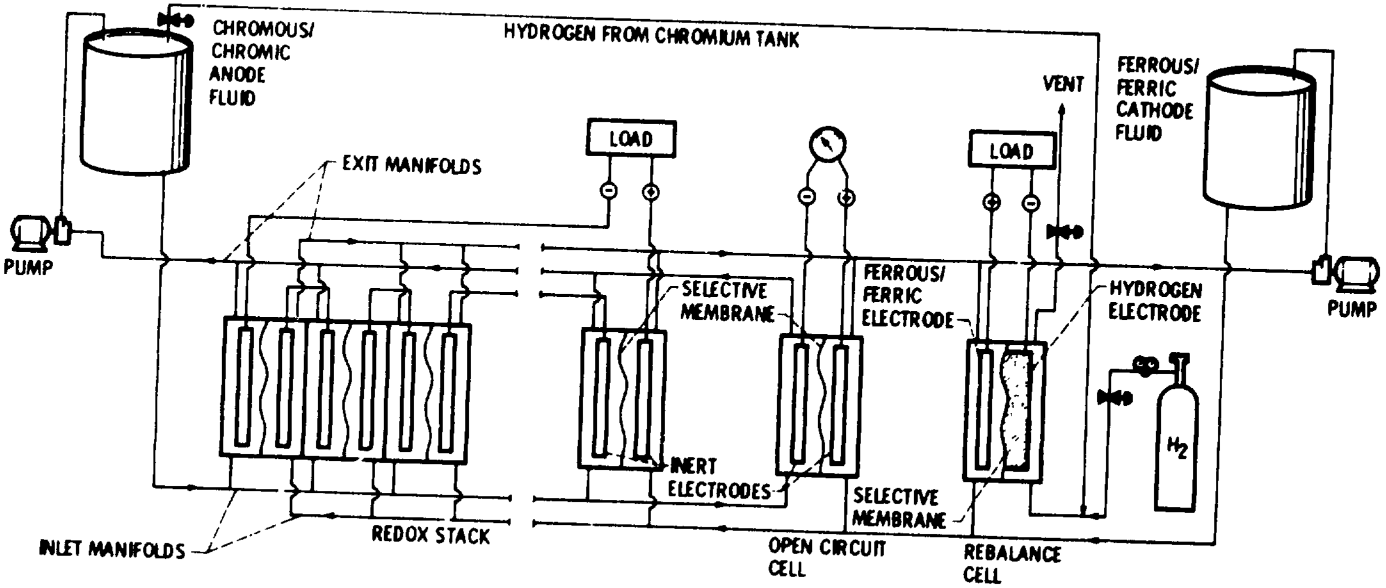

Figure 2. - Full-function Redox flow cell system.

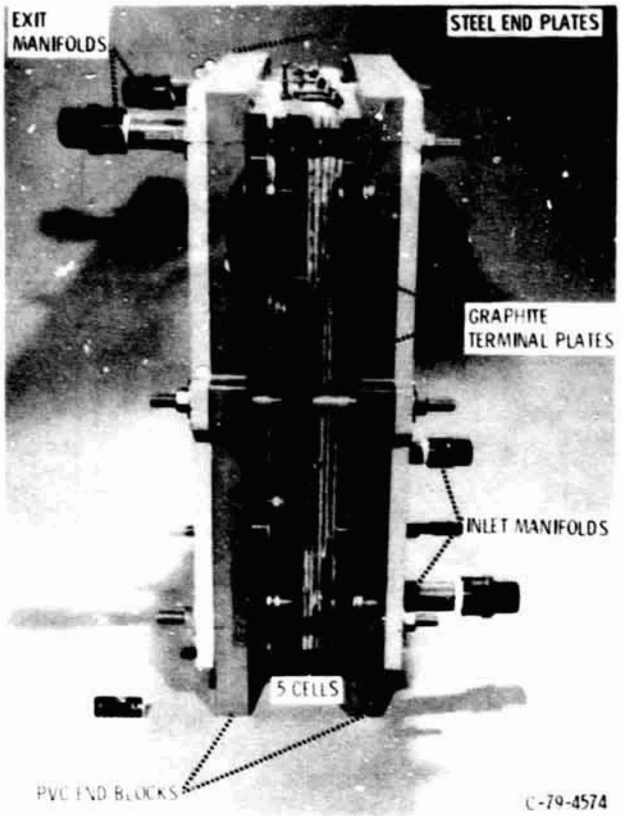

Figure 3. - Five-cell stack with 929 cm^2 (1 ft^2) active electrode area.

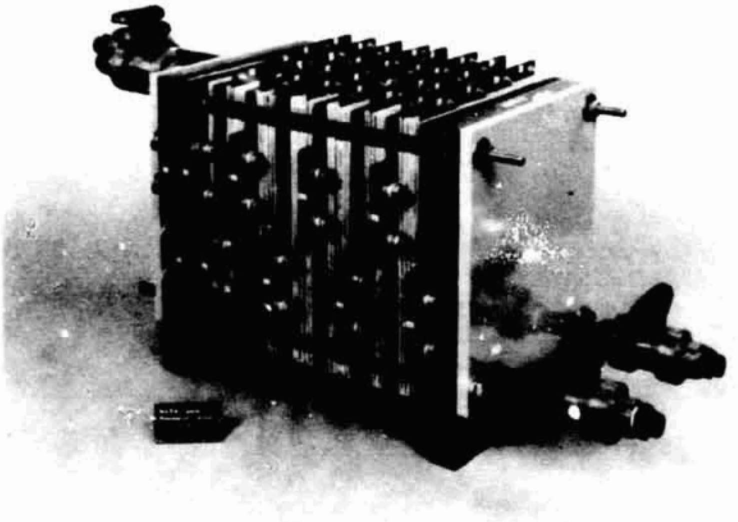

Figure 4. - Redox stack having 39 active cells and 310 cm^2 (0.33 ft^2) electrode area.

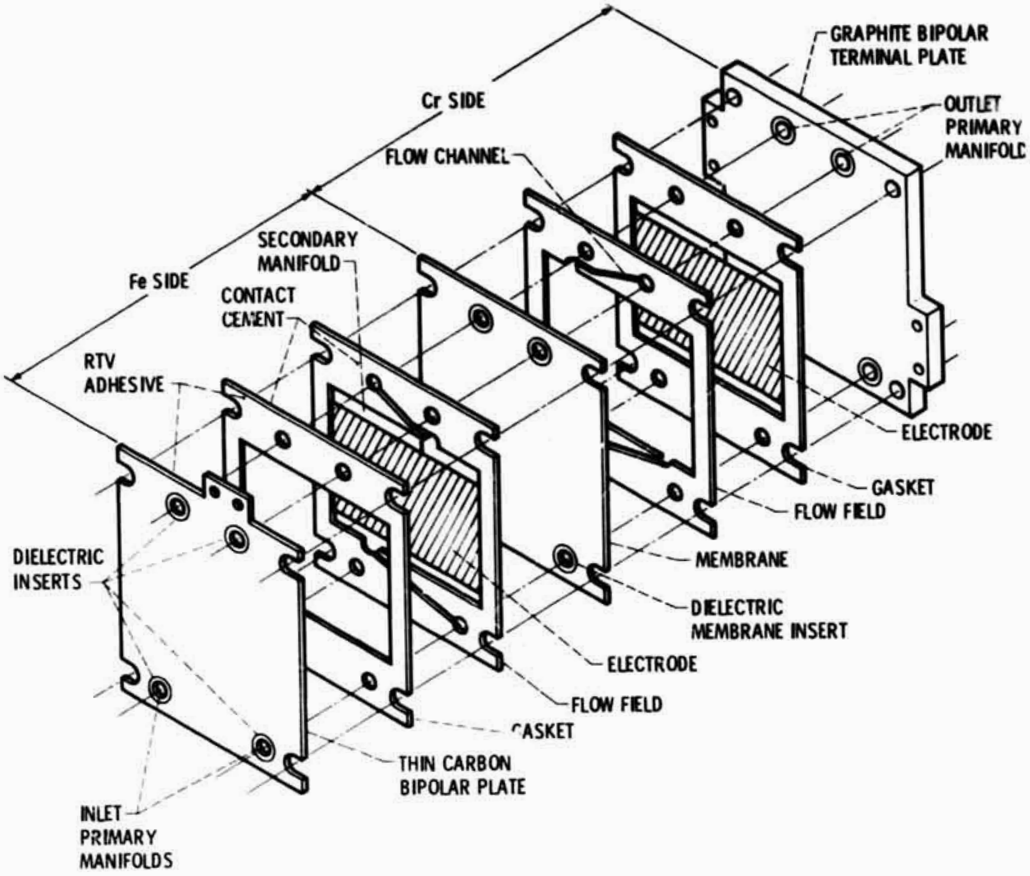

Figure 5. - A typical Redox cell.

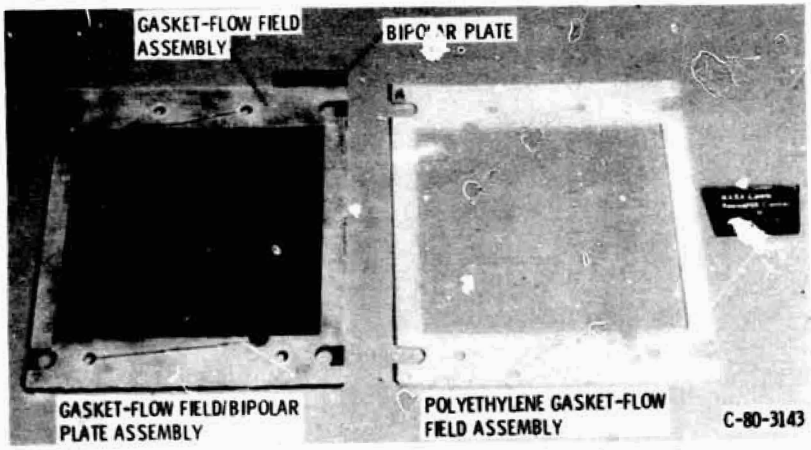

Figure 6. - Gasket-flow field/bipolar plate assembly for 310 cm^2 (0.33 ft^2) cells.

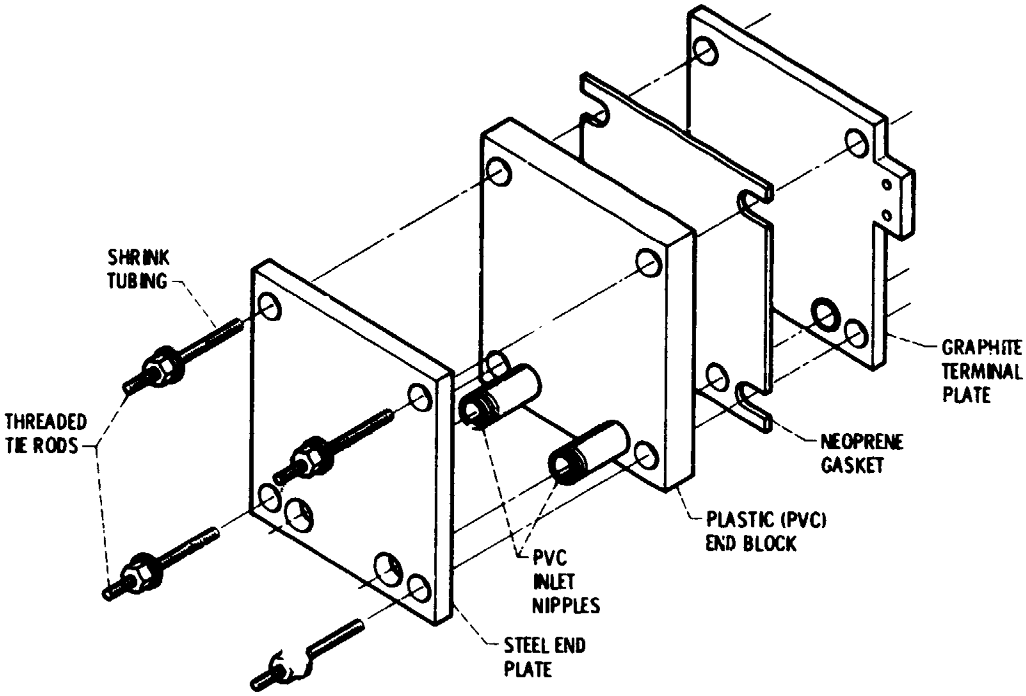

Figure 7. - Inlet end of Redox stack (expanded view).

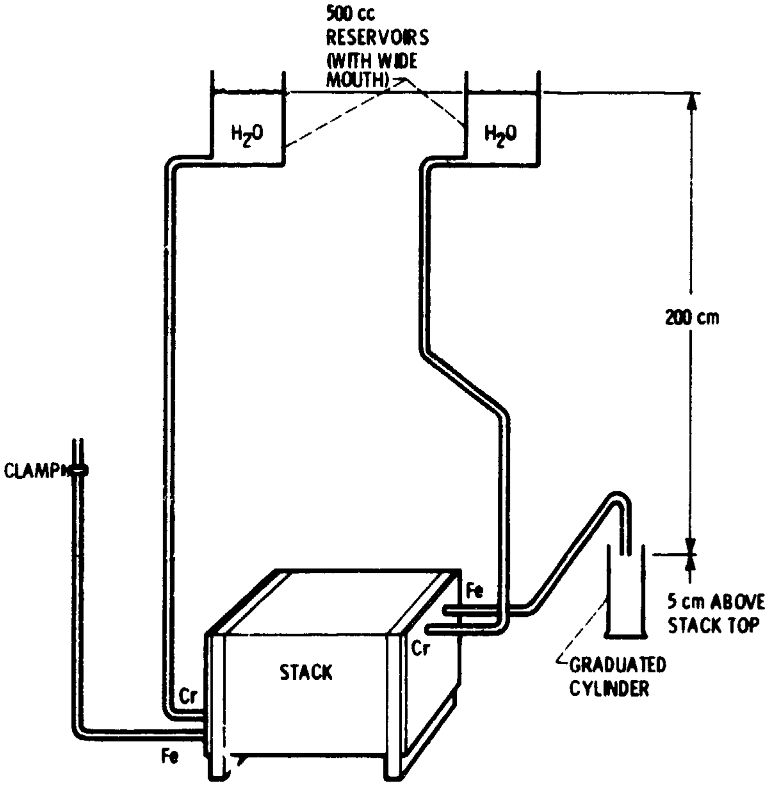

Figure 8. - Stack leakage test set-up.

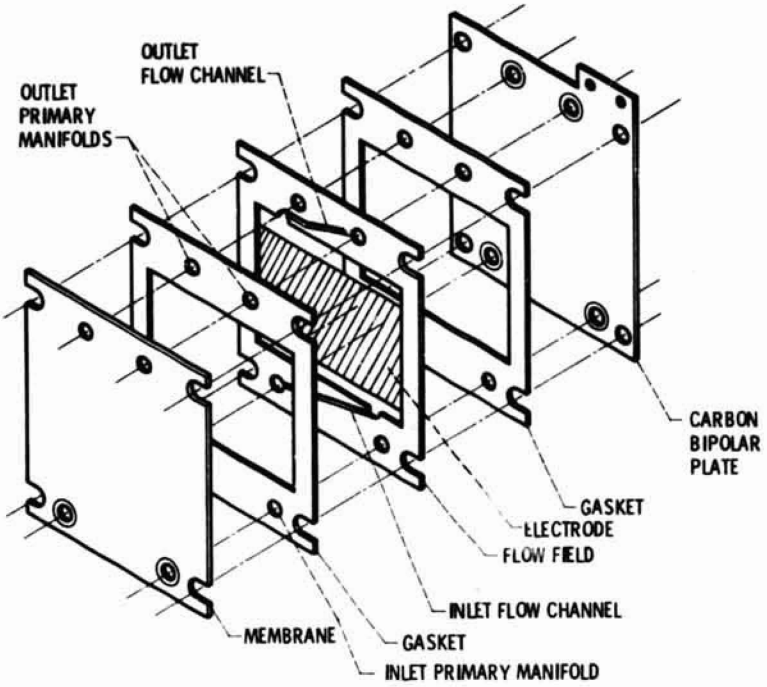

Figure 9. - Redox half-cell configuration with flow channels insulated from membrane.

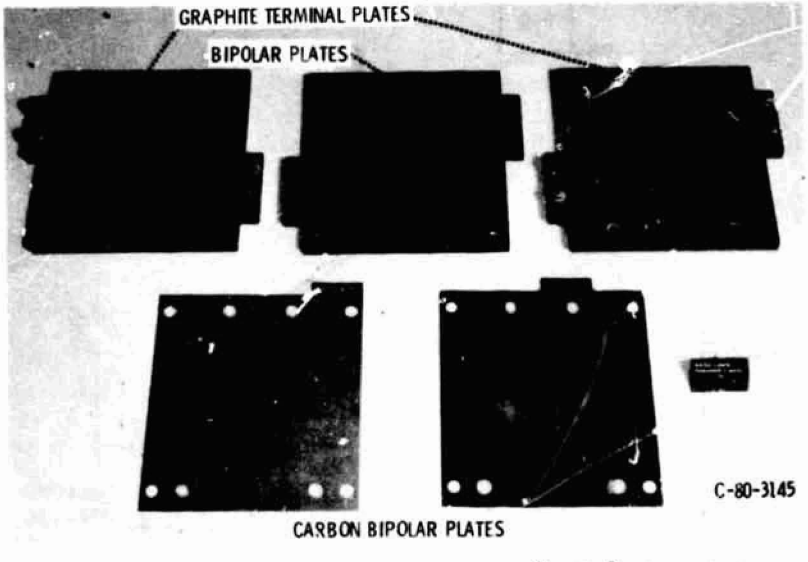

Figure 10. - Bipolar and terminal plates for stacks with 310 cm^2 (0.33 ft^2) active electrode area.