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**Design and Experimental Test Plan for Hybrid Sulfur Single Cell
Pressurized Electrolyzer**

Author: T. J. Steeper
Author: J. L. Steimke

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Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy
Under Contract Number DEAC09-96-SR18500



SRNL
SAVANNAH RIVER NATIONAL LABORATORY

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LIST OF ACRONYMS

HyS	Hybrid Sulfur Process
MEA	membrane electrode assembly
PEM	proton exchange membrane

PES Proton Energy Systems
SDE Sulfur dioxide Depolarized Electrolyzer
USC University of South Carolina

1.0 EXECUTIVE SUMMARY

The Hybrid Sulfur (HyS) process is one of the leading thermochemical cycles being studied as part of the DOE Nuclear Hydrogen Initiative (NHI). SRNL is conducting analyses and research and development for the Department of Energy on the HyS process. A conceptual design report and development plan for the HyS process was issued on April 1, 2005 [Buckner, et. al., 2005], and a report on atmospheric testing of a sulfur dioxide depolarized electrolyzer (SDE), a major component of the HyS process, was issued on August 1, 2005 [Steimke, 2005]. The purpose of this report is to document work related to the design and experimental test plan for a pressurized SDE. Pressurized operation of the SDE is a key requirement for development of an efficient and cost-effective HyS process.

The HyS process, a hybrid thermochemical cycle proposed and investigated in the 1970s and early 1980s by Westinghouse Electric Corporation, is a high priority candidate for NHI due to the potential for high efficiency and its relatively high level of technical maturity. It was demonstrated in laboratory experiments by Westinghouse in 1978. Process improvements and component advancements that build on that work are being pursued. One of the objectives of the current work is to develop the SDE in order to permit the demonstration of a closed-loop laboratory model of the HyS process.

The heart of the HyS process for generating hydrogen is a bank of electrolyzers incorporating sulfur dioxide depolarized anodes. SRNL planned, designed, built and operated a facility for testing single cell electrolyzers at ambient temperature and near atmospheric pressure during the spring and summer of 2005. The major contribution of the SRNL work was the establishment of the proof-of-concept for utilizing the proton-exchange-membrane (PEM) cell design for the SDE operation. Since PEM cells are being extensively developed for automotive fuel cell use, they offer significant potential for cost-effective application for the HyS Process.

This report discusses the modifications necessary to the existing SRNL sulfur dioxide depolarized electrolyzer test facility to allow testing at up to 80 °C and 90 psig. Because of the need for significant additional equipment and the ability to infer performance results to higher pressures, it recommends delaying further modifications to support testing at up to 300 psig (the commercial goal) until other, higher priority technical issues are addressed. These issues include membrane material selection, component designs, catalyst type and loading, etc. The factors and rationale that should be considered in developing and executing a detailed test matrix for pressurized operation are also discussed.

In addition, an electrolyzer assembly design has been developed to allow the testing of different Membrane Electrode Assemblies (MEA's) as part of the planned FY06 HyS Development Program to complete selection of component design specifications for the HyS electrolyzer. MEA's are used in PEM cells to allow intimate contact and minimal resistance between the electrodes and the electrolyte layer. The pressurized electrolyzer assembly presented in this report will facilitate rapid change-out and testing of various MEA designs as part of the electrolyzer development effort.

2.0 INTRODUCTION

One of the technologies proposed for producing the hydrogen is the thermochemical decomposition of water using heat from either a high-temperature nuclear reactor or a central solar receiver. SRNL is conducting analyses and research and development for the Department of Energy on the Hybrid Sulfur (HyS) Process, a hybrid thermochemical cycle proposed and investigated briefly in the late 1970s and early 1980s by Westinghouse Electric Corporation. HyS is conceptually the simplest thermochemical process and involves only sulfur chemistry. It is one of the Baseline thermochemical cycles being studied as part of the DOE Nuclear Hydrogen Initiative.

In the HyS Process hydrogen gas (H_2) is produced at the cathode of the electrochemical cell (or electrolyzer). Water is dissociated at the anode where sulfur dioxide (SO_2) is oxidized to form sulfuric acid (H_2SO_4) and protons (H^+) are generated. The electrolyzer includes a membrane that will let hydrogen ions (protons) pass through but stop hydrogen gas from flowing through. The membrane is also intended to prevent other chemical species from migrating between electrodes and undergoing undesired reactions that could poison the cathode or reduce overall process efficiency. A separate high temperature reaction decomposes the sulfuric acid to water and sulfur dioxide which are recycled to the electrolyzers, and oxygen which is separated out as a secondary product. The process chemistry is illustrated below in Figure 1.

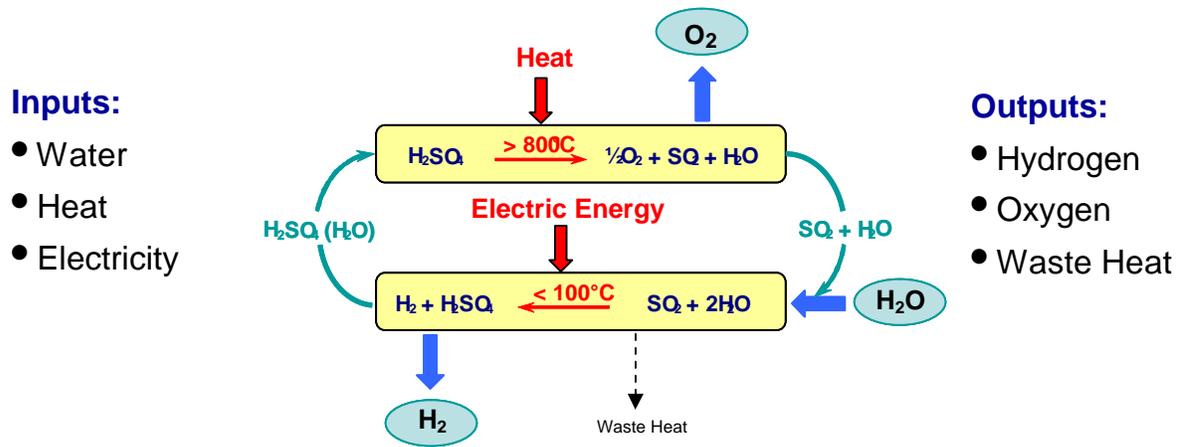


Figure 1. HyS Process Chemistry

In conventional water electrolysis, water is dissociated yielding hydrogen gas at the cathode and oxygen gas at the anode. The minimum possible cell voltage (reversible voltage) for conventional water electrolysis is 1.23 volts at $25^\circ C$. However, commercial electrolyzers typically require higher voltages ranging from 1.8 V to 2.6 V [Kirk-Othmer, 1991].

In the HyS electrolyzer, hydrogen gas is still produced at the cathode, but SO_2 is oxidized to SO_3 which combines with water to form sulfuric acid at the anode. The SO_2 oxidation occurs at a much lower voltage than water electrolysis. For example, the reversible voltage for SO_2 oxidation at $25^\circ C$ in 50 wt % sulfuric acid is 0.29 V [Westinghouse, 1980]. Since power consumption by the electrolyzers is equal to voltage times current, and current is the same for the same hydrogen output in the two types of electrolysis, a large reduction in voltage results in a large reduction in power cost. Although this advantage is partially offset by the need to regenerate the sulfur dioxide in a thermal step for the HyS Process, a through analysis of the entire process shows the HyS process should have a higher overall efficiency than conventional water electrolysis.

SRNL planned, designed, built and operated a facility for testing single cell electrolyzers at ambient temperature and near atmospheric pressure. Results were reported previously [Steimke, 2005]. This report provides details and a discussion for necessary modifications to that facility to allow testing at higher pressures and temperatures. The factors that should be considered in developing and executing a detailed test matrix are discussed. A design for a pressurized single cell electrolyzer is also shown and discussed.

3.0 DISCUSSION

3.1 PREVIOUS WORK

During the period 1977-1982, P.W. T. Lu and others at Westinghouse Electric Corporation tested electrochemical cells using sulfur dioxide depolarized anodes for producing hydrogen. The half-cell and overall cell reactions are:

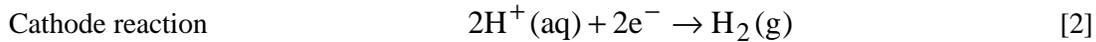
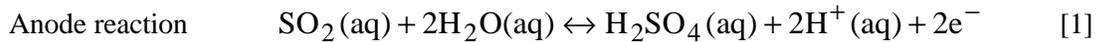


Figure 2 shows the parallel plate cell and the reaction chemistry that occurs at each electrode. A porous rubber membrane was used which allowed hydraulic communication between the two parallel flow channels. A slight positive pressure difference from the catholyte to the anolyte channels was imposed to minimize SO₂ crossover to the cathode while still allowing diffusion of hydrogen ions, or protons, to the cathode. (Actually, protons covalently bond to water molecules to produce hydronium ions, H₃O⁺, which are stable.)

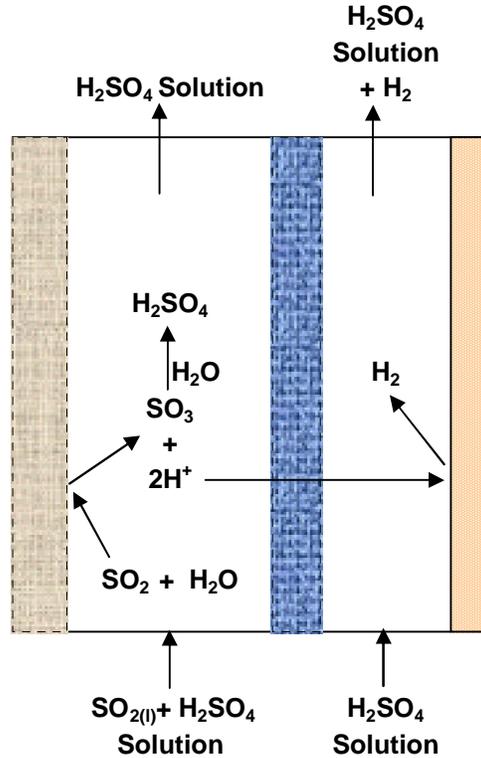


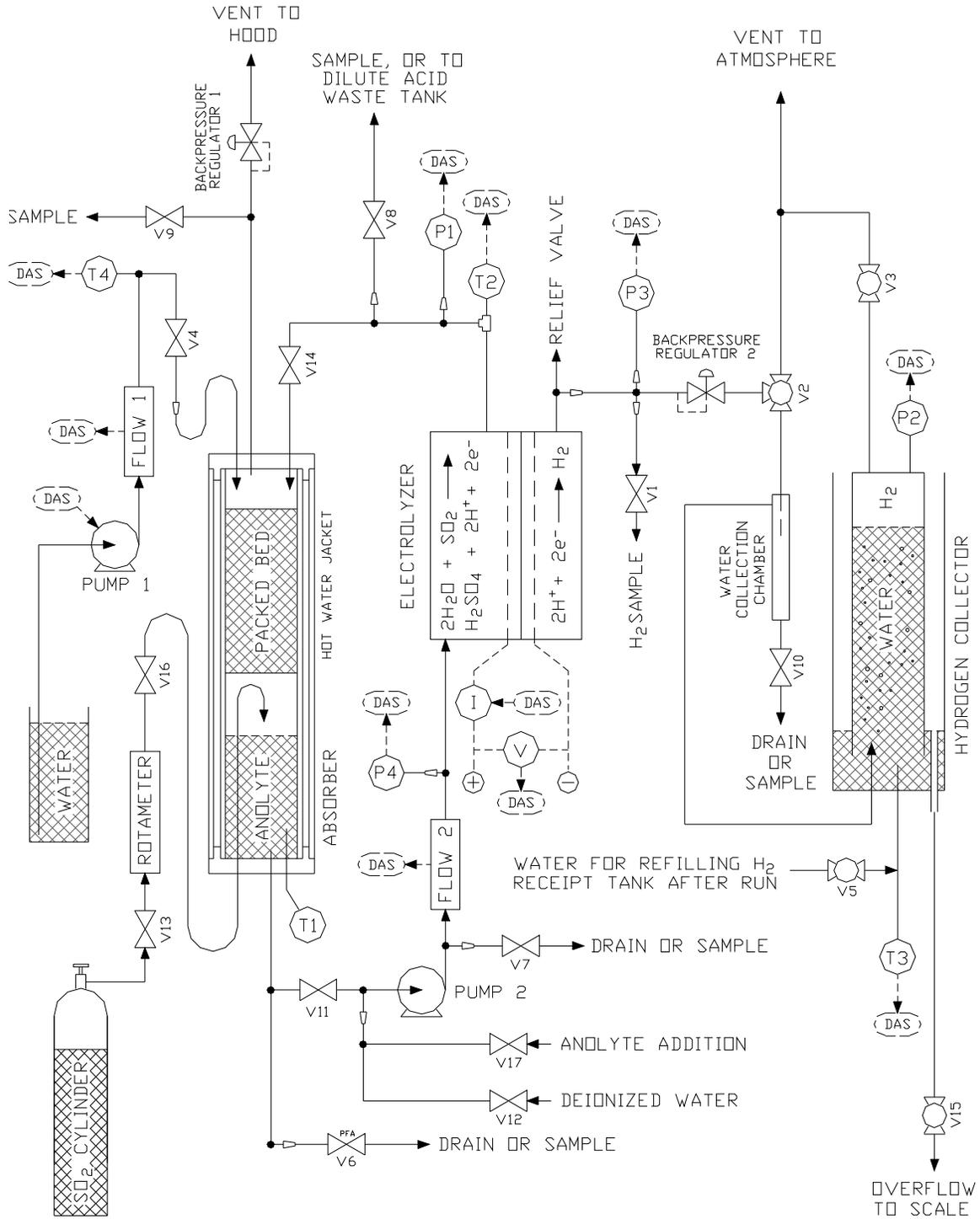
Figure 2 SO₂-depolarized electrolyzer for hydrogen production (Lu, 1980)

In the Westinghouse tests, separate liquid streams fed the electrolyzer and are referred to as the catholyte and the anolyte. The catholyte was a solution of sulfuric acid and water and the anolyte was a solution of sulfuric acid, water, and dissolved sulfur dioxide (SO₂). Sulfur dioxide was oxidized at the anode to produce sulfuric acid and protons (actually hydronium ions). Thus, the outlet anolyte stream had a higher concentration of sulfuric acid than the inlet anolyte stream. The protons produced at the anode transport as hydronium ions across the cation-exchange membrane into the catholyte and are reduced at the cathode to produce hydrogen gas.

Testing by the Westinghouse Electric Company indicated that the anode overpotential decreased with increased temperature, indicating that higher electrical efficiency might occur at higher operating temperature. However, there was little or no improvement in the limiting current with increased temperature at atmospheric pressure [Lu, 1983]. The lack of improvement in the limiting current arises primarily from the reduced solubility of SO₂ at the higher temperatures. To overcome the effects of reduced SO₂ solubility at higher temperature, Lu recommended operating the electrolyzer at elevated pressure. At elevated pressure (e.g., 20 bar) the solubility of SO₂ will be sufficient to allow operation at high current density and low anode overpotential to achieve increased electrical efficiencies. The low anode overpotential was previously demonstrated in laboratory tests in which increasing the pressure from 1 to 20 bar reduced the anode overpotential by about 0.17 V [Lu, 1983].

SRNL recently built a facility and tested two versions of the more modern Proton Exchange Membrane (PEM) electrolyzers that have been developed for fuel cell and water electrolysis applications. These electrolyzers employ a Membrane Electrode Assembly (MEA) consisting of a thin membrane with thin, porous electrodes bonded on either side. Because the MEA is thin, the electrons have shorter distances to travel and hence have lower resistive voltage drops. For the SRNL

SO₂ depolarized electrode tests the anolyte was a solution of water and sulfuric acid saturated with SO₂ gas. Hydrogen gas was produced at the cathode, and no catholyte was required. Figure 3 shows the schematic of the current facility at SRNL.



LOW PRESSURE (0-20 PSIG)
ELECTROLYZER TEST LOOP SCHEMATIC

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Figure 3 Schematic of Current SRNL Electrolyzer Cell Test Facility

The objective of the initial test program was to establish the viability of a PEM-type cell for use as a sulfur dioxide-depolarized electrolyzer (SDE). In order to accelerate the schedule and to minimize costs, it was decided to first test a commercially available electrolyzer rather than design and build one from individual components. The first cell tested was a HOGEN® PEM Water Electrolyzer Test Cell built by Proton Energy Systems (PES) of Wallingford CT. The commercial electrolyzer was designed for operation up to 200 psig and 80 °C. Its “off the shelf” configuration included some materials of construction that were questionable as far as handling the very corrosive anolyte solution was concerned, but material changes were specified in the SRNL purchase that eliminated some of the concerns. The porous titanium electrodes could not be replaced without major design changes, however. The electrolyzer was purchased knowing it would have a limited life, but it was expected to provide worthwhile and cost effective data before failure. That proved to be the case, although rapid titanium corrosion resulted in a short test duration. The Proton Energy electrolyzer is shown below. The purchase agreement specified that the internal details of the cell were proprietary; therefore there are no pictures of the internals.



Figure 4 Photograph of Proton Energy Systems Cell

The second cell tested was made by the University of South Carolina (USC). It is shown in the center of Figure 5. The USC cell is a nearly square sandwich. The outer layer of the sandwich is a ½” thick piece of stainless steel for structural strength. Next is a thin fiberglass insulator. The insulator is followed by a copper terminal plate with large tabs used to connect the power supply cables and voltage taps. Contacting the terminals are 0.8” thick solid graphite blocks as shown in Figure 6. Each block has a groove machined in it to accept an o-ring seal. The graphite blocks also have two holes with pipe threads to allow inlet and outlet of fluid. Each graphite block also has a nearly square recess machined in it. A porous graphite wafer fits snugly in each recess. The anode wafer has thin

grooves machined in it to facilitate flow of anolyte. There are no grooves in the cathode wafer. The last and innermost layer is the MEA shown in Figure 7. The MEA consists of a sheet of Nafion 115, which looks like heavy duty plastic wrap, and a slurry of powder consisting of 40 wt% of platinum on carbon and Nafion hot pressed onto the Nafion sheet. The total thickness of the MEA was 0.030". The wetted parts of the USC cell were made of very corrosion resistant materials. The overall design pressure was limited, and differential pressure across the membrane was another concern.

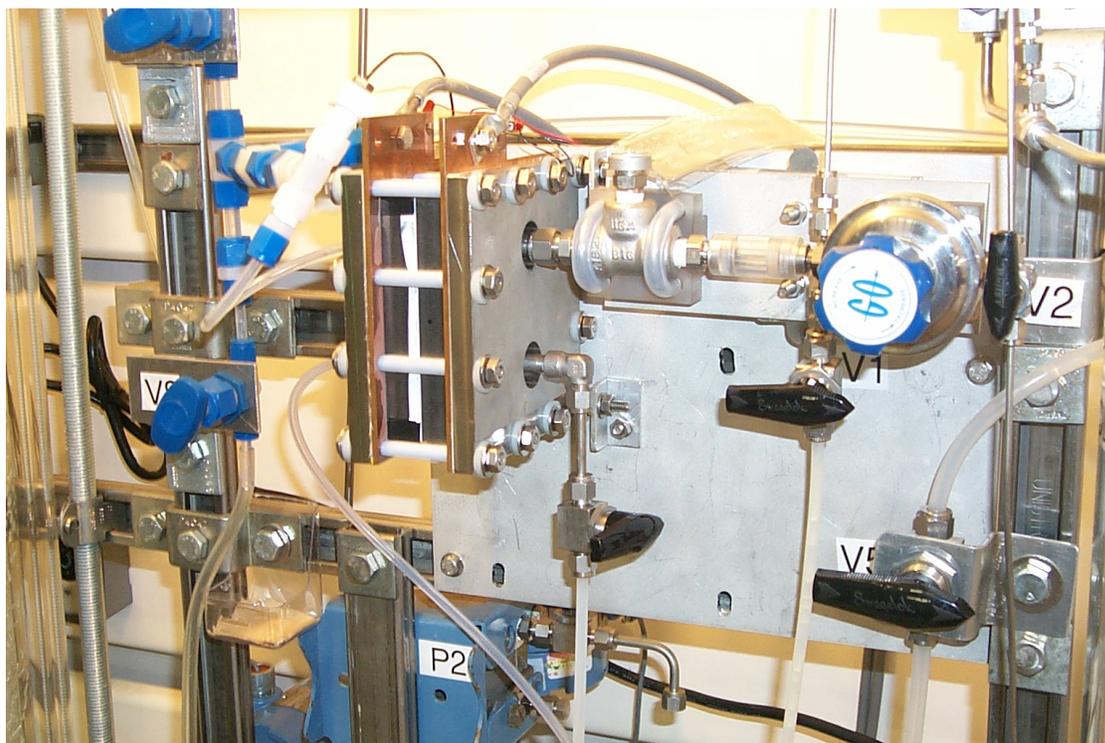


Figure 5 Photograph of USC Cell

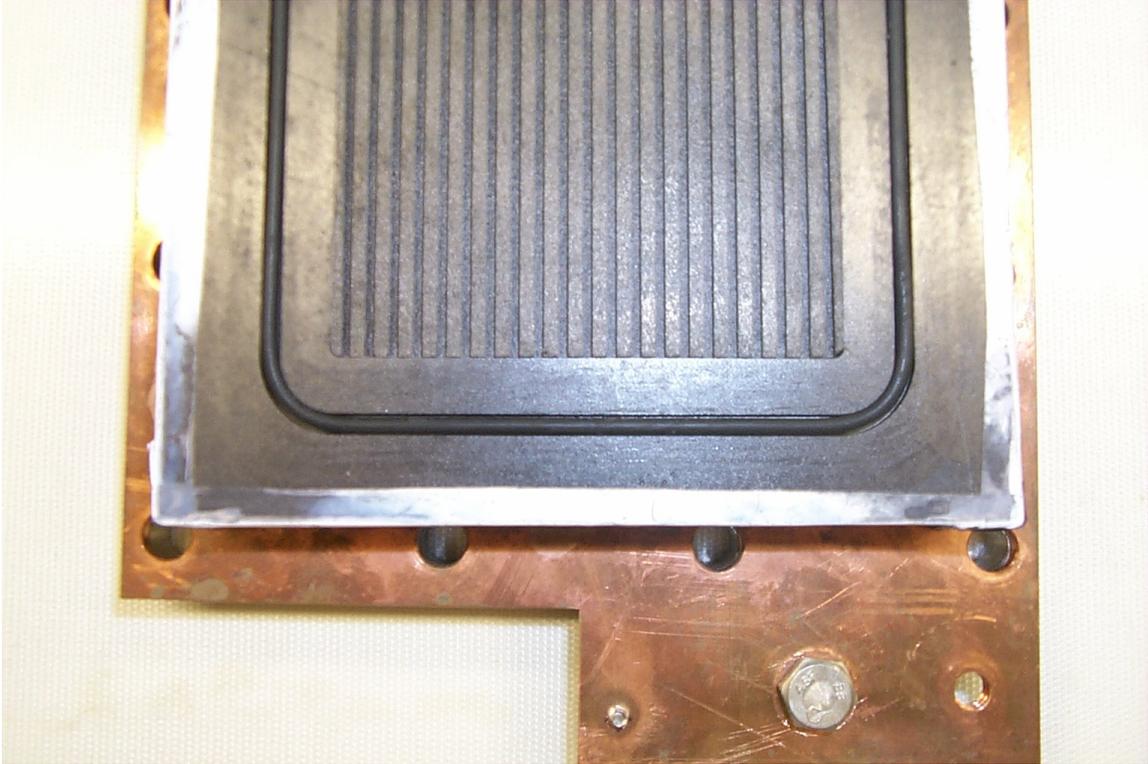


Figure 6 Photograph of Graphite Block, Grooved Wafer and Copper Connector



Figure 7 Photograph of Membrane Electrode Assembly from Anode Side

3.2 FACILITY MODIFICATIONS FOR ELEVATED PRESSURE TESTING

Testing performed to date has been conducted at room temperature and near ambient pressure. A photograph of the test facility is shown below.



Figure 8 Photograph of Existing Electrolyzer Test Facility

System analyses and process design studies were performed for the HyS Process in order to establish operating parameters that maximize overall system efficiency [Buckner et al., 2004]. The current baseline process flowsheet for the entire HyS process is based on operating the electrolyzer at 100 °C and 20 bar (300 psig). In order to conduct electrolyzer tests under these conditions, the current electrolyzer test facility will require modifications. Because of equipment limitations discussed below, along with funding and schedule considerations, it will be advantageous to modify the facility in stages rather than try to reach these conditions all at once.

The current facility includes an absorber where sulfur dioxide gas was absorbed in either water or solutions of sulfuric acid and water to form anolyte. The absorber contains 96 cm in height of 8 mm by 8 mm by 1 mm wall glass Raschig Rings in a column having an inside diameter of 13.4 cm (5.275"). Below the packed bed is a reservoir for about a liter of anolyte. This absorber operates in countercurrent operation, anolyte flows into the top and sulfur dioxide gas flows upward. Fifty percent excess of sulfur dioxide gas was used and the excess gas was vented. Anolyte is pumped out of the absorber, through a flowmeter, through the anolyte side of the electrolyzer and back into the top of the absorber.

The absorber had to have sufficient contact area for the anolyte solution and sulfur dioxide gas to interact, and had to have a large enough cross section to prevent flooding at the required anolyte and gas flows. These factors fixed the minimum diameter for a single unit. Glass was a good material of construction from corrosion considerations and had the added benefit of transparency allowing the anolyte/gas interaction to be observed. The heaviest wall glass available was used, resulting in an allowable operating pressure of 200 psig. It will be necessary to use multiple absorbers with smaller diameters, or give up the advantage of transparency, to operate at pressures above 200 psig.

A clear cylinder was placed around the absorber forming a jacket through which hot water could be passed to achieve temperatures greater than ambient. Another clear cylinder was placed around that to allow the annulus to be evacuated providing reasonable thermal insulation while not restricting visibility. These features were not used during the initial test program. A hot water system can easily be built and connected to provide the capability of operation at up to 80 °C for the next stage of testing. Excessive evaporation rates and the difficulty of pumping water close to its boiling point preclude operating an open water bath much higher than 80 °C. Using anything but plain water raises safety concerns that lead to a more complicated and costly system, with little gain in temperature of operation.

Sulfur dioxide was purchased in a 100 lb. cylinder and the flowrate was measured using an available inexpensive gas rotameter during the previous low pressure testing. Excess sulfur dioxide gas was vented from the absorber through a backpressure regulator valve. This was provided so the absorber pressure could be increased, which increases the concentration of dissolved sulfur dioxide. However, at room temperature the vapor pressure of sulfur dioxide is only 20 psig. This fixes the maximum operating pressure for the existing facility. To operate at higher pressures it will be necessary to turn the cylinder over so liquid will be delivered instead of gas. A pump will have to be provided to increase the pressure of the liquid from the 20 psig available from the cylinder to the desired level for some of the testing. It would be highly undesirable to have to invert the cylinder and repipe the supply every time testing varies from low to high pressures. Therefore, another backpressure regulator will be added to ensure the sulfur dioxide will remain a liquid in the pump during any tests at low pressures. Under some conditions of pressure and temperature the sulfur dioxide will flash to a gas as it enters the absorber, for other conditions it will remain a liquid. When in the gas phase, excess sulfur dioxide will simply exit the absorber through the backpressure regulator as during previous low pressure tests. When delivered as a liquid the flow will have to be more closely controlled. A new flowmeter providing feedback to the control computer will be provided.

Pressure relief was not needed on the absorber during the previous low pressure tests since the pressure could not exceed the 20 psig vapor pressure of room temperature sulfur dioxide. All of the hardware was designed to withstand pressures above 20 psig. Once liquid sulfur dioxide is pumped into the absorber the potential exists to exceed the design pressure of the equipment if the temperature control should fail causing the liquid SO₂ to flash into gas. Although the vapor pressure of SO₂ over a water/sulfuric acid solution is not well known it is expected to be about 400 psig at 100 °C (the maximum temperature possible with an open water bath heating system).

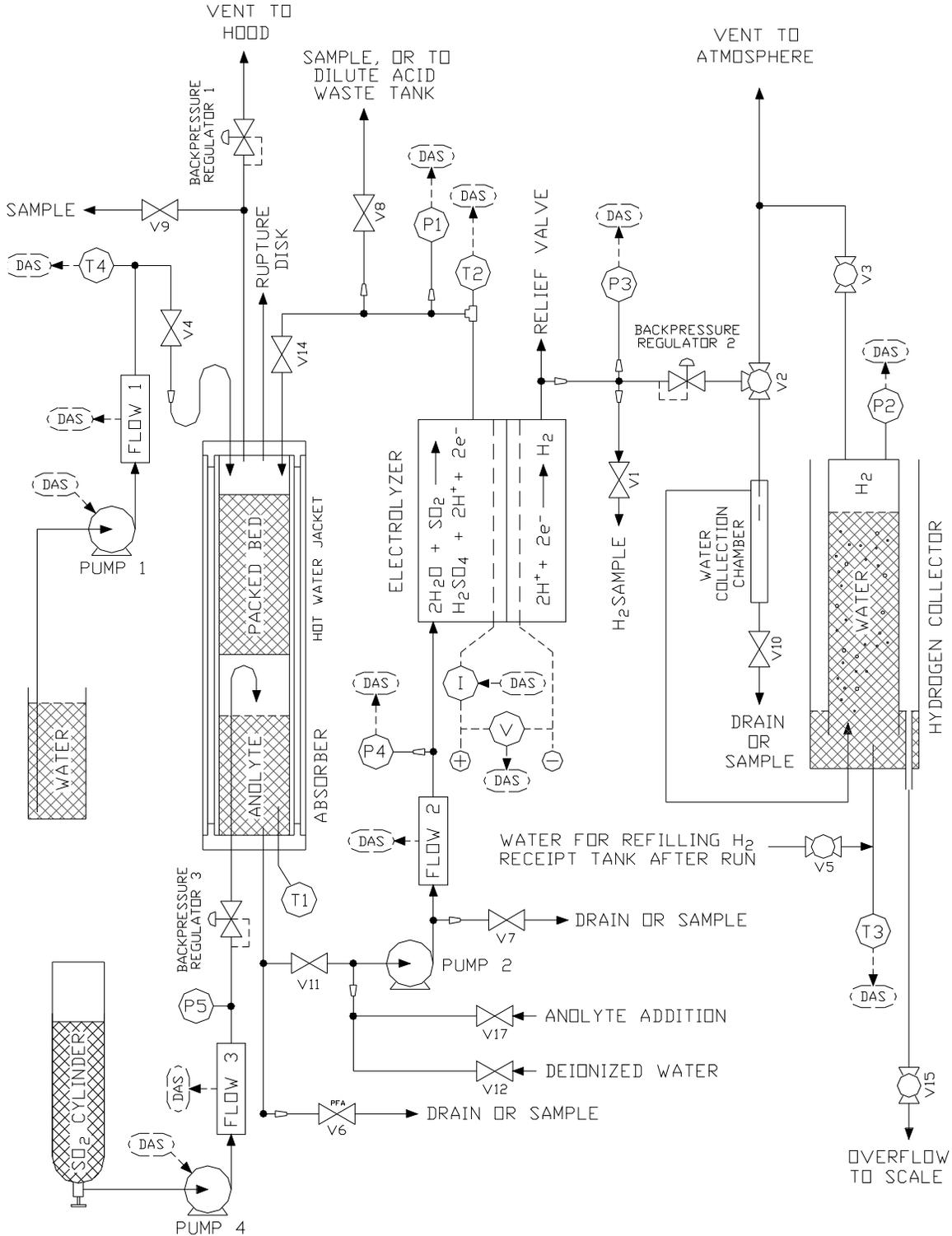
The existing backpressure regulators have design strengths of well over 300 psig. Additional springs and associated internal parts will have to be purchased to allow the pressures to be adjusted to the higher desired levels. The existing instrumentation and pumps are also rated for at least 300 psig operation.

All tubing, valves, and connectors in the present anolyte flow loop were made from fluorocarbon (PTFE or PFA). These components are very good from a corrosion standpoint, are readily available,

and reasonable in cost, but have an operating pressure limit of about 90 psig at 100 °C. Metal tubing, fittings, and valves of Hastelloy B would be excellent for both pressure and corrosion considerations, but are not readily available and are very expensive. The translucent fluorocarbon tubing was also useful in determining if lines were full of liquid or were passing a two phase mixture. SO₂ depolarized operation produces only sulfuric acid at the anode; straight water electrolysis produces oxygen bubbles which are easily visible in the anolyte. Limiting the test pressures to 90 psig for the near future will allow continued use of the fluorocarbon components, while still providing sufficiently high pressure to identify trends and allow verification of theoretical relationships.

For these reasons, it is recommended that the pressurized test facility be limited to 90 psig for the next phase. Even with limited pressure dependence data it may be possible to verify theoretical relationships that can then be used to extrapolate the results to higher pressures. A scoping effort should be expended to look for corrosion resistant, higher pressure capable components at a reasonable cost so additional facility modifications can be made in a timely manner to extend the testing capabilities to 300 psig.

The revised facility schematic is shown in Figure 9 for comparison to the current schematic shown earlier.



HIGH PRESSURE (0-90 PSIG)
ELECTROLYZER TEST LOOP SCHEMATIC

REVISED
8/25/2005

Figure 9 Schematic of SRNL Electrolyzer Cell Test Facility as Modified for Higher Pressure Testing

3.3 TEST MATRIX

A preliminary test matrix for testing of SDE's at pressures up to 90 psig and 80 °C is discussed below. The final test matrix will be established based on final funding guidance. Higher pressure testing (90 - 300 psig) and higher temperature testing (80 – 100 °C) will be considered at a later date.

The Test Matrix for the previous testing was designed with safety in mind. This was important because the testing involved pressures as high as 50 psig, potentially flammable gas mixtures, sulfur dioxide, and solutions of sulfuric acid which can cause serious chemical burns. The philosophy of testing was to introduce one new hazard at a time. The first testing was shakedown with water and air to verify the operation of the instruments, valves and pumps and also to check for leaks. Next was electrolysis of water only in the Proton Energy cell. This gave a benchmark that other tests could be compared to. The next step added one hazard, sulfur dioxide. Water with dissolved sulfur dioxide was electrolyzed. It was expected that this mixture would demonstrate sulfur dioxide depolarized anode behavior. The final step was electrolysis of sulfur dioxide dissolved in sulfuric acid solutions.

This cautious approach will be continued for future testing at higher pressures and elevated temperatures. The modified system will undergo a water and air shakedown. However, electrolysis of plain water will not be performed because the graphite electrolyzer structure itself will electrolyze at the 1.2 to 2 volts needed to electrolyze water. The testing performed previously showed that the SO₂ alone added to water did not depolarize the electrodes and reduce the required voltage, so there appears to be no point in testing that combination in the future. 30 wt% sulfuric acid saturated with SO₂ will be tested at 20 °C and 80 °C, with some tests at 50 °C. Pressure will be varied from ambient to 90 psig, with some tests at about 50 psig. The concentration will be increased to 70 wt% acid and the temperature and pressure variations repeated. The current will be varied in several increments to establish the voltage/current relationship at each of the above combinations of conditions.

One of the main technical issues that will be investigated is SO₂ crossing through the membrane from the anode to the cathode side of the cell. The SO₂ reacts with the hydrogen at the cathode and produces elemental sulfur. Not only does this reduce the yield of hydrogen gas, but it requires periodic flushing of the cathode to remove the sulfur. Different MEAs will be developed and tested in an attempt to eliminate this problem. Comparison of MEAs will most likely not require variations over the full range of temperature and pressure conditions possible. Experience obtained during early testing will of course guide subsequent testing, with the goal of limiting the number of experiments necessary to reach valid conclusions.

Another research topic is the design of the non-MEA components of the electrolyzer. Hopefully, the initial design of the pressurized single cell electrolyzer will provide a versatile unit that does not have significant flow restrictions or other factors limiting the ability to evaluate different MEAs at the necessary pressure, temperature, and current conditions. Eventually, some redesign and testing of the other components of the electrolyzer will be necessary to help develop a robust and cost effective design for a multicell electrolyzer. The extent of this development effort next year will depend a great deal on the success with the other technical issues as well as the level of funding available. Assuming the initial design is reasonably successful, the development effort on non-MEA components of the electrolyzer will take a back seat to establishing the pressure/temperature relationships and evaluating MEAs.

3.4 ELECTROLIZER DESIGN

The next electrolyzer to be tested in the SRNL facility has been designed primarily as a versatile unit that can be used to investigate the main technical issues as discussed in the previous section. This electrolyzer is similar to the previously tested USC electrolyzer design, but with improved flow paths to handle liquid flows better. Other changes were made to allow it to handle higher pressures and be more robust. Drawings of individual custom machined parts are shown in Appendix A. The next several figures show the assembled SRNL Pressurized Single Cell Electrolyzer and should be useful in understanding the following description.

Thick S/S plates (part 1 in Figure 12) held together by twelve bolts will provide the primary pressure containment up to 300 psig. The slightly dished Bellevue washers (part 18) act as very stiff springs to transmit the restraining force of the bolts while still allowing for the few thousands of an inch thermal expansion caused by increasing the temperature of the electrolyzer to 100 °C. Commercially available Viton o-rings (parts 15, 16, and 19) will be used as seals. A Hasteloy B alloy flow distributor (part 5) resists any differential pressure across the membrane while still allowing flow of anolyte or hydrogen gas through. The USC electrolyzer tested previously did not have such a flow distributor, and therefore could not withstand a high differential pressure across the membrane.

The electrical terminals (parts 3 and 8) will be copper to provide low resistance to the high currents employed. Low resistance solid graphite blocks (parts 4 and 17) with porous graphite inserts (part 6) carry the current to the porous graphite electrodes that are an integral part of the MEA (part 7). The structural parts will be isolated from the current carrying parts by Teflon or fiberglass insulators (parts 2, 9, and 12). The USC electrolyzer tested previously did not have the insulating flow connectors (part 9); the graphite blocks were drilled and tapped directly for fittings. Since the graphite is brittle and easily damaged, using the flow connectors will result in a more robust design. Also, since the flow connectors are also electrical insulators, higher pressure capable metal fittings and tubing can eventually be used without having to worry about shorting across the electrolyzer.

The wetted components will be constructed of highly corrosion resistant materials such as graphite (parts 4, 6, 17), Teflon (part 9), and Hasteloy B alloy (part 5). The solid graphite seal blocks (parts 4 and 17) will be machined with generous flow passages so there will be little restriction of the anolyte flow or any flush water needed to remove elemental sulfur that may be formed at the cathode. The porous graphite inserts (part 6) will have numerous narrow grooves on their inside faces and a series of small holes at the top and bottom lined up with the holes in the flow distributors. The holes and grooves will allow free flow of liquids at the surface of the electrodes that are an integral part of the MEA, while still supporting differential pressures across the MEA. The porous graphite inserts (part 6) are slightly compressible and will maintain good electrical contact while allowing for slight variations in MEA thicknesses.

All materials will easily be able to handle operation at 100 °C. The cell will be easy to take apart and reassemble to allow multiple MEAs to be tested quickly. The internal flow passages should not restrict anolyte flow to the surface of the MEA, and should allow thorough flushing of elemental sulfur from the cathode if necessary. The SRNL electrolyzer is designed to handle 300 psig internal pressure and a full 300 psig differential across the MEA without damage (in case one side is inadvertently vented with the other pressurized).

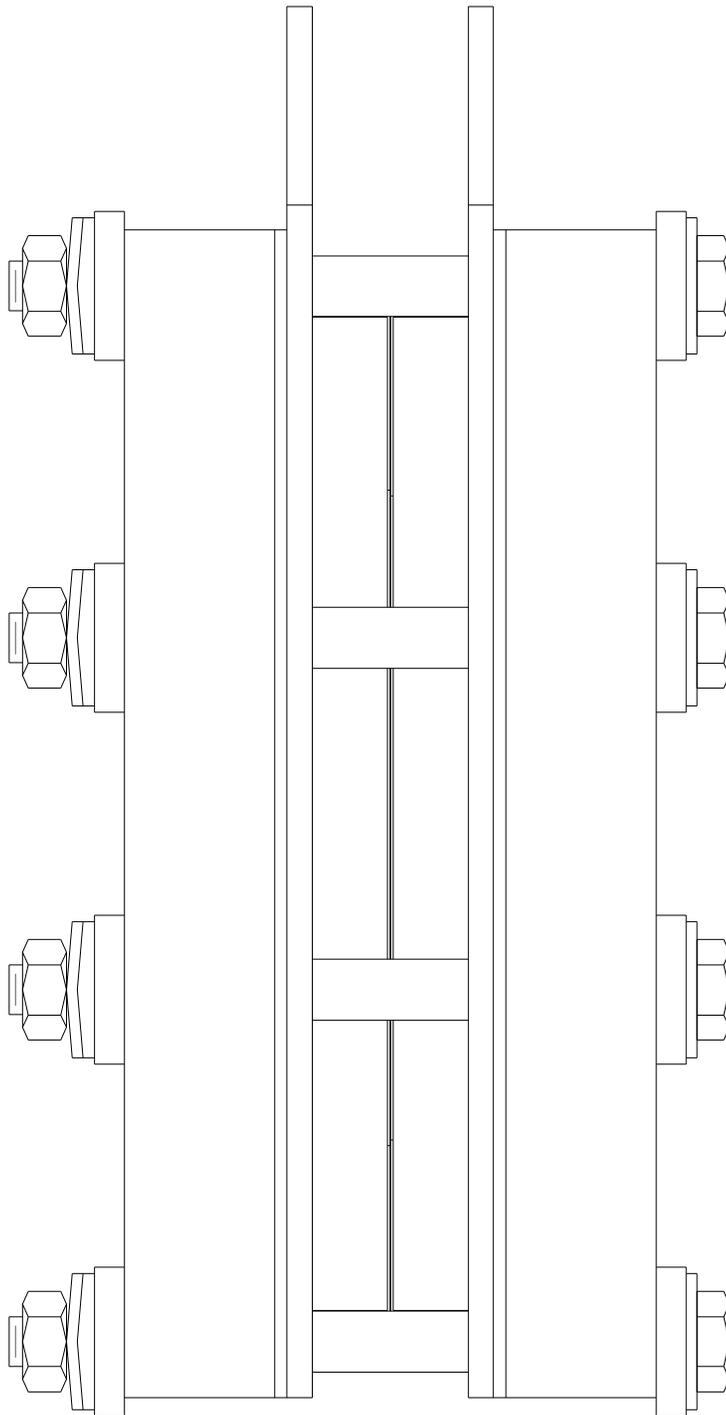


Figure 10 Front View of SRNL Pressurized Single Cell Electrolyzer

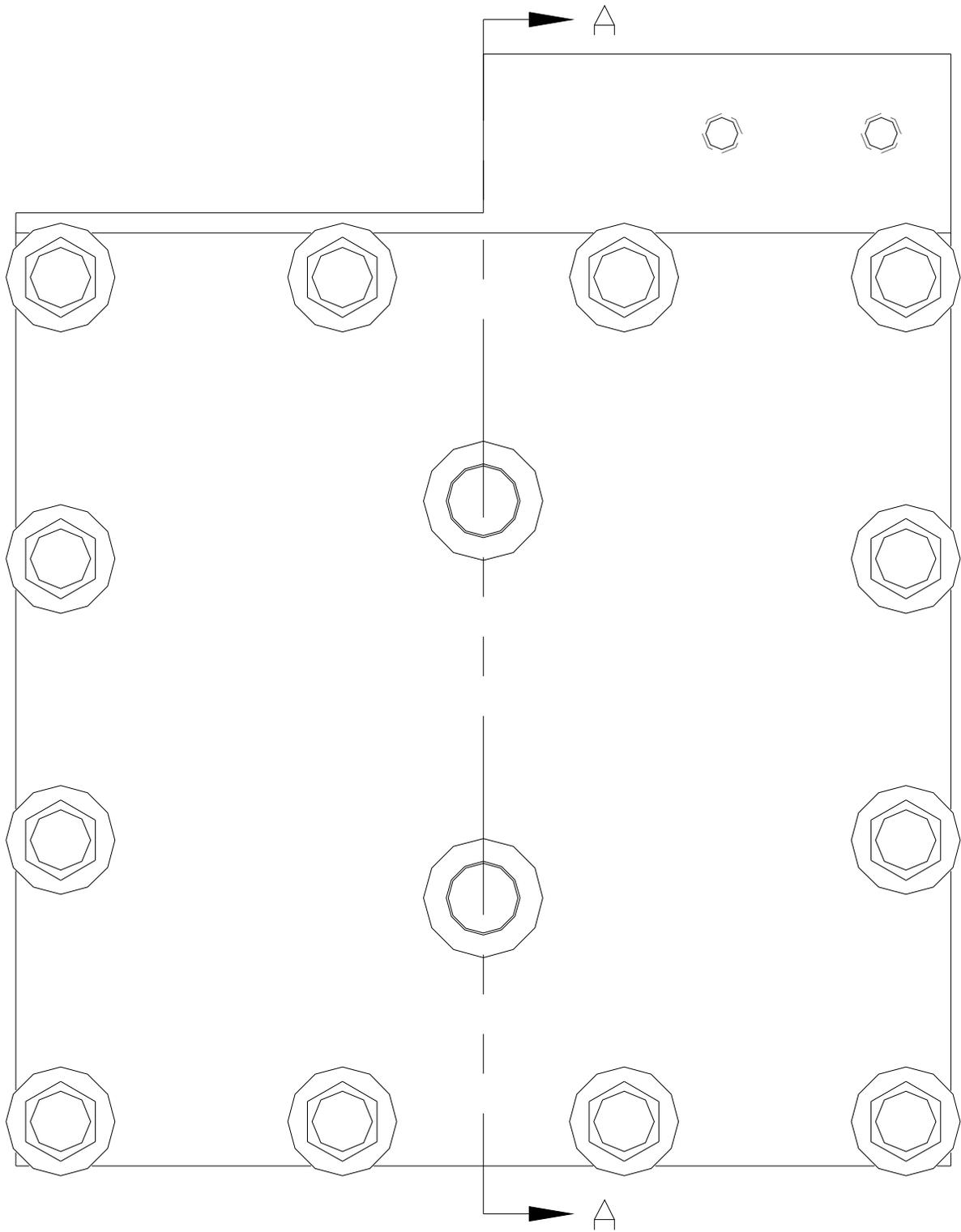


Figure 11 Right Side View of SRNL Pressurized Single Cell Electrolyzer

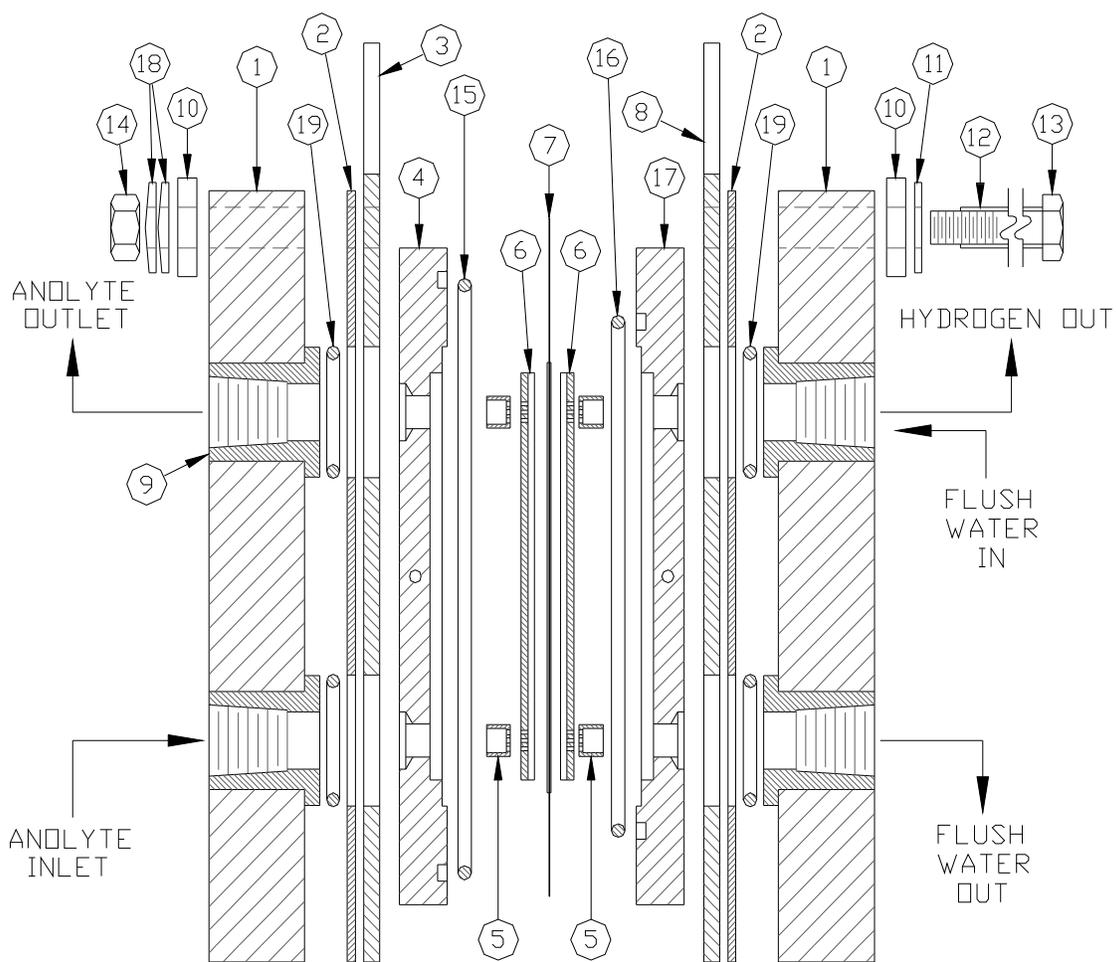


Figure 12 Exploded Section A-A View of SRNL Pressurized Single Cell Electrolyzer

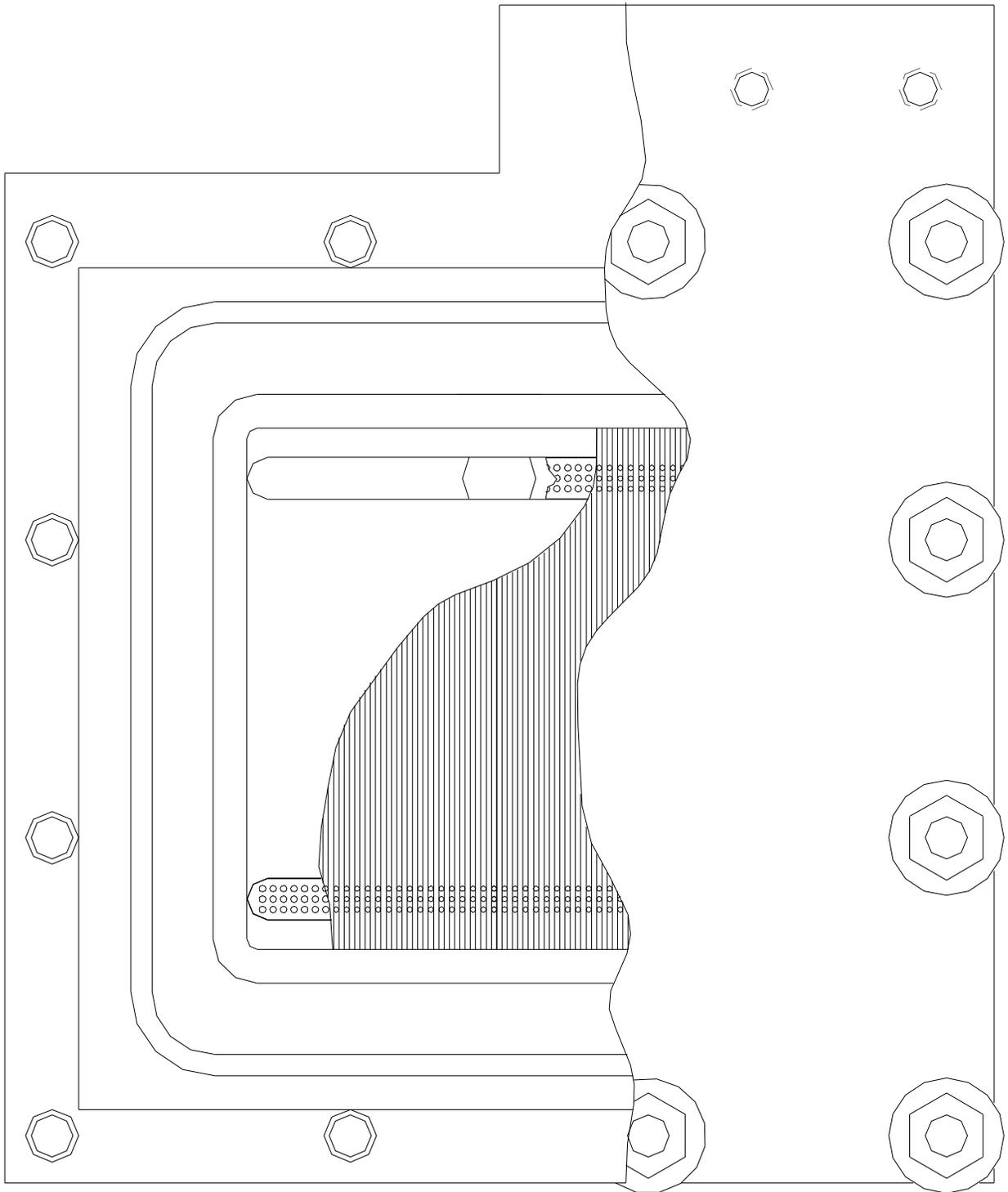


Figure 13 Cut-Away View showing Flow Passages in SRNL Pressurized Single Cell Electrolyzer

4.0 CONCLUSIONS

1. The SRNL electrolyzer test facility can be fairly easily modified to allow testing up to 80°C and 90 psig. Many provisions for higher pressure operation were made in the initial design of the facility.
2. A lack of suitably corrosion resistant, higher pressure capable tubing, valve, and fittings will make the cost of further modification for operation at pressures above 90 psig high. Further modifications to support testing in the range of 90 - 300 psig will require substantial additional efforts, and may be deferred until the 90 psig test program is complete.. A scoping effort should be expended to continue to look for the necessary components so additional facility modifications can be made in a timely manner when higher pressure testing is required.
3. A robust pressurized electrolyzer design has been developed for near-term testing. The primary purpose of the testing should be to evaluate temperature and pressure effects with the SO₂ depolarized electrolyzer, and to evaluate various MEAs to try and address the SO₂ crossover issue. Further development of non-MEA components of the electrolyzer will also require additional effort, but they may need to be deferred until later unless necessary to support the higher priority testing.

5.0 SUMMARY

This report discusses the modifications necessary to the existing SRNL sulfur dioxide depolarized electrolyzer test facility to allow testing at up to 80 °C and 90 psig. Because of the need for significant additional equipment, it recommends delaying further modifications to support testing at up to 300 psig and 100 °C until other, higher priority technical issues are addressed. The factors that should be considered in developing and executing a detailed test matrix are discussed. Finally, the design of a pressurized single cell SO₂ depolarized electrolyzer design is presented and discussed.

6.0 REFERENCES

Buckner, M. R., T. M. Adams, M. B. Gorenssek, L. L. Hamm, N. M. Hassan, D. T. Hobbs, C. A. Nash, Z. H. Qureshi, T. J. Steeper, J. L. Steimke, and W. A. Summers, 2004, *Conceptual Design for a Hybrid Sulfur Hydrogen Production Plant (U)*, WSRC-TR-2004-00460, Savannah River Site, Aiken, SC 29808.

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Kirk-Othmer, 1991, **Encyclopedia of Chemical Technology**, Fourth Edition, article on Hydrogen.

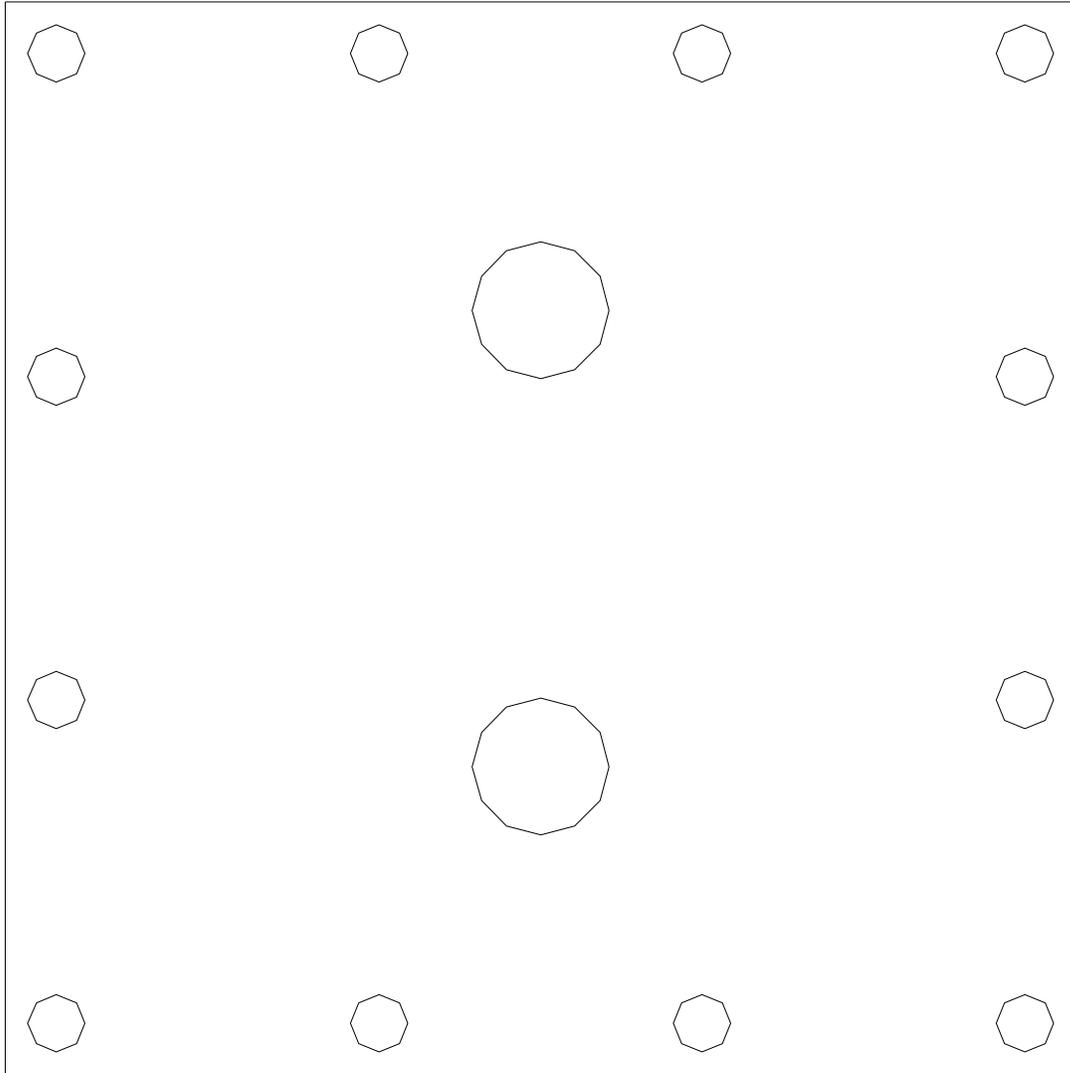
Lu, P. W. T., and R. L. Ammon, 1980, "An Investigation of Electrode Materials for the Anodic Oxidation of Sulfur Dioxide in Concentrated Sulfuric Acid", *J. Electrochem. Soc.: Electrochemical Science and Technology*, Vol. 127, No. 12, pp. 2610-2616, December.

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Westinghouse Electric Corporation, 1980, "A Study on the Electrolysis of Sulfur Dioxide and Water for the Sulfur Cycle Hydrogen Production Process", AESD-TME-3043, July.

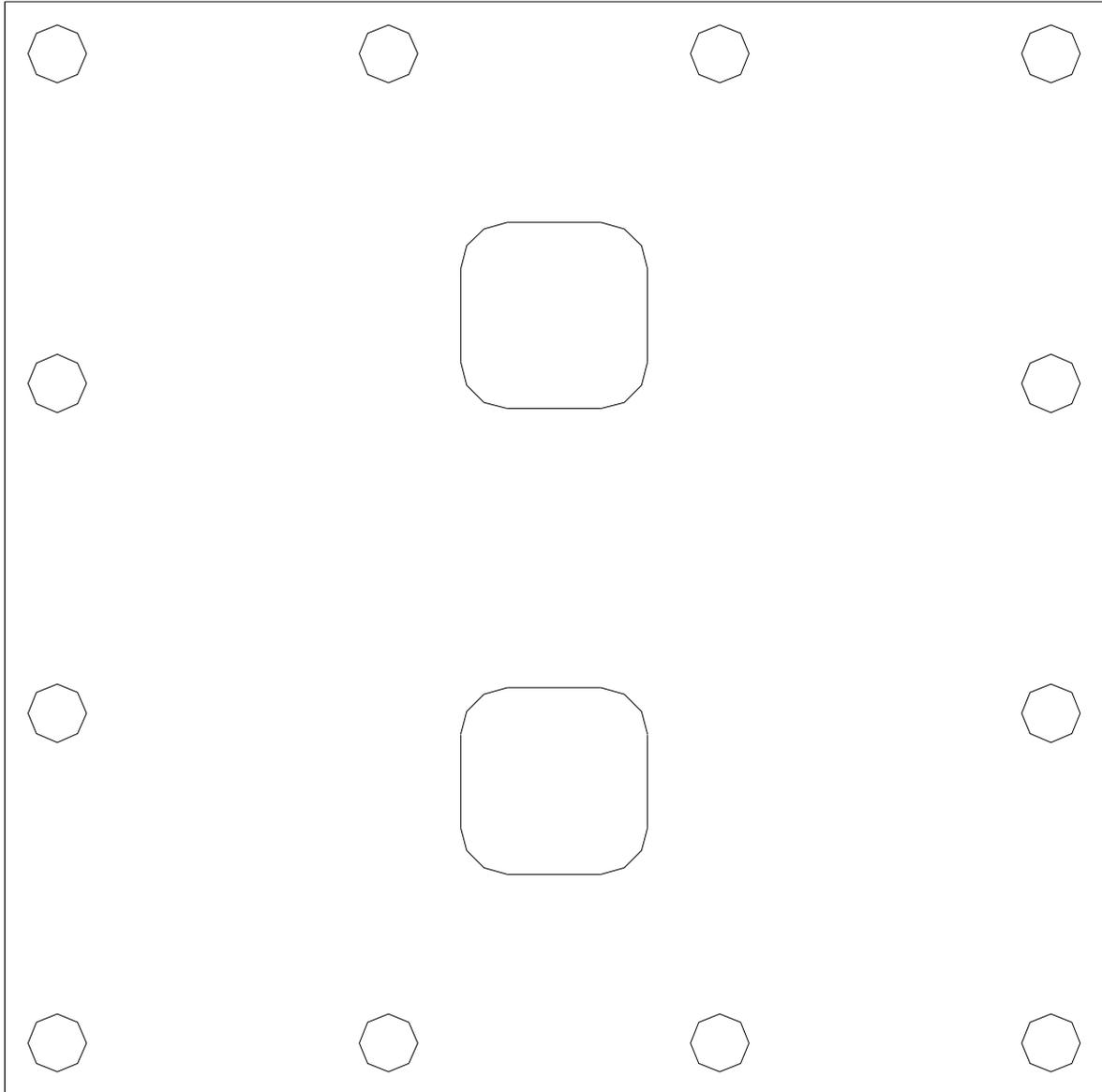
APPENDIX A

Drawings of custom machined parts for SRNL Pressurized Single Cell Electrolyzer



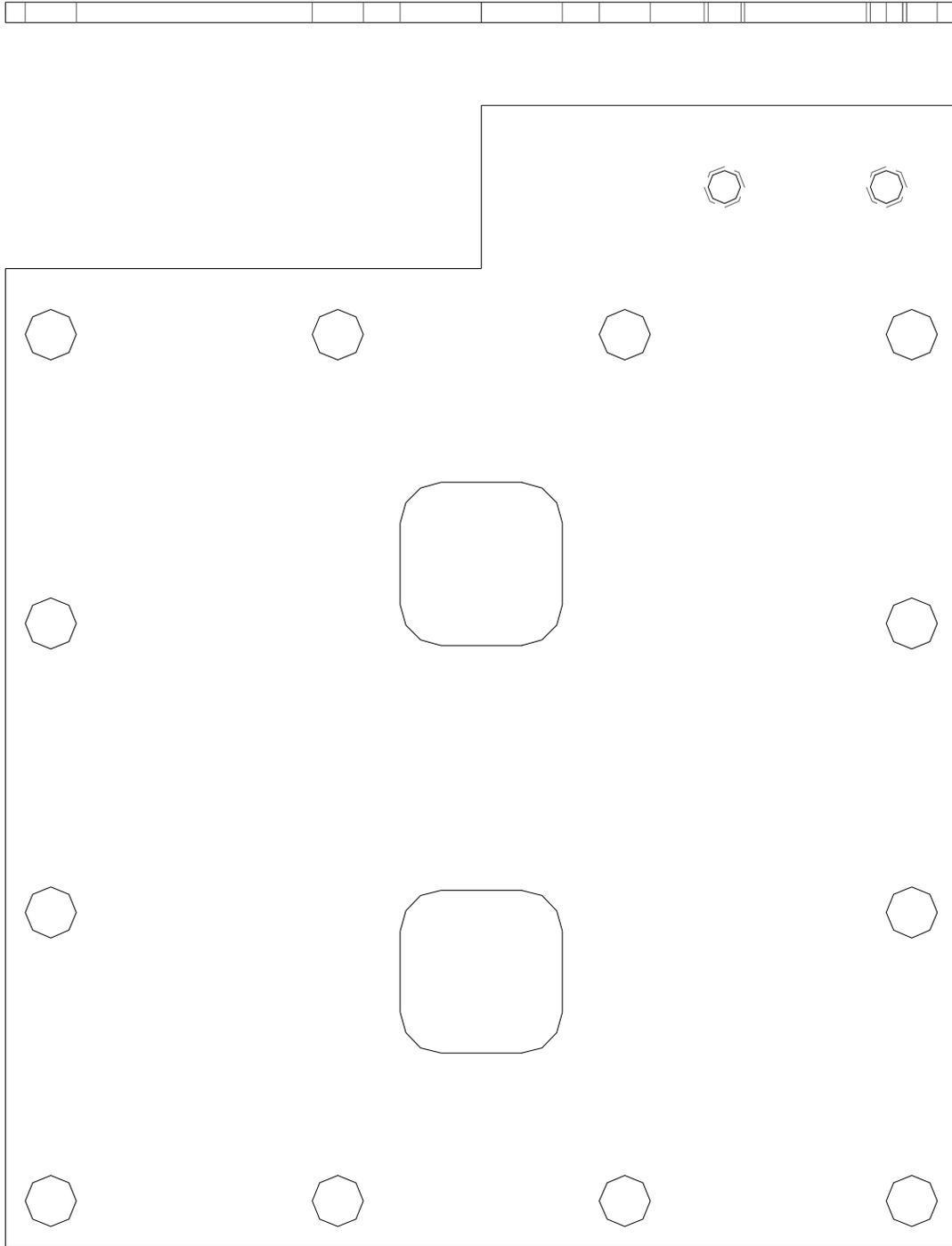
ITEM 1 PRESSURE PLATE
MTL: 3/4" THK 300 SERIES S/S

Figure 14 Pressure Supporting Plate Detail



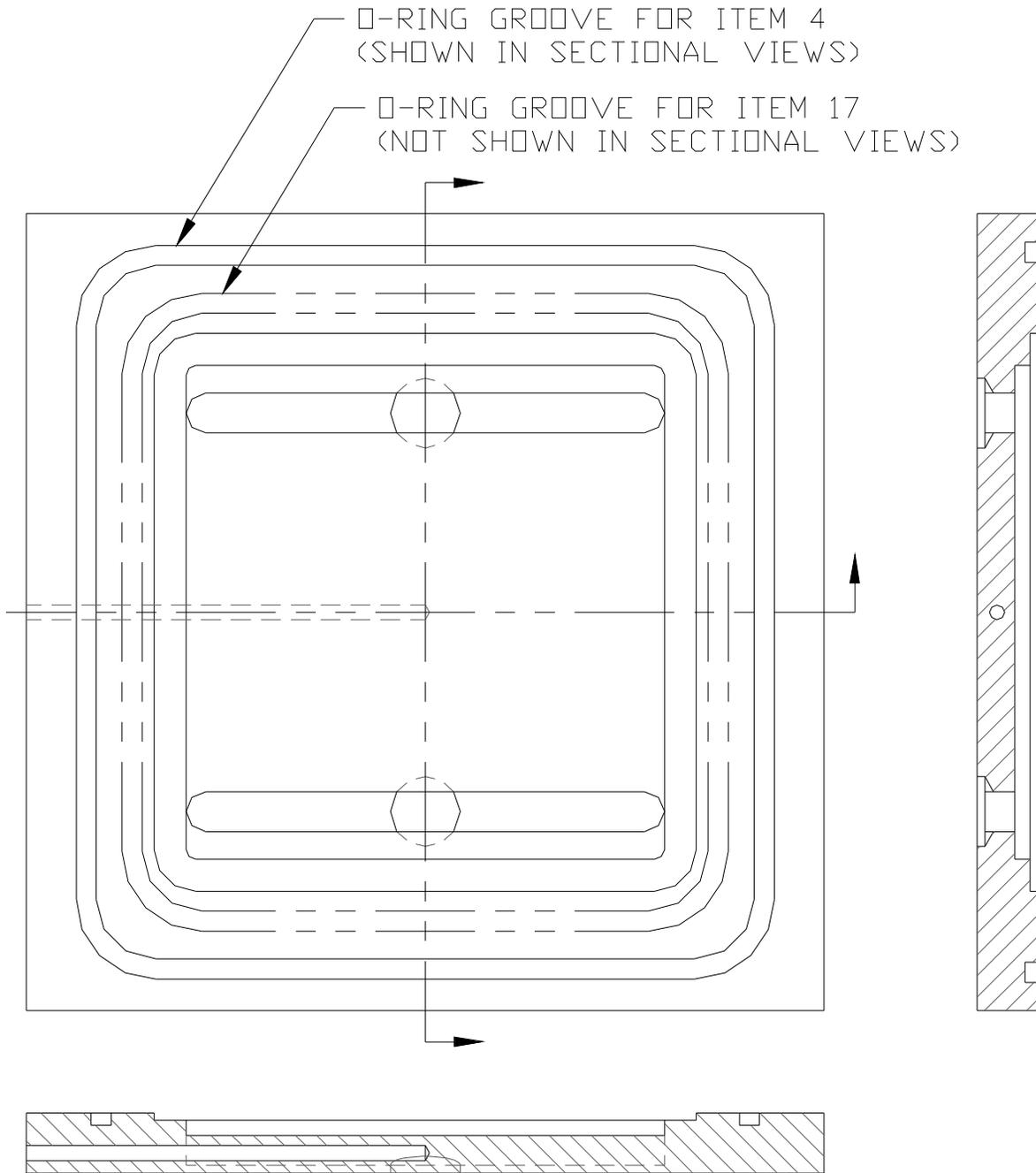
ITEM 2 INSULATOR
MTL: 0.063" THICK FIBERGLASS

Figure 15 Pressure Plate Insulator Detail



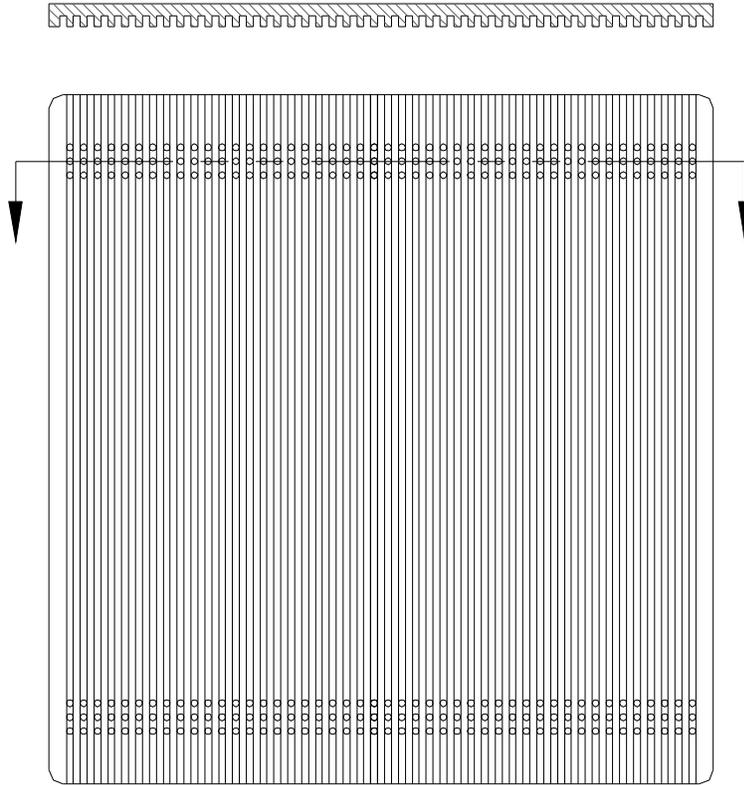
ITEM 3 ANODE SIDE TERMINAL PLATE (AS SHOWN)
ITEM 8 CATHODE SIDE TERMINAL PLATE (OPPOSITE HAND)
MTL: 1/8" THK COPPER

Figure 16 Terminal Plate Details

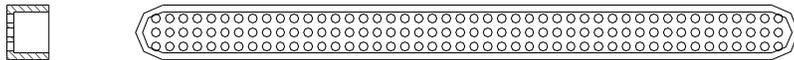


ITEM 4 ANODE SIDE GRAPHITE SEAL BLOCK
ITEM 17 CATHODE SIDE GRAPHITE SEAL BLOCK
MTL: 3/8" THICK SOLID GRAPHITE
NOTE: THE ANODE AND CATHODE SIDE BLOCKS ARE IDENTICAL
EXCEPT FOR O-RING GROOVES.

Figure 17 Graphite Seal Block Details

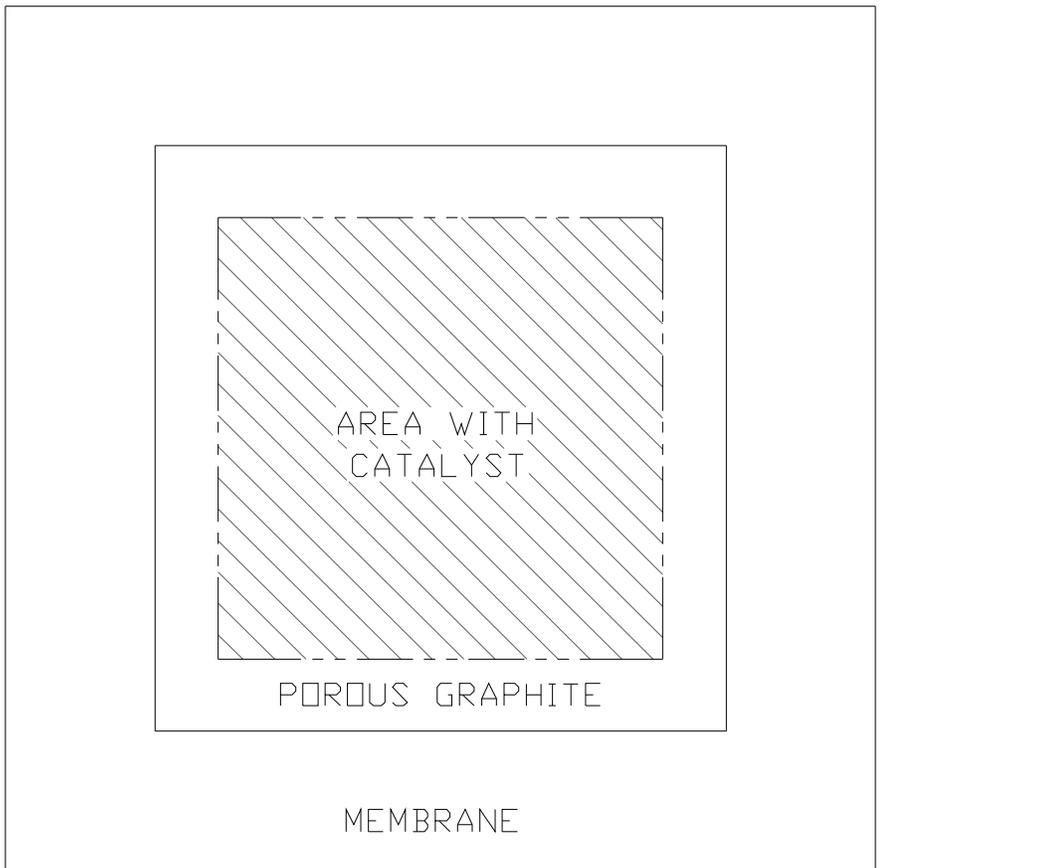


ITEM 6 MEA SUPPORT INSERT
MTL: 0.104" THK POROUS GRAPHITE

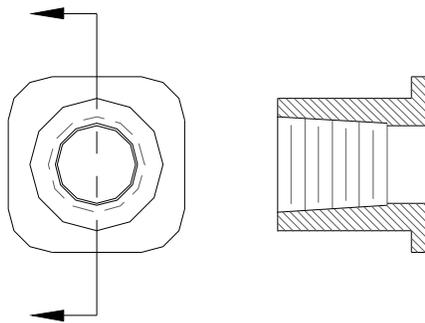


ITEM 5 FLOW DISTRIBUTOR
MTL: HASTELLOY B

Figure 18 MEA Support and Flow Distributor Details



ITEM 7 MEA ASSEMBLY



ITEM 9 FLOW CONNECTOR
MTL: PTFE FLUOROCARBON

Figure 19 MEA and Flow Connector Details