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Development of Components for Waste Management Systems Using Aerospace Technology

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DEVELOPMENT OF COMPONENTS FOR WASTE MANAGEMENT SYSTEMS USING AEROSPACE TECHNOLOGY

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Abstract

An aerospace fluid management technology called "platelets" has been applied to components that are critical to the economic operation of waste management systems. Platelet devices are made by diffusion bonding thin metal plates which have been etched with precise flow passage circuitry to control and meter fluid to desired locations. Supercritical water oxidation (SCWO) is a promising waste treatment technology for safe and environmentally acceptable destruction of hazardous wastes. Performance and economics of current SCWO systems are limited by severe salt deposition on and corrosion of the reactor walls. A platelet transpiring-wall reactor has been developed that provides a protective layer of water adjacent to the reactor walls which prevents salt deposition and corrosion. Plasma arc processing is being considered as a method for stabilizing mixed radioactive wastes. Plasma arc torch systems currently require frequent shutdown to replace failed electrodes and this increases operating costs. A platelet electrode design was developed that has more than 10 times the life of conventional electrodes. It has water cooling channels internal to the electrode wall and slots through the wall for injecting gas into the arc.

Introduction

Recently, a significant "Defense Conversion" activity has been underway at Aerojet. The focus of this work has been to identify, demonstrate, and develop products for non-defense markets that benefit from the technology developed for aerospace and defense programs in the past 53 years.

One area of technology which has been considered for several non-defense applications is platelet technology. Platelet technology has been developed over the past 30 years and applied to a variety of aerospace devices which require efficient fluid management. Examples are rocket engine injectors and combustion chambers. Platelet devices are made by diffusion bonding thin metal plates which have been etched with precise flow passages, and then stacked and bonded in a predetermined sequence to control and meter fluid to desired locations at precise flow rates. An overview of platelet technology is given in the next section. Additional information is available in the open literature[1,2].

To date, several potential non-defense applications for platelet technology have been evaluated and this activity is ongoing. Two successful applications in components that are critical to the economic operation of waste management systems have been developed. These applications are: (1) a supercritical water oxidation reactor, and (2) a plasma arc torch electrode. The successful transfer of platelet technology to these components is the subject of this paper.

Supercritical water oxidation is a promising treatment technology for safe and environmentally acceptable destruction of hazardous wastes[3]. Performance and economics of current systems are limited, however, by severe salt deposition on and corrosion of the reactor walls. A patented platelet transpiring wall reactor design has been developed that provides a protective layer of clean water along the reactor walls to prevent both salt deposition and corrosion[4,5].

Another Possible method of waste disposal is by plasma arc torch treatment[6]. In this process, the waste is vitrified and stabilized by torch heating, then stored in the ground. Plasma arc torch systems currently require frequent shutdown to replace failed electrodes. Increasing electrode life will reduce operating costs and increase worker safety, especially when radioactive wastes are being processed. A patented platelet plasma arc electrode has been developed that has more than 10* times the life of conventional electrodes[7]. This design has both water cooling channels internal to the electrode wall and slots for injecting argon or nitrogen (or other gases) into the plasma arc region of the electrode.

Platelet Technology Overview

Backrgound

Platelet technology can be used to create compact, nearly monolithic structures containing thousands of intricate, precisely located fluid passages. The platelet design concept was invented in 1964 for transpiration cooling of high pressure rocket engine combustion chambers[1] (Figure 1).

* The platelet plasma arc electrode was not tested to failure. Consequently, the 10 times factor may be significantly understated.

Subsequent aerospace applications include propellant injectors[8,9], convectively cooled combustion chambers[10], transpiration cooled forebodies for reentry vehicles[2], and high performance heat exchangers[11].

Fabrication Process

Platelet fluid management devices are created by bonding together thin metal sheets , called platelets, which contain chemically etched fluid passages. The basic fabrication process is illustrated on Figure 2. Prior to etching, the flow passage pattern is precisely located by the use of photographic negatives. After etching, the platelets are stacked in a predetermined sequence to form flow passages and wall geometries. Subsequent diffusion bonding of the platelets forms a structure with the desired internal fluid flow passages. This bonded structure can then be formed, welded, or machined to produce the final desired configuration.

Platelet devices have been fabricated from a wide variety of metals and their alloys. Almost any metal can be considered if it is available in foil stock, and if it can be etched and bonded. The bonding process is developed by application of metallurgical principles and experience. Once the proper bond parameters have been established, the physical properties of the bonded structure can be nearly the same as the parent material.

Design Flexibility

Platelet technology provides the designer with a very flexible design tool for fluid circuits because virtually any idea which can be drawn on paper can be fabricated from platelets. It is particularly well suited for fluid management devices where a two or three dimensional fluid passage network is desired or where a fluid stream must be divided into many small streams in predictable proportions. The flow passages can be varied from platelet to platelet within the structure, thereby creating two and three dimensional fluid passages impossible to obtain by conventional manufacturing.

This design flexibility can translate into significant efficiency and weight improvements. It can, of course, also, lead to analysis challenges since the complex circuits which can be fabricated are sometimes difficult to analyze. In the more difficult cases, flow test data are required to finalize a design. Very often the cost impact of a flow test iteration can be minimized by flow testing a clamped platelet stack, before the bonding and final machining work is done.

There is also considerable flexibility in material selection for platelet devices, since there are numerous metals available for use as platelet stock. This means that a designer can pick the best material for the application at hand. In cases where no one metal has the desired properties, laminates of two or more metals can be used.

Defense Conversion Process

The general approach for developing products for non-defense markets using aerospace technology is diagrammed on Figure 3. The first step is to identify a potential product. In the case of platelet products, product development ideas are generated in two ways: (1) an idea comes from within Aerojet as a result of brainstorming, exposure to a new fluid management problem, or while responding to a new business opportunity; (2) an idea is generated by someone outside of Aerojet for a product area they understand very well after they have been briefed on the capabilities of platelet technology.

In order to justify the cost of proceeding with work on an idea, three important questions must be asked, and all must be answered in the affirmative. They are: Is the product real? Can we win? Is it worth it? Product reality, or technical capability, is rarely a problem with platelets. A "yes" answer to the "win and worth" questions means that the desired product can be produced at an acceptable market price, and that a significantly large potential market exists. The "win and worth" questions are always difficult to evaluate and will require some analysis – negative answers are common. Teaming arrangements are often considered at this point in order to establish a strong business position.

Next it is necessary to procure funding for a product demonstration, and then demonstrate that the product performs the desired function. Three funding sources have been utilized: company discretionary resources, government programs, and private capital. The demonstration can range from a simple fabrication experiment to a sophisticated test program depending on the product being considered.

If the results of the demonstration are positive, it is then appropriate to reaffirm that the market potential is significant and that the cost of the product is still consistent with the perceived market price. This picture may have changed during the demonstration phase.

Finally, funds to develop, produce, and market the new product must be obtained. Three potential funding sources exist as mentioned above. Significant funding may be required depending on the complexity of the design.

As indicated in Figure 3, there are five critical steps between the identification of an idea and the actual development into a product. At each of these steps, one of the possible outcomes is to stop! With this in mind it is easy to understand why the vast majority of ideas do not become products.

Supercritical Water Oxidation Reactor Application

Background

In a supercritical water oxidation (SCWO) reactor, supercritical water is a reaction medium in which waste and oxidizer are both miscible. Testing has shown that the

SCWO process is safe, clean, and an efficient process for destruction of a variety of wastes such as pyrotechnic colored smoke, dye compositions, explosives, propellants, and miscellaneous petroleum based materials[3]. The process is potentially applicable to a wide range of military, industrial, and municipal wastes.

Testing at Sandia Laboratories in Livermore, California, has successfully demonstrated destruction of pyrotechnic colored smoke and dyes generated during the demilitarization of conventional munitions. A 99.99% destruction efficiency was obtained for a 15 second residence time at 550°C and 3800 psi[12]. These tests also showed that SCWO processing of the smokes and dyes produces sticky salts that plug the reactor and acids that eventually corrodes the reactor walls. It was found that a 9/16 inch diameter reactor can plug in about 10 minutes[13].

Platelet Design

A platelet transpiration reactor wall was identified as a potential solution to the salt plugging and corrosion problems by Aerojet, Foster-Wheeler, and Sandia in early 1993. Subsequent hardware development and testing with Sandia contract funds and Aerojet IR&D funds demonstrated proof of concept using the simplified flat platelet device shown on Figure 4. This design was fabricated and flow tested at low pressure in an acid solution by Aerojet in FY93 and at supercritical conditions in a salt solution at Sandia in FY94.

The engineering demonstration of a tubular transpiring wall reactor which incorporates the design features of the flat platelet was then undertaken on a U.S.Army/Sandia contract. This configuration is desireable for SCWO waste destruction plants. A schematic diagram of a tubular design is shown on Figure 5. Water is injected uniformly around the ID of a platelet liner and a distribution manifold is positioned on the OD of the liner. The pressure vessel forms the outer manifold wall. The injected water forms a protective layer along the reactor wall and forces high concentrations of salt or corrosive fluids, and high temperature fluids (produced by waste oxidation) away from the reactor wall.

The bench scale platelet SCWO reactor shown in Figures 6 and 7 was designed and fabricated by Aerojet to Foster-Wheeler requirements and tested by Sandia in early 1995. For the bench scale test system, the flexibility of platelet technology was utilized extensively. Hot water for heating simulated waste to a supercritical temperature was injected at the forward end of the reactor, and cold water for cooling it below critical was injected at the downstream end (see Figure 6). The region in between was the transpiration or "wall protected" region which was evaluated for its ability to resist salt deposition at supercritical conditions. The total length of the reactor was 36 inches and the ID was 1.1 inches.

Demonstration Testing

The demonstration testing of the bench scale reactor by Sandia showed that wall transpiration provides significant protection against salt deposition in a SCWO reactor. A series of tests were conducted at 4000 psi nominal reactor pressure and at simulated waste temperatures in the 400 to 450°C range. Salt solutions of 1% to 3% concentration were injected upstream of the reactor inlet. With wall transpiration flow, salt deposits in the 0.010inch to 0.020 inch thickness range were observed in the wall protected region of the reactor. Much thicker salt deposits, approximately 1/2 thick, were observed without wall transpiration.

The only significant platelet design issue encountered in transfering aerospace platelet technology to the bench scale reactor was that the transpiration fluid mass flux is an order of magnitude less than the aerospace experience base (see Table 1). New flow manifolding concepts were developed for the lower flow condition and uniform injection was verified by cold flow testing and the bench scale tests.

Table 1. Transpiration Wall Mass Flux Requirements

Application	Approximate Mass Flux, lb/sec in.^{2}
Transpiration Cooled Thrust Chamber	0.01 - 0.1
Transpiration Cooled Forebody	0.002 - 0.02
SCWO Bench Scale Reactor	0.0002

Pilot Plant

Based on the positive results from the bench scale tests, design of a pilot plant was authorized by the U.S. Army. Foster-Wheeler and Aerojet are now designing a SCWO pilot plant reactor that will include a platelet transpiration liner. The reactor will process 80 lb of waste per hour.

The transpiration water flowing through the pilot plant wall will perform a thermal management function as well as a wall protection function. After ejection from the reactor wall, it will cool the waste stream as it oxidizes exothermically. This will prevent excessive temperatures which could produce NOX emissions or structural damage to the reactor.

Commercial Development

Commercial development of platelet SCWO reactors will depend on the performance of the pilot plant reactor, results from other planned test programs, and a future reassessment of the market.

Plasma Arc Electrode Application

Background

The U.S. Department of Energy (DOE) Morgantown Energy Technology Center is currently developing environmentally sound technologies to process, stabilize, and store mixed radioactive waste. Mixed radioactive waste contains both organic and inorganic components, plus radioactive elements. An example of mixed radioactive waste is the contaminated dirt which exists at some DOE sites where nuclear material was manufactured. One of the technologies being considered is plasma processing, a continuous feed process in which an electric arc is passed between an electrode and the waste material[14]. Some of the waste constituents off gas while others become molten slag which cools to a glassy black rock resembling obsidian that has a low volume and low leach rate.

An operational problem which has been encountered is rapid failure of the electrodes caused by localized surface erosion where the arc jumps from the electrode to a work piece or to another electrode. This is due to the very high local heat fluxes which can occur. Some heat flux estimates are as high as 1500 Btu/in.^{2}-sec. Plasma arc mixed waste systems would be more economically attractive to potential users if electrode life could be increased.

Platelet Design

Design concepts for a long life platelet plasma torch electrode were developed at Aerojet in 1993. They were proposed to the U.S. Department of Energy (DOE) in Morgantown, VA, and the DOE subsequently sponsored the program of work performed by Aerojet[6]. The objective of this project was to increase electrode life without loss of electrical power efficiency or arc stability.

In order to vigorously attack the electrode life problem, Aerojet devised a highly flexible platelet electrode design concept which could be used to investigate several concepts for improving electrode life. This flexible but relatively expensive design approach was chosen because, prior to testing, the mechanism for increasing life was not known.

Three specific design approaches for extending life were evaluated with the flexible platelet electrode design concept: (1) improved water cooling, (2) improved water cooling plus an iridium sleeve on the arc attachment surface,and (3) improved water cooling plus swirl gas injection.

As discussed below, a significant life improvement was obtained with the design that included gas injection. A cross section of it is shown on Figure 8. The electrode was fabricated by diffusion bonding 298 zirconium copper platelets stacked perpendicular to the axis. Coolant water flows in forty eight 0.017 x 0.042 inch internal cooling channels and provides increased cooling effectiveness compared to a reference design with back side water cooling that is currently being used The reference design is low cost but has a short operating life. The increased cooling effectiveness in the platelet design is due to increased heat transfer area and reduced wall thickness (0.060 inch) between the coolant water and the arc attachment surface. Gas is injected through 120 slots positioned at ten axial stations located 1/8 inch apart. Each station has six pairs of 0.004 x0.010 inch injection slots spaced 60 degrees apart circumferentially.

Demonstration Testing

A Retech Inc. RP-75T torch was selected as the electrode test bed. This plasma torch, shown in Figure 9, operates at a power level of 90 KW and uses a hollow type, backside water cooled electrode[15]. Demonstration testing was done at the Retech facility in Ukiah, California. The general procedure followed was to test the existing reference electrodes first to establish a life data base for the selected torch operating condition, then test the platelet electrodes.

A significant life improvement was obtained with the platelet electrode design that included both improved water cooling and gas injection. Table 2 summarizes the life test results. Two platelet electrodes with gas injection were tested. The first one, AJ2-1, was tested with argon gas injection for 66 hours, the second one was tested with nitrogen gas injection for 26 hours. Neither of these platelet electrodes failed during normal operation although the nitrogen unit failed when the nitrogen supply was inadvertently depleted. By comparison, six water cooled reference electrodes failed after 1.5 to 8 hours of operation. Post-test photographs are shown on Figure 10.

Table 2. Summary of Electrode Life Test Results

Electrode Type	Electrode ID	Life
Reference Electrode	R-1	87 minutes
	R-2	4 hours, 24 minutes
	R-3	8 hours
	R-4	4 hours, 39 minutes
	R-5	5 hours, 37 minutes
	R-6	82 minutes
Platelet Electrode With Gas Injection	AJ2-1	>66 hours (argon injection)
	AJ2-2	26 hours (nitrogen injection)

The life improvement obtained with the platelet electrodes is believed to be caused by the effect of gas injection on the rotation of the arc foot. The swirl gas injection apparently decreased the time any point on the wall was exposed to the high heat flux of the arc. Since life increased for both gases, the life improvement does not appear to be related to the specific gas injected.

Future Work

Subsequent to this very successful demonstration testing of the platelet electrode, a patented lower cost platelet electrode design has been identified[7] which incorporates the gas injection features of the platelet electrode design shown on Figure 9. Development and marketing of this low cost unit is planned for the future.

Summary and Conclusions

Aerojet has successfully transitioned a space derived fluid management technology, platelets, to two commercial waste management products, namely, supercritical water oxidation reactors and plasma arc electrodes. Platelet technology was invented 30 years ago for space applications where high performance and extremely lightweight devices are required. These same platelet attributes now find great utility in the commercial world. The major challenges for wide spread acceptance and use of platelet technology is the significant reduction in development and unit costs. Aerojet envisions many more commercial applications such as very fine filters, injectors for the chemical and oil industries, compact heat exchangers, etc.

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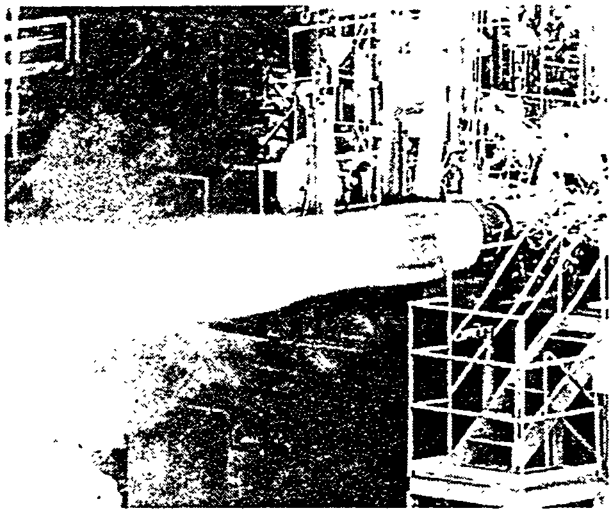

Figure 1. Test Firing of a Rocket Engine With a Platelet Transpiration Cooled Thrust Chamber (Mid 1960's)

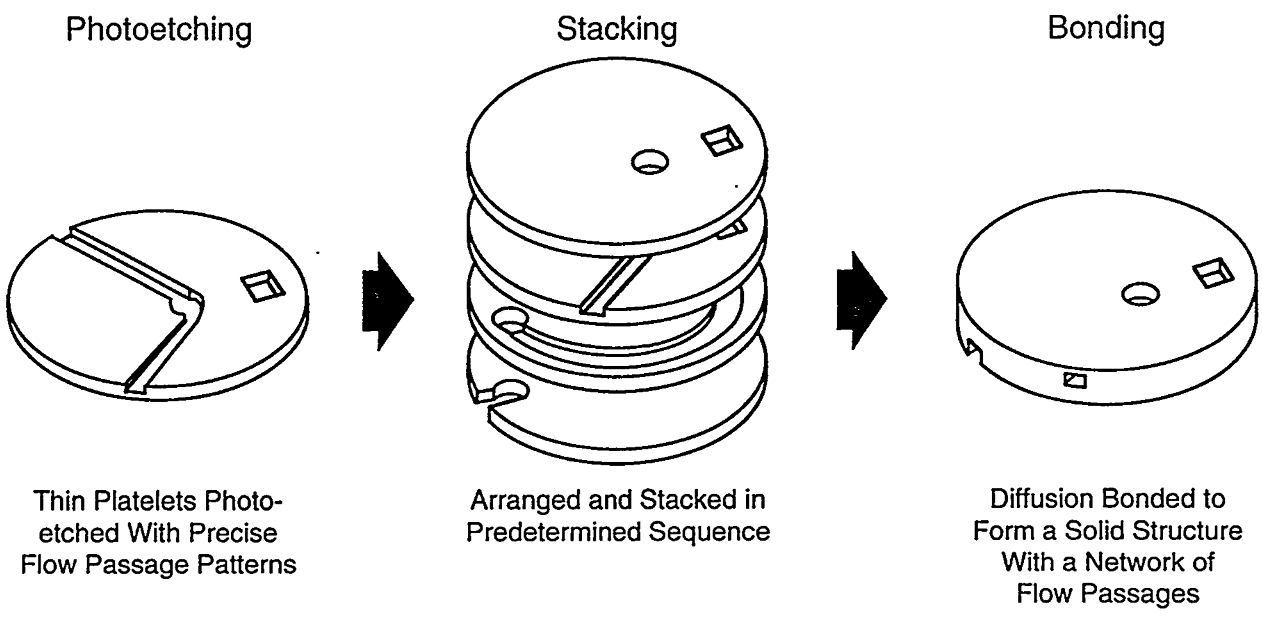

Figure 2. The Platelet Fabrication Process

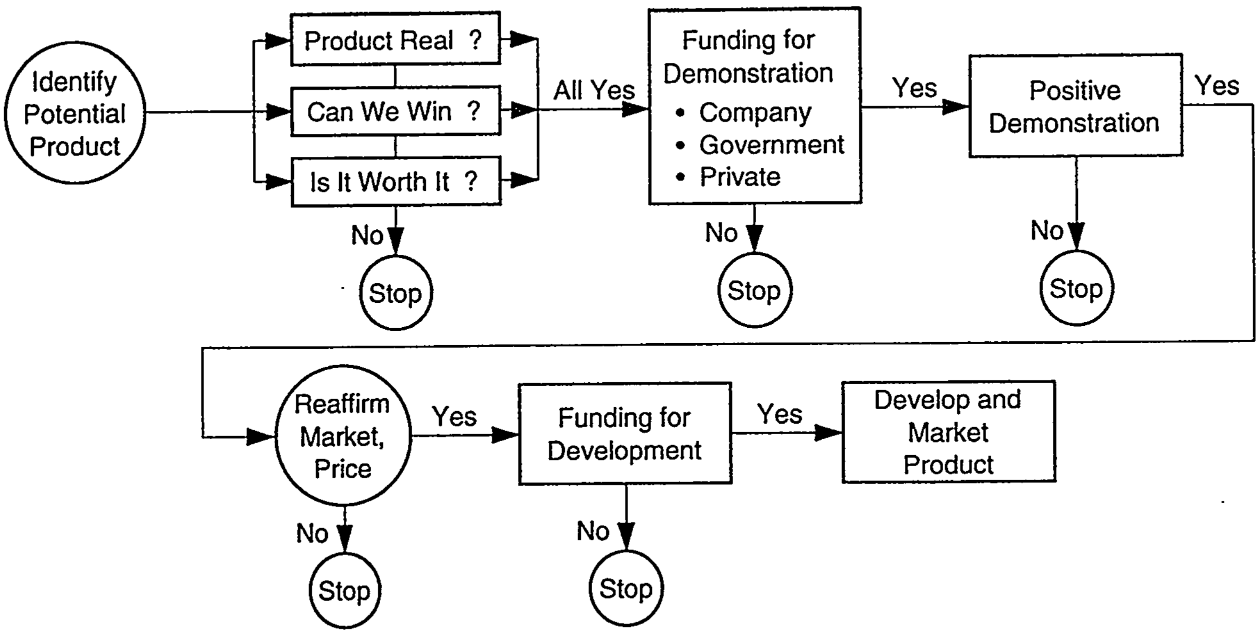

Figure 3. Idealized Defense Conversion Road Map

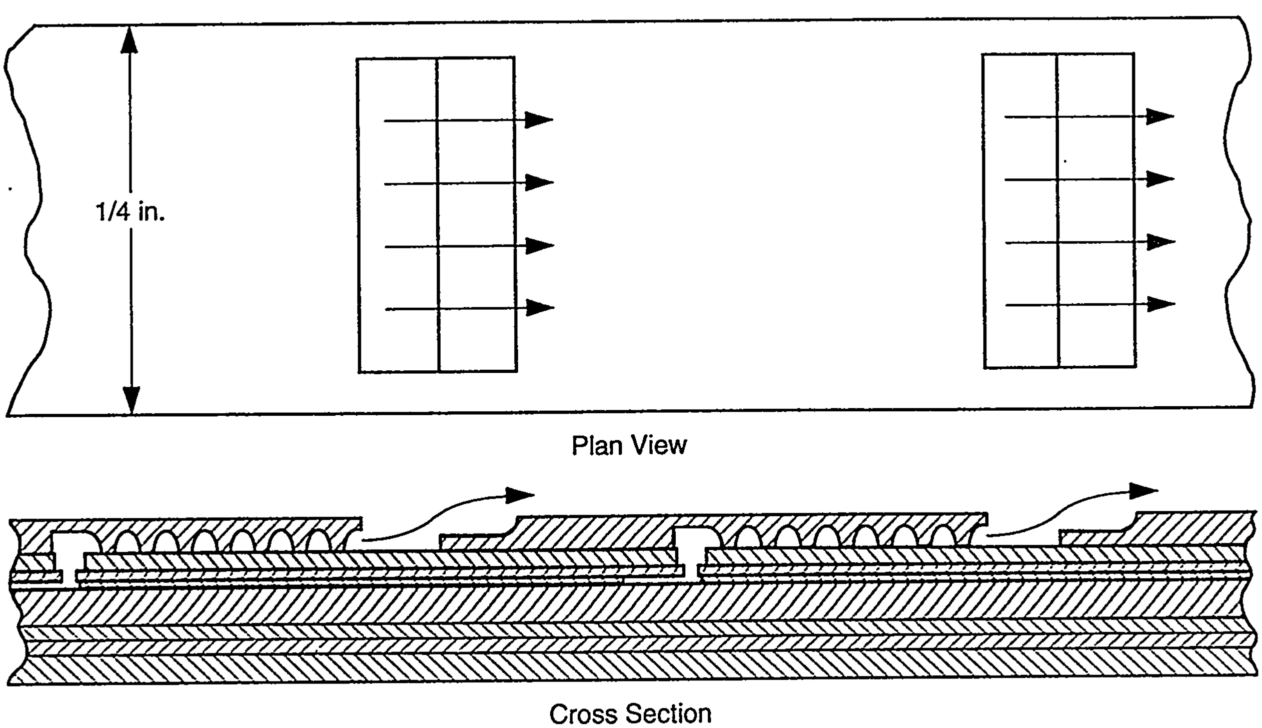

Figure 4. Flat Platelet Device Used to Demonstrate Transpired SCWO Reactor Wall Concept

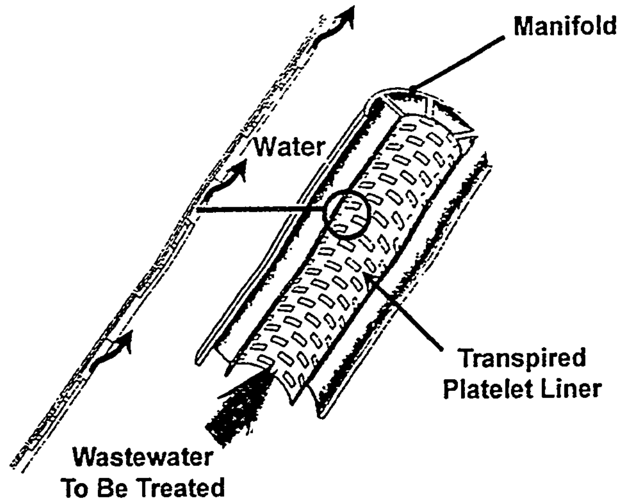

Figure 5. Tubular SCWO Reactor With Transpired Platelet Liner

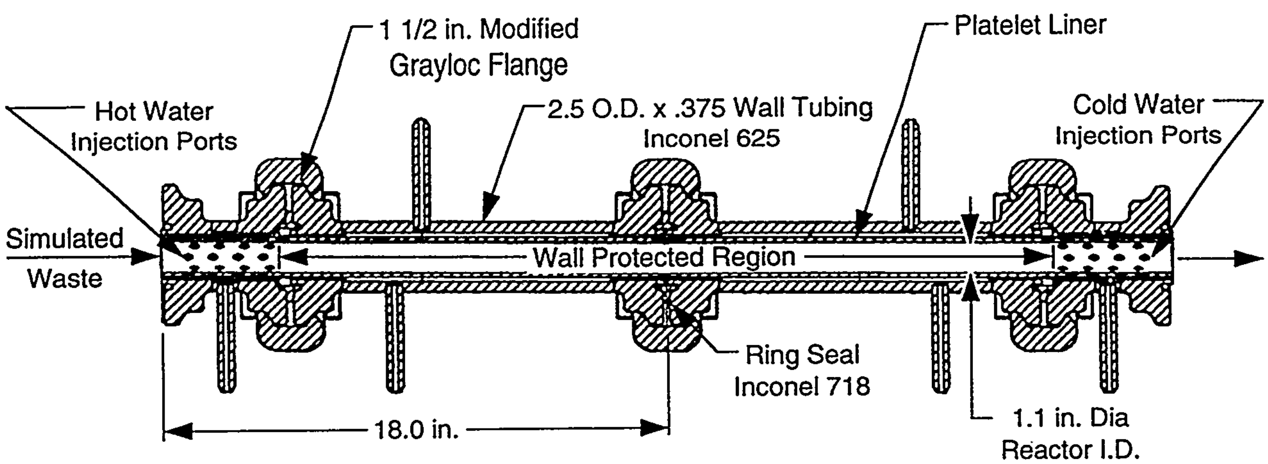

Figure 6. The Bench Scale Is a Modular Assembly

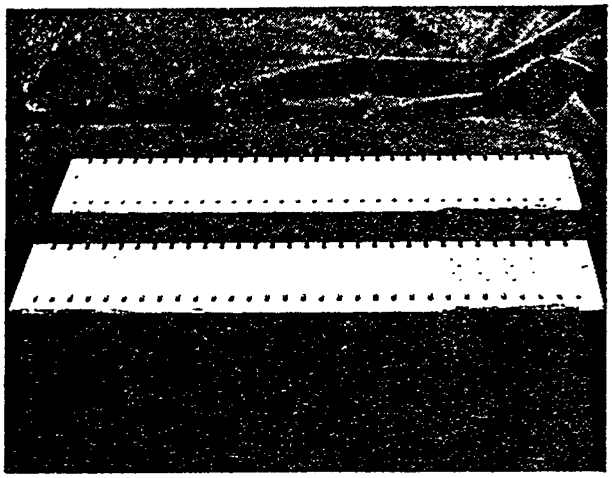

Figure 7a. Bonded Platelet Transpiration Liners

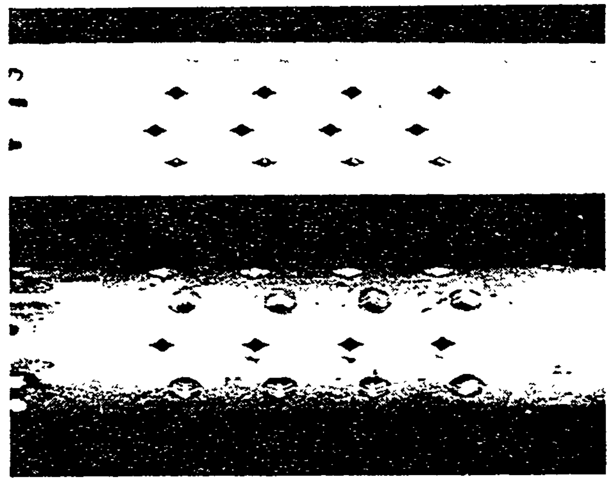

Figure 7b. Formed Platelet Transpiration Liners

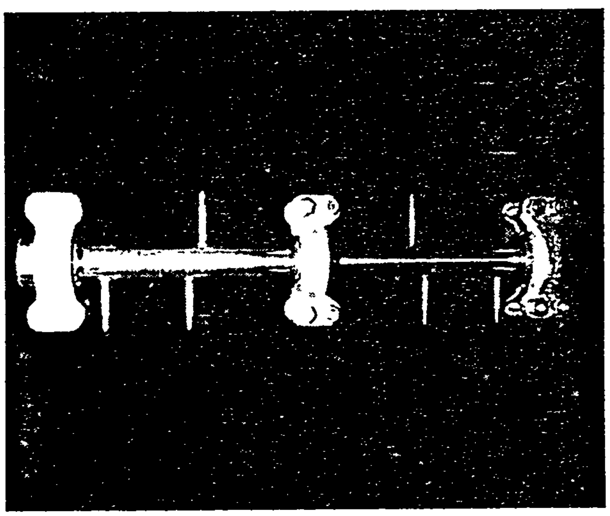

Figure 7c. Completed Bench Scale Reactor

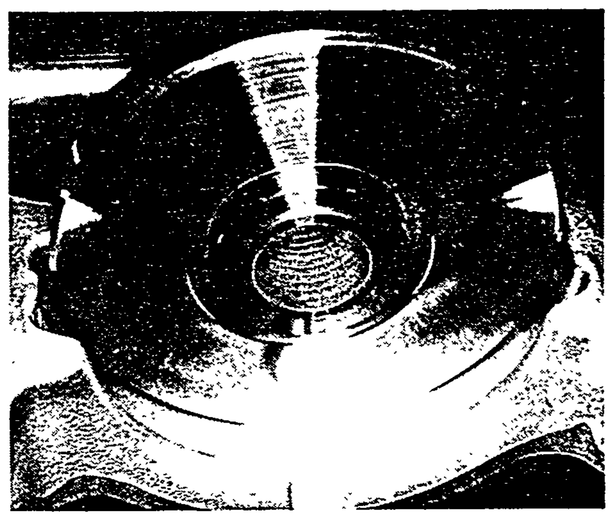

Figure 7d. End View of Reactor Showing Transpiration Slots on Reactor I.D.

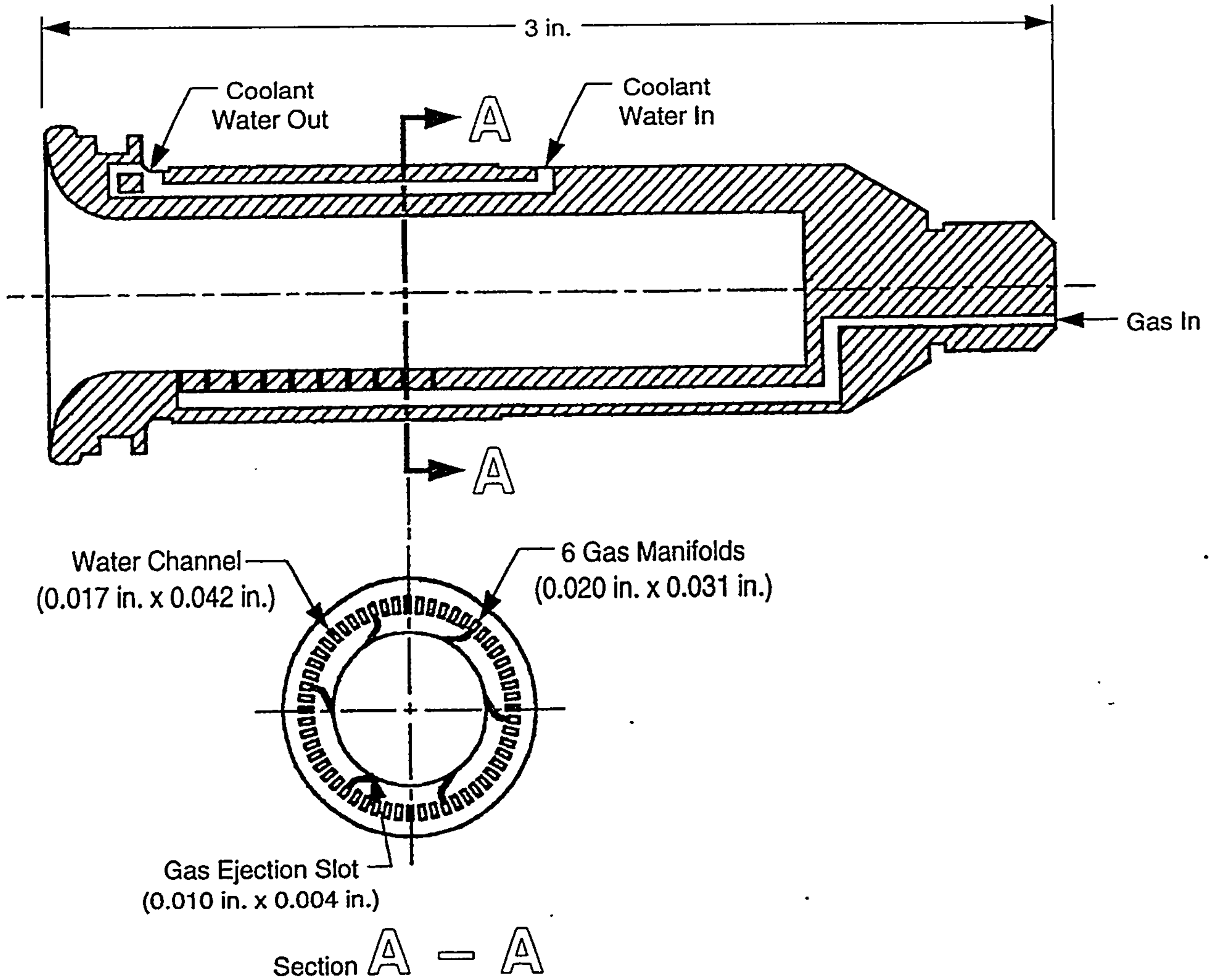

Figure 8. Cross Section of Platelet Electrode Design With Gas Injection

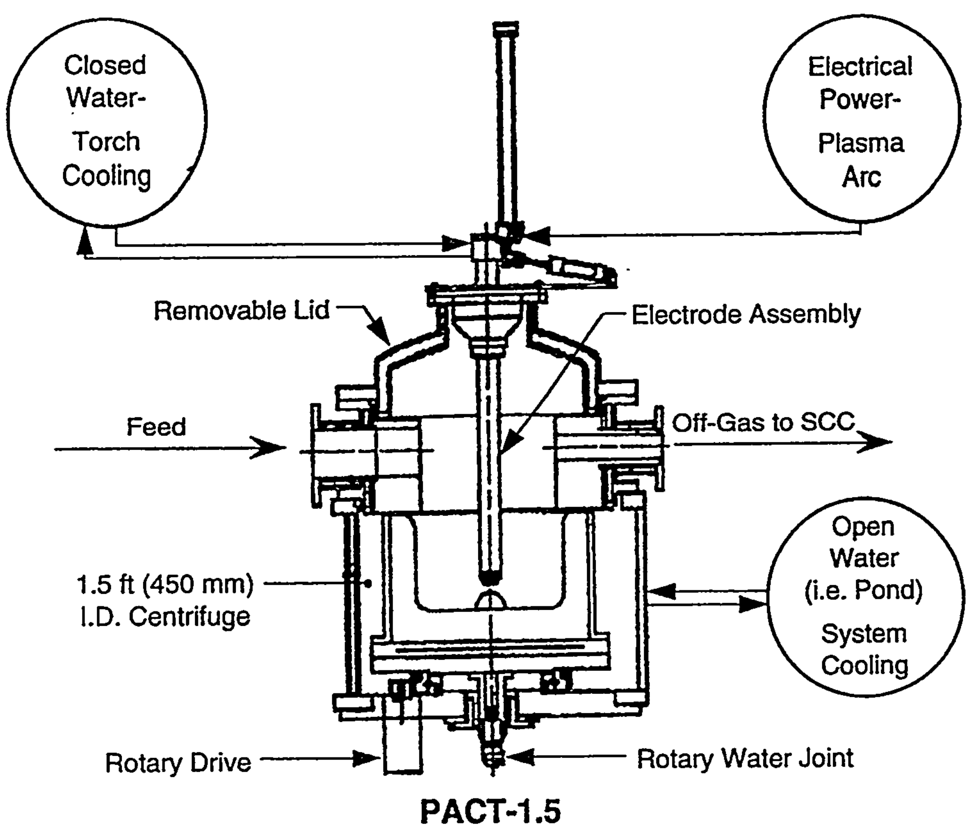

Figure 9. Retech RP-75T Plasma Torch

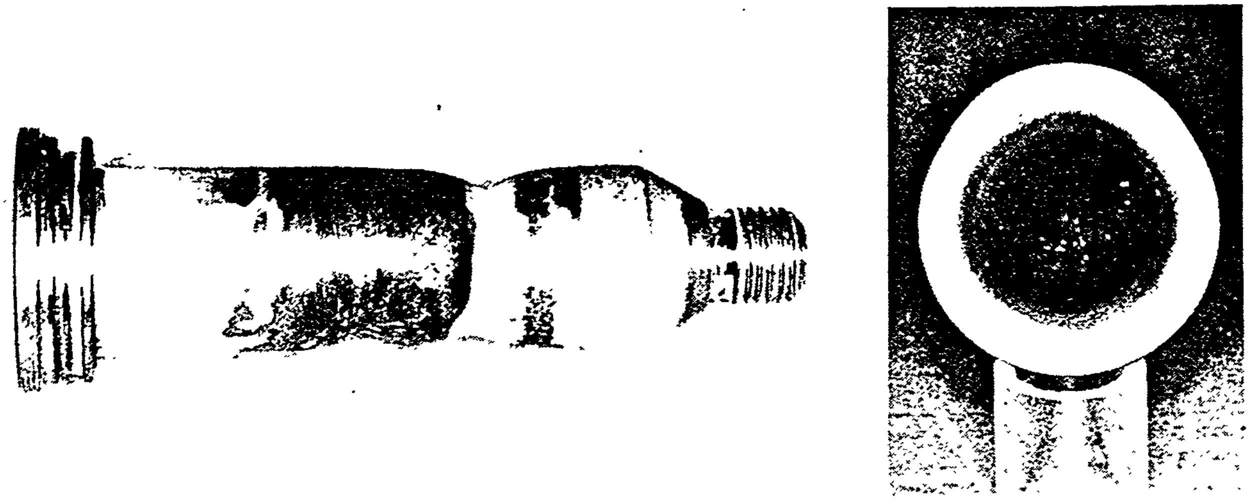

Figure 10A. Reference Electrode R-1, Post-test (Failed after 87 minutes)

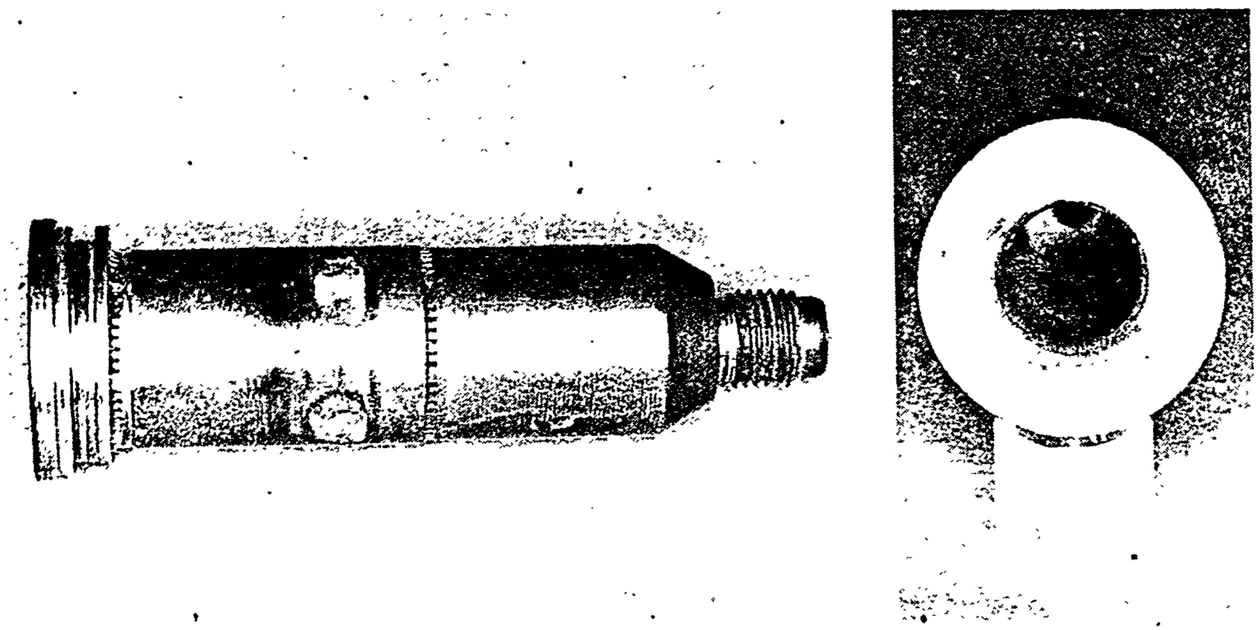

Figure 10B. Platelet Electrode AJ2-1, Post-test (No failure after 66 hours of Operation with Argon Gas Injection)