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Prepared For:

U. S. Department of Energy
Division of Biomedical and Environmental Programs

Contract: EE-77-S-02-4256

and

U. S. Department of Interior
Bureau of Land Management

Interagency Agreement: IA 7-20

WHOI-78-94

FINAL REPORT

A RECIRCULATING SEA WATER BENTHIC CHAMBER
FOR THE STUDY OF THE BIOGEOCHEMISTRY OF PETROLEUM
COMPONENTS AT THE SEDIMENT WATER INTERFACE

by

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December 1978

TECHNICAL REPORT

*Prepared for the U.S. Energy Research and
Development Administration under Contract
EE-77-S-02-4256.*

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A Recirculating Sea Water Benthic Chamber

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Abstract

The experimental benthic chamber was designed to conduct both laboratory and in situ investigations on the transport and degradation of petroleum type hydrocarbons at the sediment water interface, and to investigate the sediment/water/organism interactions. In its basic form, it consists of a rectangular flume constructed of stainless steel tube, a windowed observation chamber, a variable velocity pumping system and its associated controls, battery packs, and interconnecting cables. The base of the observation chamber is a removable assembly, allowing the user to select either a closed rectangular box for laboratory use, or a mud grab bottom sampler configuration for in situ evaluation.

For in situ use, the mud grab doors are opened, the device lowered until it contacts and settles into the bottom. The side walls of the mud grab, its jaws, and the observation chamber walls effectively seal the assembly into a closed recirculating sea water system that uses the bottom sediment as the controlled sample. Hydrocarbon, oxygen, or other materials may be used to spike the recirculating sea water or bottom sediment. Several instrumentation ports have been provided to allow monitoring of the internal system chemistry.

The self-contained power pack is pressure compensated with gaseous carbon dioxide, providing a non-explosive atmosphere within the battery box compartment as well as the pump drive motor package. A five day, on-the-bottom, operational test indicated that the battery system would provide sufficient reserve power to operate the device for an extrapolated minimum of 10 days without serious degradation of the internal water flow within the system.

On completion of the bottom program, the mud grab doors are pneumatically closed, retaining the sea water and sediment sample as a complete ecological test system that can be returned to the surface for additional evaluation.

Acknowledgements

The development of the recirculating sea water benthic chamber was made possible by the U.S. Energy Research and Development Administration under contract EE-77-S-02-4256.

Special thanks are also extended to the principal investigators, Drs. John W. Farrington, John M. Teal, and Mr. Bruce W. Tripp for their design comments and suggestions throughout the conceptual phase, fabrication, and test, as well as their most helpful participation during the in situ evaluation experiment.

Recognition and appreciation are also in order for the various sections within the Woods Hole Oceanographic Institution, especially those who provided expertise and considerable patience in the areas of welding, machine shop fabrication, mechanical assembly, and final test of the device.

Specific thanks are given to Cindy Moor, Betsy Pratt, Jeff Zwinakis, and Frank Medeiros of the Graphic Arts Department for the numerous line drawings, photographs, and artist's concepts used throughout the report.

Special appreciation is also extended to Ms. Susan Smith for her patience and expertise in assembling and typing the data contained in this publication, and to Mr. Moe Moniz of the Purchasing Department for his untiring efforts in obtaining a wide variety of components on short notice.

1.0 Discussion of the Problem and General Approach

This research effort was performed to design, construct, and demonstrate a system that will provide science personnel with the means to study fossil fuel contaminated sediments and their effect on organisms living in contact with these oiled sediments.

The report will cover in detail the preliminary design concepts, the proto-type design, construction, weight, deployment and recovery characteristics, and will include a discussion on design improvements based on experience obtained during laboratory and sea trials.

The device is designed for operation either in the laboratory or, through the use of an integral pre-packaged support system, as a self-sustaining investigative device that can be deployed in situ for periods up to 10 days. It is capable of operating at any depth from the surface to 40 meters.

2.0 Primary Design Objectives

The following design objectives were considered as the primary goals to be met by the operational prototype.

The experimental system is an elongated toroid with a specimen observation chamber in one leg of the run. The specimen chamber provides glass viewing ports and has provisions for the attachment of a laboratory sediment box or an in situ mud grab assembly. The enclosed sediment sample is 3700 square cm, with a sediment depth of 25 cm.

The sea water above the sediment is 25 cm deep, with the capability of being recirculated within the system at a rate that can be varied between stagnation and 10 cm/sec. A sediment trap for the retention of coarse particles, fecal pellets, and fine particles that are re-

suspended in the water column by organisms, can be placed down-stream of the observation chamber. Figure 1 is an artist's concept of the device.

Construction materials that are in direct contact with the sediment and/or recirculating sea water are glass and stainless steel. Sealing gaskets are teflon or silicone material, designed and sized to expose the minimum surface area to the system media. Materials containing hydrocarbons or heavy metals are not used where they could possibly infiltrate the system as a result of seal failure.

The recirculating pump, bearings, and seals are free of contaminating materials that could rub and flake off into the system. The drive motor is a separate assembly located within the recirculating system. The power source is self-contained and attached to the apparatus, and is capable of providing sufficient stored energy to operate the recirculating pump for a minimum of 10 days.

The recirculating sea water system is designed so that, with a minimum of effort, it can be converted for use within the laboratory or in situ bottom programs that can be monitored through the use of divers equipped with scuba apparatus.

Sufficient sampling ports, as well as syringe septums for spiking the system, are available for use by the science team. Temperature and oxygen probe entries are provided, and through the use of extension leads, read-outs can be obtained by surface instrumentation.

3.0 Design Concepts and Construction Details

In addition to the design of the stainless steel sea water benthic chamber, a secondary effort was initiated to investigate acceptable

Figure 1. Artist's Concept of Basic System

methods for the fabrication of an all-glass system. As construction details are discussed, it will become clear that some portions of the existing system could have been simplified. Many of the construction features, however, were directed toward obtaining practical experience in devising assembly methods that could also be used with a more fragile device.

3.1 Support Frame

Figure 2 illustrates the basic support frame constructed for the system. As shown in the photograph, it is a rectangular structure fabricated from 3/16" wall by 1 1/2" OD aluminum pipe. The interconnect fittings are standard scaffolding or fence rail assemblies that are available in numerous sizes and configurations. The frame is lightweight, has a reasonably high strength factor, and is fairly rigid, even in the rectangular form shown in the photograph. The fittings are attached with locking set screws, and the pipe can be cut to size with a common hack saw. Special machining is not required to assemble a framework of this type.

Modifications or additions to the system structure are relatively easy, making it an ideal method of assembling a wide variety of configurations. If additional rigidity is required, several cross members may be positioned to form a triangular structure that will improve the stability of the frame. In this case, however, the overall rigidity and strength of the welded stainless steel pipe and specimen chamber formed a sufficiently strong assembly such that the frame did not require additional braces.

The PVC (polyvinyl chloride) straps used to "hang" the stainless steel recirculating system and specimen chamber from the frame provide several important design factors. (1) They isolate the stainless steel pipe and chamber from direct contact with the aluminum frame, reducing galvanic action when the system is immersed in sea water. (2) By virtue of their inherent

Figure 2. System Support Structure

flexibility and single point bolt attachment, they provide a considerable measure of strain relief to the system, while still retaining the pipes, chamber, and especially the bolted flanges, in proper alignment. In the system illustrated, several sections of the flanged pipe were removed and modified to provide additional instrumentation ports. Disassembly, reassembly, flange alignment, and tightening of the bolts were all accomplished without applying undue stress to any of the components, verifying the alignment efficiency of the mounting method.

The system illustrated in Figure 2 is 3 meters in length, 1.9 meters wide, and 1.3 meters high. The mounting frame and recirculating system, less the power supply on the upper rack, weighs 588 kg.

3.2 Specimen Observation Chamber

Figure 3 illustrates the construction features of the stainless steel observation chamber. The inside dimension of the upper rectangular section is 60 cm x 60 cm x 25 cm deep. Each conical section is 45 cm long, originating as a 16 cm pipe diameter, expanding into a 60 cm x 25 cm rectangular cross section. A closed bottom sediment tank is shown secured to the base of the observation chamber; it matches the chamber cross-sectional area of 60 cm x 60 cm, and is 25 cm deep. The sediment tank is removable and can be replaced with a two-jaw mud grab when the assembly is to be used in bottom sediments.

The side view port is fixed, while the top port is attached to a stainless steel frame hinged at the back end. The top entry capability provides access to the sediment without loss of fluid media when operating in the laboratory. The side port is 50 cm x 15 cm, the top port is 45 cm x 45 cm. Both ports are tempered plate glass 6 mm thick, assuring operator safety as well as reducing optical distortion to a minimum. Both view ports have molded gaskets to provide a mechanical cushion against twisting loads and shock, as well as

Figure 3. Specimen Observation Chamber

to form a water-tight seal. The gaskets are molded from Dow Corning Silastic Type E silicone rubber.

Four PVC mounting straps are used to support the chamber in the aluminum structure. Similar to the straps used on the circulation pipe, they provide system stress relief and galvanic isolation between the stainless steel components and the aluminum structure.

As a point of information, the aluminum fittings and pipe were not protected by paint or other coating prior to the five-day sea water immersion. With the large surface area of stainless steel in close proximity to the aluminum, it was the designer's opinion that reduced galvanic corrosion would be obtained by keeping the surface area of the least noble metal (aluminum) as large as possible. Sacrificial anodes (zinc) were purposely not installed on the system to assure that there would be no chance of system contamination from this source.

To preclude the possibility of ground currents circulating between electrically connected components, no portion of the aluminum structure, stainless steel circulating system, battery boxes or motor housing were used as a common electrical path. The batteries, control switches, voltmeter, ammeter, and pump motors all used separate leads to interconnect the respective positive and negative sides of the 12 volt DC energy source. Both the stainless steel system and aluminum structure "electrically floated"; there were no impressed voltages or currents from the system power source to accelerate corrosion.

While a five-day submerged period is not considered a long term immersion test, there were no indications of localized pitting, corrosion, large discoloration areas or matt-surface conditions noted on any portion of the system. Both the stainless steel and aluminum appeared in excellent condition after recovery from the sea water.

3.3 Sea Water Recirculating System

The sea water contained in the benthic chamber is continuously recirculated by an integral pumping system. Figure 1 depicts the relative position of the pump in relation to the other components in the system. Figure 4 provides a view of pump and pressure compensation motor housing attached at the 90° intersection of the two 16 cm recirculating pipes. The pump mechanism is completely internal to the pipe, and draws its inlet flow through the pipe originating from the upper center of the photograph, discharging it back to the system through the pipe on the left.

Figure 5 is a close-up of the pump scroll housing and the pump assembly mounting flange. In operation, the sea water enters the 5 cm diameter inlet, and is discharged from the rectangular port shown at the top of the scroll housing. The pump configuration was designed to provide a pre-packaged assembly that could be installed internally in the system, eliminating extraneous pipe and fittings that would otherwise be required with an external pump.

Figure 6 provides a view of the pump drive motor with the external pressure compensation housing removed. The device is a permanent magnet DC servo motor having a variable speed capability between 100 and 1500 RPM. Control of the motor speed is dependent on the voltage source used to power the assembly. Rated operating voltage is 24 VDC, with a maximum allowable current load of 5.6 amperes.

The motor drives the squirrel cage pump impeller through the use of a magnetic drive coupling. Figure 7 is a cross-sectional drawing illustrating the magnetic drive, with Figure 8 providing an exploded view of the assembly. The magnetic drive concept was used as a means of isolating the drive motor

Figure 4. Pump and Motor Housing Assembly

Figure 5. Pump Scroll Housing

Figure 6. DC Drive Motor and Pump Housing

Figure 7. Cross Sectional Drawing of Magnetic Drive

Figure 8. Exploded View of Motor/Pump Assembly

pressure compensation system from the sea water within the chamber. The design does not require the use of elastomer shaft seals, and eliminates all possibility of system contamination from particles of carbon, plastic, or elastomer materials that frequently flake off a conventional shaft seal. The magnetic drive concept also assures the operator that the media used to pressure compensate the motor housing cannot enter the sample area and alter the system chemistry.

3.4 Levels of Extraneous Construction Materials

The recirculating sea water benthic chamber is, for the most part, fabricated from 300 series stainless steel. The fluid media within the system is, however, in direct contact with several other materials necessary to form watertight seals between mating parts. All sealing gaskets are used in a static mode, with the compounds selected not considered as materials that flake, shed, outgas, or leach their plasticizer excessively at room temperature conditions.

The following is a tabulation of the material exposed to the recirculating chamber sea water and the total calculated surface area in direct contact with the system fluid:

<u>Type Material</u>	<u>Exposed Area</u>
(1) Teflon (TFE - Fluorocarbon)	
A. Pipe Flange Gasket Seals	72.58 sq cm
(2) Penton (Chlorinated Polyether)	
A. Squirrel Cage Impeller Drive Magnet (Note: drive magnet enclosed in an area with little fluid interchange)	4.93 sq cm

(3) Silicone Rubber (Red)

A. Mud Box Seal Gasket	63.68 sq cm
B. Side View Port Screw Head Seals	9.22 sq cm
C. Chamber Support Bracket Seals	14.83 sq cm
D. Top Cover Latch Plate Seals	16.13 sq cm

(4) Buna N - "O" Ring (Nitrile)

A. Magnet Water Barrier Cup Seal	5.65 sq cm
(Note: encapsulated in "O" ring groove)	

(5) Neoprene (Chloroprene Rubber)

A. Motor Compensation Housing Flange Gasket	4.12 sq cm
---	------------

(6) Silastic Sealant (Dow Corning Type E)

A. Side View Port Gasket	42.32 sq cm
B. Top View Port Gasket	66.06 sq cm
C. Hinged Cover Gasket	66.13 sq cm

3.5 Examination of Specimen Chamber Flow Characteristics

In preparation for running system flow tests, two aluminum plates were marked off in a grid pattern as shown in Figure 9. The grid is formed in squares 5 cm x 5 cm, using black masking tape applied over a smooth surface, gloss white background. The bottom grid is at a level that closely approximates the height of the bottom sediment when the system is operating with the mud box in place.

A telltale water flow network was constructed as illustrated in Figure 10. The frame is fabricated from 1.5 mm x 6.0 mm stainless steel flat stock, with the cross member grid constructed of 0.7 mm stainless rod tack welded to the frame. Light weight yarn approximately 5-6 cm in length has been attached to the grid with a small drop of Duco cement. Figure 9 also provides a close-up view of the flow grid mounted at the inlet to the specimen chamber. Its overall size is 9.5 cm high and 60 cm long.

Figure 9. Specimen Chamber Flow Test Grid

Figure 10. Tell-Tale Water Flow Network

Initial laboratory flow tests performed as expected. The main flow mass tended to form along the outside wall of the 90° elbow, with the inside radius of the elbow having an almost stagnant flow condition. Figure 11 illustrates the initial flow pattern, including the reverse flow eddy formed along the chamber side wall, directly opposite the main body of the stream.

The honeycomb grid structure illustrated in Figure 12 was fabricated and installed in the system. Figure 13 depicts the decreasing eddy and improved flow pattern that resulted from the straightening vanes. Further improvement was obtained through the use of the adjustable vanes illustrated in Figure 14. The final flow pattern shown in Figure 15 was reached by adding the horizontal deflector plates noted in Figure 16.

The pattern illustrated in Figure 15 was not a steady state condition as indicated in the sketch. Food coloring dye trace injected into the stream, as well as potassium permanganate crystals positioned on the bottom, illustrated a fairly uniform flow across the base with some meandering in a cyclic nature. The flow within the chamber, while driven by a steady state pump, had a tendency to speed up and slow down at a fairly consistent cyclic rate. These variations in flow formed random meanders across the bottom, with occasional small excursions of upstream movement of the dye trace. As the flow velocity increased, the dye moved downstream and the eddy or meander disappeared into the main body of water passing through the chamber. Flows across the bottom appeared, in general, to be fairly linear, with velocities varying between 5-7 cm/sec at the high flow rate, and between 1.5-3.0 cm/sec at the low pump rate.

Figure 11. Chamber Plan View Flow Pattern

Figure 12. Flow Straightening Grid

Figure 13. Improved Water Flow Pattern with Straightening Grid

Figure 14. Modified Straightening Grid with Adjustable Vanes

Figure 15. Final Water Flow Pattern within Test Chamber.

Figure 16. Modified Straightening Grid with Adjustable Vertical and Horizontal Vanes

3.6 System Power Package

The power source required to operate the pump and motor assembly is supplied by a bank of lead-acid storage batteries. Figure 17 provides an overall view of the two plastic containers used to house the batteries. Each container is 76 cm long, 60 cm wide, and 40 cm high. They are constructed of PVC (polyvinyl chloride) sheet stock, cemented and welded along all seams. A fiberglass cover formed in the shape of a shortened four-sided pyramid is bolted to the top flange of the battery box. A soft rubber gasket is used as the seal between the box and cover flange.

Figure 18a provides a view of the male mold used to form the fiberglass cover plate. Figure 18b illustrates the completed component. The grapefruit-sized cup molded to the inner surface of the cover acts as a drip pan for any sea water that may seep back through the relief valves as they burp during the vent cycle. The rubber tube is positioned near the base of the battery box to prevent any back flow of water from dripping on the battery terminals and wiring. The cover was molded using several layers of 1 1/2 oz fiberglass mat impregnated with catalyst cured polyester resin. The fabrication technique is known as the wet layup method, and is similar to the construction used in various boat yards. It is a reasonably uncomplicated and inexpensive method of fabricating simple or complex structures. It is weather- and water-resistant, has high strength, and can be worked with the tools available in a reasonably equipped machine shop. Materials of construction are readily available, and depending on the strength required, the wall thickness can be built up by application of multi-layers of mat. The component illustrated has

Figure 17. Power Package Installation in Re-circulating System Structure

Figure 18a. Male Mold for Battery Box Cover Plate

Figure 18b. Fiberglass Battery Box Cover

a final layer thickness of 6 mm.

The two boxes have been positioned slightly off-center of the frame structure, providing a balance mechanism to counteract the water-filled weight of the specimen chamber, the interconnecting pipe, and the mud box. The total air weight of one battery box is 200 kg. This weight includes 6 batteries, with electrolyte, PVC box and fiberglass cover, and the aluminum "I" beam structure used to support and mount the boxes.

While the mounting structure appears excessively rugged, it provides a dual role during system operation. When on the surface, it evenly supports the 200 kg load to prevent twist and mechanical damage to the seams and walls of the PVC container. On being immersed in water, the frame provides a large measure of side wall, bottom, and top cover strength by becoming the rigid member that resists the internal pressure used to compensate the system during submerged operation.

Each container has a snug-fitting plywood rack to separate and secure the six batteries. Figure 19 provides a view of the rack configuration as well as the battery wiring. The plywood separator also acts as an internal support for the container side walls as the external water pressure increases at initial immersion. Once the pressure compensation system balances this pressure, side wall loading against the plywood rack is eliminated.

Each battery pack houses six 12 V DC batteries. For the initial five-day "in-water" bottom experiment, they were wired in parallel to make full

Figure 19. Internal View of Battery Box Assembly

use of their combined ampere hour capacity. Figure 20 is the circuit schematic for the battery system and the control panel.

Assuming a full charged 12.5 V DC lead acid battery of the type shown, with an individual capacity of 100 ampere hours, each battery pack is capable of providing 600 ampere hours of energy to the pump system. With both packs connected in parallel, a total of 1200 ampere hours is theoretically available to power the system.

Neglecting the degradation of battery capacity resulting from cold-soaking the cells at reduced ambient water temperatures and the possible effect of the pressure compensation system, the two battery packs could power the pump for a maximum of 13.5 days at a 3.7 ampere discharge rate. In actual practice, a lead-acid cell seldom approaches its theoretical capability of returning the total available energy, and as such is usually de-rated depending on the load's ability to accept some level of voltage degradation during the operating period. In the case of the DC motor in the pump system, it will vary its RPM based on the voltage level provided by the source. Preliminary testing of the pump flow indicates voltage variations between 10 and 12 volts did not appear to have a great effect on motor RPM and, as such, would not appreciably affect the chamber flow during the experiment.

Based on some level of expected battery degradation, it was assumed that a 15% decrease in capacity would still provide 1020 ampere hours, or eleven days of operation at the 3.7 ampere load. Assuming a 15% reduction in battery voltage toward the end of the eleven day period, the voltage available to drive the pump would be 10.6 volts, which is still above the

Figure 20. Battery and Control Panel Schematic

established minimum of 10 volts.

3.7 Electrical Control Panel

Surface and diver control of the two battery packs is provided by an enclosed switch mechanism mounted on the chamber structure, as shown in the center of Figure 21. It consists of a cemented and welded PVC box with a clear plastic view port for visual observation of the ammeter and voltmeter. Figure 22 provides a close-up, illustrating the four position rotary battery switch at the end of the box. The switch provides the operator with the following control options:

Position 1 - all batteries disconnected

Position 2 - battery pack #1 connected

Position 3 - battery pack #2 connected

Position 4 - both #1 and #2 connected in parallel

The battery control switch shaft has been designed to accomodate an elastomer "O" ring assembly, providing a watertight rotary seal. Two danco wire penetrator assemblies are located at the base of the box, providing the entry point for the two power cables connected to the battery packs. The four position battery control switch is a modified off-the-shelf and readily available component used on small power boats. It is capable of switching 50 amperes, and can carry loads as great as 150 amperes.

A fuse block is located within the control panel, with two 10 ampere fuses used to protect the individual battery packs. The two meter assemblies

Figure 21. System Control Panel Installation

Figure 22. Control Console and Battery Switch

are modified electronic components and, depending on the battery switch position, they continuously monitor the battery voltage and system load, providing the operator with visual indications of system and battery performance.

In lieu of designing a pressure resistant housing, the control box was constructed as a light weight fluid filled system. A low viscosity mineral oil is used as the dielectric/compensation fluid, completely filling the inside of the box. Both meters and fuses have sufficient vent holes to assure that all internal parts of the assemblies are completely flooded. It is important that no air filled voids exist within the multi-contact switch or the tubular fuse housings; they must be completely filled with fluid. The oil filled system effectively prevents any sparks from switch contacts or blown fuses from occurring in a gaseous medium. All possible ignition sources are completely squelched by the fluid. The location of the oil filled box is sufficiently high so that any leakage is directed away from the observation chamber, reducing any possibility of specimen contamination. The rationale for the fluid filled design is covered in the following section.

3.8 Pressure Compensation System

The benthic chamber was designed for operation either on the surface or in situ at diver depth. Assuming a qualified diver in good health can perform meaningful work at depths to 40 meters, the various support systems on the chamber were also designed to operate at this pressure level.

Based on a depth pressure of 56 lbs/sq in acting on all closed containers, a design decision was required concerning the most favorable method to use for the protection of the motor, batteries, and their associated switches and meters. There are three commonly used methods

that will perform this function, each having its own good points as well as objectionable features. Examining each method based on the requirements of this particular system, the following reasoning was used:

3.8.1 Method 1: Pressure Resistant Housings

For deep water operation, the pressure resistant housing is an ideal method of protecting components that are unable to withstand pressures in excess of atmospheric, the most efficient configuration being cylindrical or spherical in form. Although not easily adaptable to either of these designs, the battery pack and control console used with the benthic chamber could be protected by this method.

As illustrated in Figure 23, the housing has been fabricated with considerable wall thickness and rigidity to resist the external sea water pressure at operating depth. In view of the large flat surface area of the proposed battery packs, it would require an exceptionally heavy reinforced wall thickness and strengthening ribs to resist a 56 lb/sq in external pressure, and consequently, the weight of the system would be significantly increased. Welded seams, seals and cable penetrators would have to be completely watertight, as any leakage would eventually flood the system. The method, however, could be made operational, despite the possible leakage and weight problems.

The one area that presents the greatest hazard, and the major reason for rejecting a straight pressure resistant housing design, was the possibility of explosion. When using lead-acid batteries in a closed compartment, hydrogen gas is given off by the battery cells. In an enclosed watertight chamber, the hydrogen gas could be ignited by a spark from a loose terminal connection, resulting in a catastrophic explosion. Preliminary investigations indicate that a safety catalyst cap is available

Figure 23. Typical Pressure Resistant Battery Housing

for use on batteries of the lead-acid type. It operates by converting the gaseous hydrogen back into water, returning it to the individual cells in the battery. A device of this nature would reduce or eliminate the explosion hazard previously discussed. Time did not permit a thorough examination of this method, and no further information is available at this time.

3.8.2 Method 2: Fluid Filled Pressure Balanced Systems

A fluid filled system has several advantages over the pressure resistant housing method, provided of course that the internal components are capable of withstanding the pressure transmitted by the compensating fluid. Figure 24 illustrates a simplified static pressure balanced fluid filled compensation system. It consists of a rigid, thin-walled container, a flexible elastomer diaphragm, and a compensating fluid. In actual practice, the fluid is usually a dielectric material, especially if open electrical wires or relay contacts are present.

When submerged beneath the surface, an external pressure is exerted against the outside walls and to the top of the rubber diaphragm. The pressure on the diaphragm is transmitted through the flexible elastomer, applying this pressure to the compensating fluid. The fluid in turn pushes out against the inner walls of the container with a force equal to the applied pressure on the outer walls. Consequently, with a pressure balanced system, lighter container construction is acceptable, as it does not depend on the strength of a pressure resistant housing to prevent collapse.

In actual practice, this method of compensation is used for many deep water systems, especially with lead-acid battery packs that power deep water instrumentation as well as manned submersibles. Figure 25 is a typical battery pack using the fluid compensation method. In this case, the flat diaphragm has been replaced with a rubber bladder, and the top cover formed

Figure 24. Static Fluid-Filled Pressure-Balanced System

Figure 25. Typical Fluid-Filled Pressure-Compensated Battery Pack

into the shape of a squat pyramid. The pyramid provides a small volume pocket for hydrogen gas to collect above the oil, where it is eventually vented off through the relief valve.

Unlike the large volume of hydrogen/air mix found in the pressure resistant container of Figure 23, the gas is restricted to a small volume at the top of the cover, with all potential ignition, or spark points, completely immersed in oil. The fluid filled compensation system, while not fail-safe from leakage, is far superior to pressure resistant housings that have an internal pressure below that of the external water pressure. When properly designed, the internal fluid can be maintained at a slightly higher pressure than outside ambient. Consequently, any leakage would force oil out, rather than allow water to enter the system.

Oil filled systems, however, do have several objectionable features. The fluid contained in the tank and bladder adds to the air weight of the system, and when repairs or normal battery maintenance are required, the system must be drained before service can be performed. The battery fill and vent ports also require special caps that reduce the expulsion of electrolyte into the oil each time the cell burps or vents its hydrogen gas bubbles. Despite careful design, an oil filled system will spit out small quantities of oil each time the relief valve opens. This could result in a possible contamination point for the organisms in the specimen chamber. It is, however, a very practical method of using lead-acid batteries at extreme depths.

3.8.3 Method 3: Pressure Balanced Inert Gas Compensation System

The use of compressed gas as a pressure compensation medium, in lieu of using an oil or dielectric fluid, appears to have several advantages in systems operating at diver depth. A properly designed pressure balanced

gas system would allow the use of lightweight, thin-walled containers that are easily vented and recharged during routine maintenance. The system is clean and dry, with the air weight of such a system equal only to the sum of the pressure flask, support framework, internal apparatus, and the container. It is not subject to the extra weight of the fluid filled system, and is essentially non-contaminating to the recirculating system.

Compressed gas storage flasks, regulators, scuba equipment, as well as fittings, are, for the most part, off-the-shelf hardware and readily available. The use of a straight gas system, however, does require the use of an inert medium when used with a lead-acid storage battery system. The gas selected must be capable of displacing all oxygen from the hydrogen rich atmosphere within the chamber. The use of compressed air is prohibited. The gaseous medium must displace O_2 and provide an inert blanket over all wires and connections that could be a source of possible ignition from an inadvertant spark. It is strongly advised that a system of this design be used only in a static mode electrical circuit, for example, one that has solidly attached connections, bolted or soldered cable terminals. Under no circumstances should open contact relays, fuses, motors, or frangible devices such as light bulbs or magnetic reed switches be mounted within the container.

Power or control cables must not be connected directly to another control box, switch, or motor assembly, unless the cable has a permanently potted or mechanical dam, to assure that hydrogen gas cannot diffuse through the cable and collect at some remote ignition source.

The compensating gas selected for this application was carbon dioxide. It is a dense gas that is inert, commercially available, inexpensive, and easy to handle, store, and control. Carbon dioxide gas is soluble in water, although at the low pressures and small surface area of battery electrolyte

exposed to the gaseous carbon dioxide it is not considered to be a problem in this application. The gas is stored under pressure in liquid form. When extracted from the storage flask, the liquid passes into the gaseous state with some formation of "solid snow" when the extraction rate is sufficiently rapid.

Figure 26 illustrates the design of an inert gas compensation system. The liquid carbon dioxide is stored in the flask at the lower left. As the system is immersed, the depth sensing portion of the regulator determines that external pressure has increased above the ambient pressure within the motor housing and battery boxes. At this point, the regulator draws CO₂ from the storage flask, directing it to the low pressure area. The gas continues to flow until the regulator senses the internal pressure has exceeded the external by an approximate pressure level equal to 8 inches of water. At this point, the regulator ceases to flow and the system becomes static.

If the descent is continued, the regulator again senses the pressure differential, repeating the compensating action as long as the pressure difference exists. On reaching the bottom, the regulator reverts to a steady state or static condition, replenishing the CO₂ only if the depth is again increased or system leakage results in a pressure differential sensed by the regulator.

To assure the CO₂ entering the regulator is always in a gaseous state, thereby preventing possible freeze-up of internal components, several precautionary measures were designed into the system. The CO₂ storage flask does not have a syphon tube extending into the liquid, and the flask is mounted in a vertical position, providing mostly gas when the regulator draws on the stored charge. Figure 27 illustrates the mounting position and location of the carbon dioxide tank.

Figure 26. Pressure-Balanced Inert Gas Compensation System

Figure 27. Carbon Dioxide Storage Flask

The gross weight of the tank is 41 kg, with a CO₂ charge of 10 kg. The tank location as shown in the photograph was not determined by its proximity to the pressure compensation regulator, but more by its ability to act as a counter-weight, providing a means to "fine tune" the weight and balance of the system without the penalty of a non-functional mass.

During times of heavy CO₂ demand, the liquid in the storage flask has a tendency to boil vigorously, and some "spitting" will occur. To prevent the drops or slugs of liquid CO₂ from entering the regulator, a tubular stainless steel heat exchanger converts the occasional spurt of liquid into gas before it reaches the regulator inlet. Figure 28 illustrates the construction features and location of the coiled tube gasifier.

Relief valves have been included in the system to prevent both the over-pressurization of the battery boxes in the event of a regulator malfunction and as the primary means of venting internal pressure during ascent. They are adjusted to a reseal level approximately 1 psi higher than the maximum regulator delivery pressure to assure a leak-tight seal. Both valves are located on a common plane, or pressure depth level, as illustrated in Figure 29. With both relief valves having similar relief settings, and both exposed to an identical depth pressure, neither battery box is favored, even with the 60 cm difference in depth between the two assemblies.

In normal operation, the system is completely filled with the inert CO₂ gas. The possibility of hydrogen migrating from the battery box to an ignition source is considered as very improbable. However, a safety feature has been included to prevent an explosion of the battery boxes in the event that H₂ did collect in the motor housing and become ignited through sparking of the brushes. The precautionary device is a hydrogen gas flame arrestor. It consists of a spring loaded check valve that allows

Figure 28. CO₂ Gasifier Heat Exchanger

Figure 29. Battery Box Relief Valve Assemblies

the free flow of CO_2 in the direction of the arrow, as shown in Figure 26. Opening pressure is 2.0" H_2O , while reseal or closure against an explosion pressure front is 1.0" H_2O .

Its internal construction is such that a labyrinth of internal cooling fins and the check valve assembly quench and shut off any flame of hot gasses traveling in the opposite direction of the arrow, thereby preventing a catastrophic explosion of the battery boxes. It is a commercially available device designed specifically for the suppression of explosions and flame fronts in hydrogen gas pipe lines. Figure 30 illustrates the device mounted at the left of the instrument panel, with the low pressure depth sensing stage of the CO_2 regulator shown on the right.

As a point of interest, an atmosphere containing as little as 4% hydrogen is explosive in the presence of a spark or flame. A one cubic foot volume of air, or 1728 cubic inches, requires intermixing with only 69 cubic inches of hydrogen to reach the lower limit of explosive level. A lead acid storage battery normally liberates small quantities of hydrogen at all times, even when idle. Localized action between the alloys used to construct the negative grid, impurities in the base metal, age of the battery, temperature, amount of antimony in the structure, all have a direct bearing on the quantity of gas developed by the individual cells.

Under normal conditions, one ampere hour of overcharge produces 25.5 cubic inches of hydrogen per cell. For estimating purposes, it is considered that local action gassing of an at-rest battery is equivalent to an overcharge flow of 0.1 ampere for each 100 ampere hours of cell capacity.

Assume that six 100 ampere idle batteries of eight cells each, confined within 2.5 cubic feet of air and with an at-rest current rate equivalent to

Figure 30. H₂ Flame Arrestor and CO₂ Regulator Assembly

0.1 ampere at the negative plates: $0.1 \times 48 \times 25.5 = 122.4$ cubic inches of hydrogen evolved per hour. 69 cubic inches of hydrogen mixed in 1.0 cubic foot of air becomes an explosive mixture. $2.5 \text{ cubic feet} \times 69 = 172.5$ cubic inches of H_2 must be generated before the enclosed battery compartment becomes potentially explosive. $172.5 \div 122.4 = 1.4$ hours required to reach a concentration that could be ignited by an ignition source within the chamber.

Recharging of an enclosed battery bank becomes even more serious, and requires a careful venting of the battery compartment as well as eliminating potential ignition sources within the area. Assuming six 100 ampere hour batteries with eight cells each, again confined within a 2.5 cubic foot air space, the battery charge rate is 8.0 amperes: $8 \times 48 \times 25.5 = 9792$ cubic inches of hydrogen generated per hour. $172.5 \div 9792 = .01$ hours, or just six minutes of charging will result in sufficient H_2 to provide an explosive mixture within the chamber.

When flooding the battery compartments with CO_2 , a total of 140 liters of gas is required. Some additional volume must also be available as "make-up" to account for system leakage. The storage flask contains 10 kg of liquid CO_2 , providing approximately 5400 liters of gas at atmospheric pressure and a temperature of $21^\circ C$.

At an ambient temperature of $4^\circ C$, and a pressure depth of 40 meters, the total gas available for pressure compensation is conservatively considered as 1000 liters. Assuming that the battery compartments have a full CO_2 compensating charge, 859 liters of gas remain for leakage make-up.

Assuming 5 leak points throughout the compensation system, each with a leak rate of 1 cc/min* continuing over a 10 day period of submerged time, a total of 71 liters of CO_2 would be required to sustain the system pressure. On completion of the experiment, in excess of 788 liters of available gas

remains as the system safety factor.

* 1 cc = approximately 225 bubbles, with bubble size considered as that physical dimension obtained when a single bubble emanates from a tube orifice having an inside diameter of .15 mm.

Based on the bubble size and the rate of 1 cc/min leakage rate, a steady stream of bubbles would be clearly visible to a diving party. 5 such leakage points would provide a highly visible air cloud in the general vicinity of the battery compartments, providing sufficient time to recover the chamber before major damage had occurred.

3.9 Mud Grab and Closure Mechanism

The benthic chamber was designed to become an integral part of the bottom sediment during an in situ experiment. As part of the system, a large, open-bottom mud box with movable jaws is attached to the base of the specimen chamber, as illustrated in Figure 31. Prior to deployment, the jaws are placed in the open position and locked with a lever and latch mechanism mounted at the left of the chamber.

On deployment, the benthic system is lowered until the opening at the base of the chamber enters the bottom sediment, effectively trapping a 3700 sq cm core that is approximately 25 cm in depth, depending, of course, on how deep the side walls have penetrated. Being a closed system, the sea water initially trapped within the pipe and specimen chamber becomes a part of the experiment. The self-contained pumping system continuously recirculates the sea water across the bottom sediment, simulating the action of bottom currents. The closed system becomes a controlled mechanical ecosystem, operating as close to in situ conditions as possible. The injection of

Figure 31. Mud Box Closure Jaws in Open Position

chemicals or hydrocarbons, the measurement of oxygen levels, and the observation of sedimentation downstream of the observation chamber can be accomplished by the diving science party.

On completion of the experiment, and prior to recovery, the safety mechanism on the mud box jaws is released by the science team. A valve is manually opened on the scuba bottle shown in Figure 32. The application of 2200 psi air pressure to a set of pneumatic cylinders forces the mud box jaws to close as shown in Figure 33, trapping the sediment sample and the internal sea water within the system.

The two jaws are mechanically linked together through the use of roller chain and sprocket assemblies, with each jaw powered by a separate piston and cylinder. The use of a dual cylinder arrangement balances the load applied to the mud jaws, preventing twist as well as providing a redundant closure mechanism. A typical pneumatic actuation cylinder is shown in Figure 34.

The stored air pneumatic system used to close the mud box jaws is diagrammed in Figure 35. It consists of a standard scuba cylinder, Orifice 1, and two pneumatic piston and cylinder assemblies attached to the mud box jaws.

In operation, the valve on the storage tank is opened, allowing 2200 lbs pneumatic pressure to act on the pistons of both closure cylinders. To prevent too rapid a mud box closing action, Orifice 1 restricts the flow but not the final pressure applied to the cylinders. Once the mud box jaws have closed, the valve may be shut off or left in the open position, depending on the diver's choice. The doors will remain closed as a result of the compressed air trapped in the system, the weight of the jaws, and the off-center position of the jaw pivot point.

Figure 32. High Pressure Air Storage Bottle

Figure 33. Mud Box Jaws in Closed Position for Recovery

Figure 34. Closure Cylinder, Sprocket and Roller Chain Assembly

Figure 35. Stored Air Closure System Schematic

When a long term bottom experiment is in progress, the mud box jaws would normally remain in the open position. Consequently, the jaw actuation piston would be fully retracted. In this position, the cylinder void "B", Figure 35, must be protected from the entry of bottom mud, silt, and sea water that could damage the piston seals. To accomplish this, the void is filled with a lightweight mineral oil and connected to a flexible oil filled bladder. In the jaw closure cycle, the piston moves from "A" to "B", forcing oil through the adjustable orifice and into the rubber bladder. The volume of the storage accumulator is of sufficient size to accept the total volume of both cylinders without applying undue back pressure against the working piston.

Adjustable Orifice 2 provides a means to "slow down" the high velocity oil flow, preventing a possible rupture of the rubber bladder. The orifice complements the action of Orifice 1.

The arrangement of the piston and free wheeling sprocket on the rod end is called a "differential actuator". The design provides a 2:1 mechanical reduction, but requires a piston assembly with $1/2$ the stroke. The shorter rod length reduces the column buckling forces in a high thrust device. Another advantage is that the cylinder is working on the full piston area, and the rod packings are not subjected to high pressure.

The piston area is 3.14 sq in. When the 2200 psi pneumatic pressure is applied, a thrust of 6900 lbs is generated by each cylinder assembly. Working as a parallel circuit, they provide a reasonably balanced thrust to both sides of the clam shell doors, reducing distortion to a minimum. The total thrust is 13,800 lbs; the available door operating torque on the closure sprockets is one half the total due to the 2:1 mechanical reduction, or 6900 lbs.

4.0 Deployment, Bottom Test, and Recovery of the Recirculating Sea Water Benthic Chamber

In preparation for ocean deployment, the chamber was loaded aboard the R/V OCEANUS, a Woods Hole Oceanographic Institution research vessel. Figure 36 provides a view of the loading procedure. The station selected for the experiment was in Buzzards Bay, Massachusetts at $41^{\circ}27'$ latitude, $70^{\circ}52'$ longitude. Water depth at the site was 14 meters, with bottom conditions being a soft unconsolidated gray sediment. Visibility at the bottom was estimated to be no greater than 1.5 to 2.0 meters.

Prior to deployment, colored yarn was woven into the main lift line at intervals of 3 meters. The colored tags were to provide an accurate indication of the depth of the chamber below the surface. A flexible hose was also connected to the pressure compensation system, taped to the lift line, and attached to a pressure gauge ¹/₂" on the deck of the support vessel. Both the gauge and 3-meter depth indicator tags provided a method of monitoring the ability of the inert gas pressure compensation system to balance the internal pressure during deployment.

Surface testing had determined that the modified scuba regulator would provide 1.5 cu ft/min gas flow. The calculated total free volume within the battery compartments was 5.0 cu ft. Based on this information, a descent rate would have to be maintained that would allow the regulator to balance the continually increasing external sea water pressure, or possible catastrophic failure of the battery containers might occur.

Deployment at the selected dive site is illustrated in Figure 37. The arrow points out a float that was attached to the four part lift bridle to assure that it remained in a vertical position after the chamber settled into the bottom. It was considered an important factor to assure that the

Figure 36. Chamber Loading on the R/V OCEANUS

Figure 37. Benthic Chamber Deployment at Dive Site

lift bridle did not collapse on top of the frame, resulting in possible interference to the diving team, or entanglement and mechanical damage to the system.

Deployment, initial immersion, and descent were satisfactory and uneventful. The top side pressure gauge provided a continuous read-out that the inert gas pressure compensation system was operating satisfactorily. Contact with the bottom was soft, and divers reported indications of one "bounce" before the chamber settled into the sediment. Once contact is made, it is important to buoy off and release the lowering line as soon as possible, in order to prevent any surface vessel drift from dragging or bouncing the system across the bottom. Figure 38 provides an artist's concept of the benthic chamber deployed at the dive site.

A visual inspection of the apparatus revealed no bubbles due to system leakage, battery voltage was satisfactory, and pump operation normal. The bridle float discussed previously had unfortunately collapsed, thus allowing the four part cable bridle to partially drape over the frame. Tidal action on the surface buoy resulted in a side strain on the bridle, increasing the possibility of damage to the upper battery case relief valve and the control valve on the CO₂ tank. Divers tied off the bridle at a location that would prevent system damage, and continued with the benthic system experiment.

During the next five day period, several diving excursions were made at the site to observe the experiment and the apparatus. Operations continued to be normal, with satisfactory pump operation as well as the simulated tidal flow through the chamber. Battery voltage and the level of current drain remained within the limits established for system operation.

Visual observation of the specimen chamber, sampling, and "spiking" of the recirculating sea water was carried out by the scientific diving team. Figure 39 provides a close-up view of the oxygen regulator and flow

Figure 38. Artist's Concept of Benthic Chamber on the Bottom

Figure 39. Oxygen Injection System

meter used by the team during the oxygen replenishment phase of the investigation.

At the completion of the experiment, divers cleared the four part lift bridle, released the latch on the clam shell doors in preparation for closing the chamber bottom, and opened the valve on the pneumatic storage flask. The chamber doors closed an estimated two-thirds of the required travel, at which point an audible "crack" was heard by the divers. A large cloud of bubbles erupted from a fitting on one of the closure cylinders. At this point, the compressed gas cylinder was secured and the divers surfaced.

After discussing the malfunction of the closure mechanism, it was decided that the combined difficulty of the high pressure pneumatic leakage and the structural failure would, in all probability, result in a loss of the enclosed chamber sediment. To assure that a sample would be available for analysis, another dive was made on the system, and a hand-operated box core sample was obtained from the area within the chamber.

Retrieval of the benthic chamber was continued, with several stops being made during ascent to allow the pressure compensation system to vent. As the chamber broke the surface, the majority of chamber sediment and water remaining in the system poured out of the opening between the clam shell doors. The doors were pushed closed by hand, and a small amount of the sample was retained within the specimen box.

On surface investigation of the closure mechanism, a major leak was discovered at one of the pneumatic flare fittings, Point "A" in Figure 40. While not shown in this photograph, a structural failure had occurred at two areas of mechanical attachment, Points "B" and "C". It would appear that the bending of mounting stud "B" allowed the cylinder to break its attachment at "C", causing the cylinder to twist, which in turn resulted

Figure 40. Closure Cylinder Mounting Configuration

in the tube flare fitting failure and pneumatic leakage.

Further inspection of the benthic chamber, pump and motor assembly, battery boxes, control panel, and structural frame indicated that all other components were in satisfactory condition. The mechanical failure of the closure mechanism is not considered to require a major redesign of the system. It will be modified prior to the next deployment.

5.0 Findings and Proposed Improvements of the Recirculating Sea Water

Benthic Chamber

Based on operational observations and test information, the following suggestions, proposed modifications, and general comments are submitted for evaluation.

5.1 Primary Design Objective Deficiencies

The collection of downstream fecal pellets and fine particles resuspended in the water column by organisms within the specimen box was a design goal that was only partially realized. Some sampling was accomplished, both in the laboratory and at the in situ experiment, through the use of small glass collection bottles placed in the system.

Originally, it was envisioned that a wash board or corrugated sluice assembly would cover the bottom of the downstream conical section, providing total coverage of the sampling area. During removal, the riffled sluice would have the capability of being tightly covered to prevent the more dense particles at the front of the tray from intermixing with the lighter particles deposited at the back. The design would provide a means of removing the device and inserting a fresh assembly without opening the chamber cover, assuring a minimum of interchange between the outside water

and the internal recirculating fluid. It is anticipated that a collection device will be incorporated in the present system in the near future.

5.2 Construction Materials

The present system meets the material design goals originally established. The 16 cm diameter stainless steel pipe, however, is exceptionally heavy, with flange assemblies considerably more sturdy than required for an essentially pressure-balanced system. The pipe and flanges were obtained as surplus material, and, as such, were considered acceptable, especially when one considers the extreme relief they provided to the budget. The aluminum pipe and scaffolding fittings used to construct the basic frame provided a convenient fabrication material and will be favorably considered for use in future programs.

5.3 Sea Water Recirculating System

The present squirrel cage pump design appears satisfactory, however it may be advantageous to relocate the pump. Referring to Figure 21, its projection beyond the frame makes it susceptible to mechanical damage. Deployment and recovery from a surface vessel in anything but a calm sea state could result in hard contact with the ship's hull, as can be easily visualized in Figure 37.

The chamber circulation of 5-7 cm/sec is considered acceptable, but marginal for a high flow rate. Based on the power available for a possible 10 day in situ experiment, it is considered as extremely doubtful that the flow could be substantially improved without increasing the size and weight of the power packs and drive motor assembly.

To obtain a substantial increase in flow would require an improved motor, modifying the magnetic coupling used to transmit the torque, and

undoubtedly increasing the total motor package size and weight. While an off-the-shelf motor with improved torque characteristics might be available, it is more than likely that a special motor, designed specifically for this system, would be required. It is suggested that if flow rates must be increased, a thorough market survey be initiated for an improved motor assembly, rather than absorb the cost of having one or two special motors designed and built specifically for this application.

Some preliminary flow characteristics noted during the initial stages of the program tend to indicate that some improvement can be expected through the use of gently curved plates installed vertically against the side walls of the upstream conical section that leads to the chamber. A simplified "venturi" of this type will be tested and installed in the present system as soon as practicable. If tests indicate a substantial flow improvement, it will be incorporated as an engineering modification to the second chamber.

5.4 System Power Package

The present lead acid storage cell system is fairly rugged and relatively uncomplicated. With reasonable maintenance, it will provide sufficient power for shallow water, short term programs. For in situ experiments in deeper and consequently colder waters, its capacity for running a system for continuous periods of up to 5 or 10 days rapidly falls off. Longer bottom time experiments will require some other type of power source if they are to be successful.

A market survey could be initiated to obtain data on fuel cells, atomic powered packages, consumable dissimilar metal batteries, and high density power packages being manufactured for the space program as well as other long term Navy and oceanographic programs. It must be understood, however, that the cost will not be comparable to the readily available lead acid

storage system presently used in the existing power network.

For extremely long term shallow water experiments, some thought could be given to recharging the bottom power pack through the use of a surface-mounted power source, for example, an internal combustion engine driving a generator, a buoy-mounted wind generator, or a bank of solar cells. Unfortunately, while any of the three are technically feasible with today's technology, they are susceptible to damage from collision, and invite pilferage.

5.5 Mud Grab and Closure Mechanism

The design of the pneumatic system used to close the mud doors is simple and efficient. It is a stored energy source powering two pneumatic piston assemblies that drive a gear and chain mechanism attached to the mud doors.

The failure mode discussed at the end of Section 4.0 was due to a mechanical failure of the pneumatic piston mounting assembly. Proposed modifications to the system will mount both pistons directly to the mud doors, eliminating the weak point of using the aluminum frame as the strength member. It is also proposed to install several "suction breaker" tubes along the outer side walls of the mud grab, as an aid in lowering the break-out forces during recovery. These changes are considered minimal, and do not require major modifications to the present system.

5.6 Pressure Compensation System

The ability of the inert gas system to pressure balance the battery boxes and motor housing appeared satisfactory. As discussed in Section 4.0, the maximum flow through the regulator is 1.5 cfm, while the void it is attempting to pressure compensate is 5 cubic feet. This large difference

results in the regulator always lagging several pounds behind the pressure requirements of the battery box assemblies.

In a slow deployment, the regulator will catch up to the demand, but it does require the deck crew to use extra caution. In view of this, it is suggested that a second regulator be installed in parallel, improving the flow of compensating gas as well as providing valve redundancy.

The two relief valves illustrated in Figure 29 and discussed in Section 3.8.3 operated as expected, venting the excess internal pressure as the chamber was brought to the surface. Their flow characteristics, however, are quite low compared to the volume of gas that must be relieved during ascent. Several stops were required during the recovery mode to assure that the battery compartments did not become overpressurized from the expanding CO₂.

It is recommended that a diaphragm type, high volume relief valve be installed in place of the piston/poppet configuration presently in use.

A Recirculation Seawater Benthic Chamber for the Study of the Biogeochemistry
of Petroleum Components at the Sediment Water Interface

5.5.1 Mud Grab and Closure Mechanism

Mounting of the closure cylinder illustrated in Figure 34, has been removed from its original location on the framework, and moved directly to the stainless steel grab sampler box. Figure 41 depicts the improved mounting assembly for the cylinder and roller chain mechanism used to actuate the dual "clam shell" doors on the grab sampler. This modification was necessary because the sampler did not close on its first trial (August, 1978) and strengthening the closure mechanism was more complicated than moving it.

No other system modifications were required. The pneumatic stored energy section, as well as the mineral oil compensation portion of the device remain as illustrated in Figure 35.

This improved mounting configuration was successfully used in June, 1979 at the completion of Experiment # 3 in Buzzards Bay, Massachusetts. This first Benthic Biogeochemistry Chamber is now complete and should not require further modification beyond routine maintenance.

BIBLIOGRAPHIC DATA SHEET		1. Report No. WHOI-78-94	2.	3. Recipient's Accession No.	
4. Title and Subtitle FINAL REPORT - A RECIRCULATION SEA WATER BENTHIC CHAMBER FOR THE STUDY OF THE BIOGEOCHEMISTRY OF PETROLEUM COMPONENTS AT THE SEDIMENT WATER INTERFACE				5. Report Date December 1978	
				6.	
7. Author(s) Clifford L. Winget				8. Performing Organization Rept. No.	
9. Performing Organization Name and Address Woods Hole Oceanographic Institution Woods Hole, MA 02543				10. Project/Task/Work Unit No.	
				11. Contract/Grant No. EE-77-S-02-4256	
12. Sponsoring Organization Name and Address U.S. Energy Research and Development Administration				13. Type of Report & Period Covered Technical	
				14.	
15. Supplementary Notes					
16. Abstracts <p>The experimental benthic chamber was designed to conduct both laboratory and <u>in situ</u> investigations on the transport and degradation of petroleum type hydrocarbons at the sediment water interface, and to investigate the sediment/water/organism interactions. In its basic form, it consists of a rectangular flume constructed of stainless steel tube, a windowed observation chamber, a variable velocity pumping system and its associated controls, battery packs, and inter-connecting cables. The base of the observation chamber is a removable assembly, allowing the user to select either a closed rectangular box for laboratory use, or a mud grab bottom sampler configuration for <u>in situ</u> evaluation.</p>					
17. Key Words and Document Analysis. 17a. Descriptors 1. Benthic Chamber 2. Sediment Interface 3. Organic Contamination					
17b. Identifiers/Open-Ended Terms					
17c. COSATI Field/Group					
18. Availability Statement				19. Security Class (This Report) UNCLASSIFIED	
				20. Security Class (This Page) UNCLASSIFIED	
				21. No. of Pages 75	
				22. Price	

<p>Woods Hole Oceanographic Institution WHOI-78-94</p> <p>FINAL REPORT - A RECIRCULATION SEA WATER BENTHIC CHAMBER FOR THE STUDY OF THE BIOGEOCHEMISTRY OF PETROLEUM COMPONENTS AT THE SEDIMENT WATER INTERFACE by Clifford L. Winget. 75 pages. December 1978. Prepared for the U.S. Energy and Development Administration under Contract EE-77-S-02-4256.</p> <p>The experimental benthic chamber was designed to conduct both laboratory and in situ investigations on the transport and the degradation of petroleum type hydrocarbons at the sediment water interface, and to investigate the sediment/water/organism interactions. In its basic form, it consists of a rectangular flume constructed of stainless steel tube, a windowed observation chamber, a variable velocity pumping system and its associated controls, battery packs, and interconnecting cables. The base of the observation chamber is a removable assembly, allowing the user to select either a closed rectangular box for laboratory use, or a mud grab bottom sampler configuration for in situ evaluation.</p>	<p>1. Benthic Chamber</p> <p>2. Sediment Interface</p> <p>3. Organic Contamination</p> <p>I. Winget, Clifford L.</p> <p>II. EE-77-S-02-4256</p> <p>This card is UNCLASSIFIED</p>	<p>Woods Hole Oceanographic Institution WHOI-78-94</p> <p>FINAL REPORT - A RECIRCULATION SEA WATER BENTHIC CHAMBER FOR THE STUDY OF THE BIOGEOCHEMISTRY OF PETROLEUM COMPONENTS AT THE SEDIMENT WATER INTERFACE by Clifford L. Winget. 75 pages. December 1978. Prepared for the U.S. Energy and Development Administration under Contract EE-77-S-02-4256.</p> <p>The experimental benthic chamber was designed to conduct both laboratory and in situ investigations on the transport and the degradation of petroleum type hydrocarbons at the sediment water interface, and to investigate the sediment/water/organism interactions. In its basic form, it consists of a rectangular flume constructed of stainless steel tube, a windowed observation chamber, a variable velocity pumping system and its associated controls, battery packs, and interconnecting cables. The base of the observation chamber is a removable assembly, allowing the user to select either a closed rectangular box for laboratory use, or a mud grab bottom sampler configuration for in situ evaluation.</p>	<p>1. Benthic Chamber</p> <p>2. Sediment Interface</p> <p>3. Organic Contamination</p> <p>I. Winget, Clifford L.</p> <p>II. EE-77-S-02-4256</p> <p>This card is UNCLASSIFIED</p>	<p>Woods Hole Oceanographic Institution WHOI-78-94</p> <p>FINAL REPORT - A RECIRCULATION SEA WATER BENTHIC CHAMBER FOR THE STUDY OF THE BIOGEOCHEMISTRY OF PETROLEUM COMPONENTS AT THE SEDIMENT WATER INTERFACE by Clifford L. Winget. 75 pages. December 1978. Prepared for the U.S. Energy and Development Administration under Contract EE-77-S-02-4256.</p> <p>The experimental benthic chamber was designed to conduct both laboratory and in situ investigations on the transport and the degradation of petroleum type hydrocarbons at the sediment water interface, and to investigate the sediment/water/organism interactions. In its basic form, it consists of a rectangular flume constructed of stainless steel tube, a windowed observation chamber, a variable velocity pumping system and its associated controls, battery packs, and interconnecting cables. The base of the observation chamber is a removable assembly, allowing the user to select either a closed rectangular box for laboratory use, or a mud grab bottom sampler configuration for in situ evaluation.</p>	<p>1. Benthic Chamber</p> <p>2. Sediment Interface</p> <p>3. Organic Contamination</p> <p>I. Winget, Clifford L.</p> <p>II. EE-77-S-02-4256</p> <p>This card is UNCLASSIFIED</p>	<p>Woods Hole Oceanographic Institution WHOI-78-94</p> <p>FINAL REPORT - A RECIRCULATION SEA WATER BENTHIC CHAMBER FOR THE STUDY OF THE BIOGEOCHEMISTRY OF PETROLEUM COMPONENTS AT THE SEDIMENT WATER INTERFACE by Clifford L. Winget. 75 pages. December 1978. Prepared for the U.S. Energy and Development Administration under Contract EE-77-S-02-4256.</p> <p>The experimental benthic chamber was designed to conduct both laboratory and in situ investigations on the transport and the degradation of petroleum type hydrocarbons at the sediment water interface, and to investigate the sediment/water/organism interactions. In its basic form, it consists of a rectangular flume constructed of stainless steel tube, a windowed observation chamber, a variable velocity pumping system and its associated controls, battery packs, and interconnecting cables. The base of the observation chamber is a removable assembly, allowing the user to select either a closed rectangular box for laboratory use, or a mud grab bottom sampler configuration for in situ evaluation.</p>	<p>1. Benthic Chamber</p> <p>2. Sediment Interface</p> <p>3. Organic Contamination</p> <p>I. Winget, Clifford L.</p> <p>II. EE-77-S-02-4256</p> <p>This card is UNCLASSIFIED</p>
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