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Environmental Protection Technology Series

CATALYTIC WASTE TREATMENT SYSTEMS FOR GREAT LAKE ORE CARRIERS

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
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CATALYTIC WASTE TREATMENT SYSTEMS FOR GREAT LAKE ORE CARRIERS

by

Sheldon E. Moore
Robert W. Coleman
Peter E. Lakomski

Thiokol Corporation
Wastach Division
Brigham City, Utah 84302

Project No. S802730

Project Officer

Leo T. McCarthy, Jr.
Oil and Hazardous Materials Spills Research Branch
Industrial Environmental Research Laboratory-Cincinnati
Edison, New Jersey 08817

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the pollutional impact on our environment and even on our health often requires that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This research was undertaken as part of the objectives of the Federal Water Pollution Control Act of 1972 (PL 92-500) to eliminate the discharge of pollutants into navigable waters. To accomplish the above "it is the national policy that a major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone and the ocean." The research presented in the report addresses the objective within the stated national policy.

Based on the evidence developed in this study, the U. S. Coast Guard certified that the "aft waste treatment system" meet the standards of the U. S. Coast Guard Marine Sanitation Device Regulations. This device was one of the first to be certified.

In addition to the treatment of sanitary waste on watercraft, the physical/chemical systems developed by this project has applicability to treat sanitary wastes in remote recreational areas.

The technology demonstrated will be most useful to state administrators and legislators concerned with control and elimination of shipboard pollutants on inland waterways.

David G. Stephan
Director
Industrial Environmental Research Laboratory - Cincinnati

ABSTRACT

A research and development program to develop a waste treatment system for a 30- to 50-man commercial vessel was conducted. The program included evaluation of the system for two operating seasons (1972 and 1973) aboard the Cleveland-Cliffs ore carrier, "Cliffs Victory."

The results of the Thiokol checkout and shipboard testing are presented in depth with supporting data, data and systems analyses, and pertinent conclusions.

A summary of problems and recommended corrective action are also presented.

The Effluent from the Thiokol "aft waste treatment system" aboard the S.S. Cliffs Victory meets the standards of section 159.53(b) of the U.S. Coast Guard Marine Sanitation Device Regulations (33CFR. Part 159). The system was certified on May 12, 1975, by the U.S. Coast Guard as a discharge type marine sanitation device under 33 CFR 159.12.

The report was submitted in fulfillment of Grant No. 15020HLY under the partial sponsorship of the U.S. Environmental Protection Agency.

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ACKNOWLEDGEMENTS

This program which extended over a period of two years was accomplished with the cooperation of many individuals in the Government and the contractor organizations.

The support and guidance of the EPA, Edison, New Jersey, Water Quality Laboratory, specifically Mr. Leo T. McCarthy and Mr. William Librizzi, are acknowledged with sincere thanks.

The development and demonstration testing was carried out by a combined team from The Cleveland-Cliffs Iron Company and Thiokol Corporation, Wasatch Division. Key members of the Cleveland-Cliffs team were Mr. John Horton, Assistant Manager, Marine Department, and Mr. John C. Culbertson, Fleet Engineer. Key members of the Thiokol team were Mr. Peter E. Lakomski, who served as Project Engineer for the program, and Mr. Sheldon E. Moore and Mr. Robert W. Coleman, who were responsible for shipboard installation and testing. The cooperation and technical assistance of the Cliffs Victory crew, specifically Captain John Packer, Dan Ditschmann, Chief Engineer, and Don Draves and Frank Babilya from the ship's engineering department, are also acknowledged.

SECTION I

CONCLUSIONS

1. As a result of this program, a waste treatment system (meeting proposed standards for discharge of sanitary waste) has been demonstrated.

2. Test results indicated the need for pre-treating or eliminating galley waste from the sanitary waste treatment system.

3. Incineration was demonstrated as a feasible approach for destruction of sludge aboard ship.

SECTION II

RECOMMENDATIONS

1. Upgrade the waste treatment systems aboard the Cliffs Victory to reflect results of the demonstration testing and conduct an extended demonstration program.

2. Modify the ship's plumbing to incorporate grease traps in the galley and re-evaluate system's ability to treat combined galley/sanitary waste.

3. Apply the system to the treatment of waste in recreation areas, campgrounds, etc.

SECTION III
INTRODUCTION

STATEMENT OF PROBLEM

The need for protection of the environment in this country has received significant recognition in recent years. The Water Quality Act of 1970 addressed itself to this problem and the Federal Water Pollution Control Act Amendments of 1972, PL 92-500, enacted October 18, 1973, was probably the most comprehensive water legislation ever to come out of the Congress. The objective of the Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." As stated in the Act, "it is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985" and "that wherever obtainable, an interim goal of water quality which provides for the protection and propagation of fish, shell fish, and wild life and provides for recreation in and on the water be achieved by July 1, 1983." Further, to accomplish the above "it is the national policy that a major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone, and the oceans.

OBJECTIVES

One of the major inland waterways of the United States subject to heavy commercial and recreational boating traffic and associated pollution is the Great Lakes. The objectives of the program described in this final report were to develop and demonstrate physical-chemical waste treatment systems to treat the various waste streams (sanitary, galley, shower, and washwater) aboard an operating ore carrier on the Great Lakes. The program resulted in the demonstration of two such systems installed aboard the Cleveland-Cliffs Iron Company ore carrier, SS Cliffs Victory, as shown on Figure 1.

DESIGN REQUIREMENTS

Since no firm requirements were available for vessels operating in waters such as the Great Lakes, the design objectives utilized for the ship systems were based on data obtained from the Environmental Protection Agency, U.S. Navy, and U.S. Coast Guard. Requirements were established for a separate waste treatment system to treat sanitary and galley wastes and a separate system to treat shower water waste.

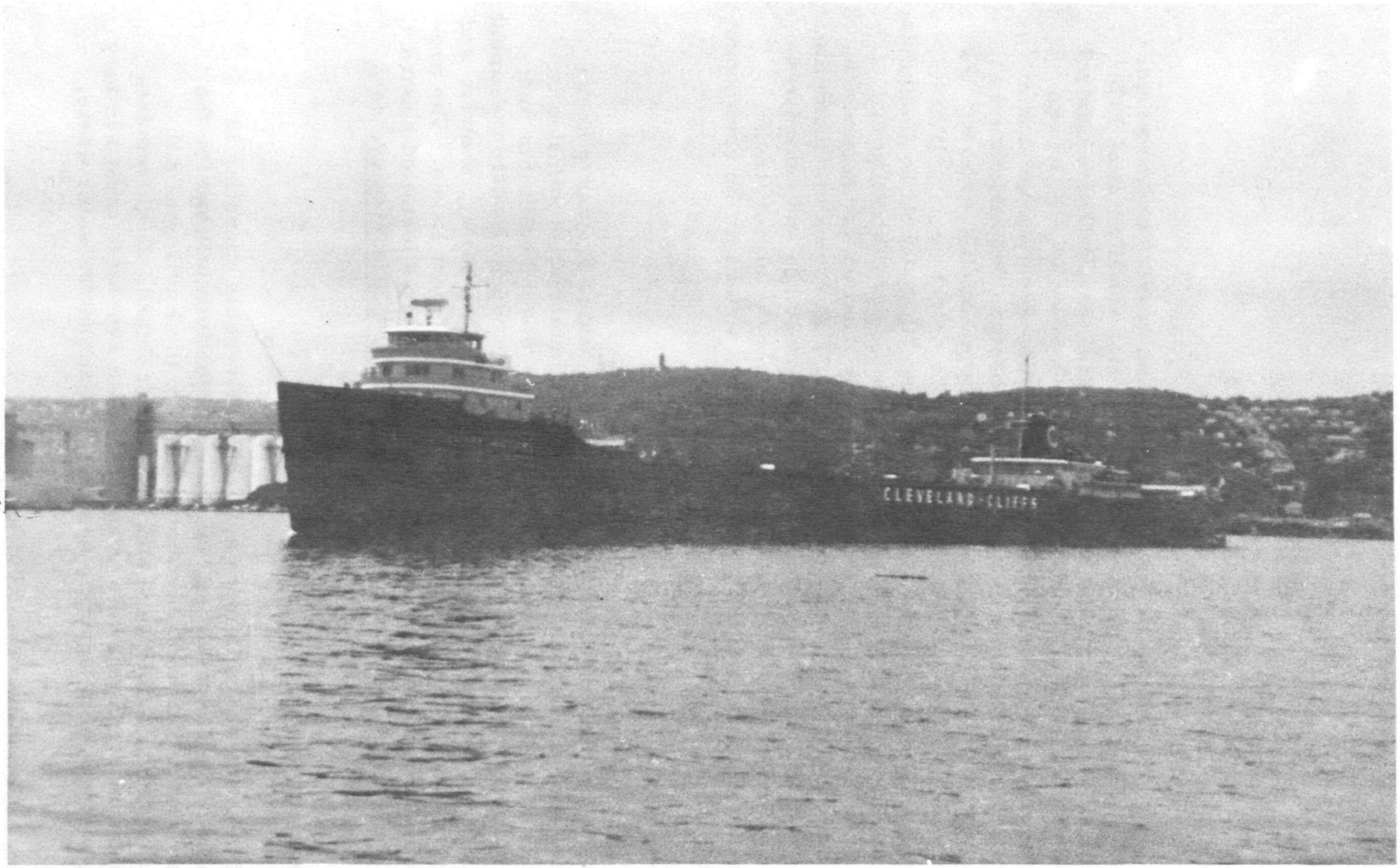


Figure 1. Cleveland-Cliffs Ore Carrier, SS "Cliffs Victory"

Table I summarizes the requirements used. The basic waste treatment system was designed to treat waste from 20 men (700 gal/day). This resulted in an average flow rate of 0.5 gpm with surge capacity for 1.0 gpm. Data obtained by Thiokol from the Coast Guard and Navy indicated that instantaneous hydraulic loadings considerably in excess of 200 percent surge could be experienced; therefore, a requirement for the system to handle an instantaneous peak hydraulic load of 20 gpm for a period not to exceed 1 minute also was established.

No specific set of design objectives was established for the shower water systems. It was agreed that these systems would consist of two 250 amp electrolytic cells each capable of generating up to 8 lb of equivalent chlorine per day, a 250 gal surge tank, and a 250 gal holding tank to provide residence time to insure complete sterilization of effluent. Identical systems were to be installed in the forward and aft ends of the Cliffs Victory.

PROGRAM DESCRIPTION

The basic program conducted involved a shore test demonstration phase followed by a shipboard installation and demonstration phase with the shipboard demonstration comprising tests over two operating seasons. The program was initiated in June 1971 and completed in December 1973. Installation of the systems aboard the Cliffs Victory was accomplished during May and June 1972. Two types of waste treatment systems were demonstrated aboard the ore carrier. The first system treated sanitary and galley waste and was comprised of a screening device and centrifuge for solids removal, a separate incinerator for solids destruction, and a catalytic oxidation system for dissolved solids removal and destruction. The second system utilized electrolytic chlorination to sterilize shower, washbasin, and laundry wastewater. Both systems were shore tested prior to shipboard installation. The objective was to produce effluents with less than 50 mg/l of suspended solids, less than 50 mg/l of BOD, and less than 240 mpn (most probable number) of coliform organisms per 100 ml from each system.

Laboratory tests on the aft waste treatment system and the forward and aft shower water sterilization systems were conducted at the Thiokol Corporation, Wasatch Division, plant site near Brigham City, Utah, during late 1971 and early 1972 and the systems were first installed and operated aboard the Cliffs Victory ore carrier during 1972. These systems were subsequently refurbished and operated for a second operating season during 1973. Table II summarizes the general results obtained during these two operating seasons. The basic systems employed during both operating seasons were identical. The aft waste treatment

TABLE I

SUMMARY OF REQUIREMENTS

Performance	
Influent physical and chemical characteristics	
Suspended solids	500 mg/l
Biochemical oxygen demand (BOD)	500 mg/l
pH	6.0 to 9.0
System capability (flow characteristics)	
Total capacity	700 gal/day
Average flow	35 gal/day/man
Surge capacity	200 percent of average
Effluent requirements	
Suspended solids	50 mg/l
BOD	50 mg/l
Coliform (most probable number)	240 mpn/100 ml
Physical	
Weight, loaded Height Length, width	Minimum compatible with space available
Durability	Capable of intermittent operation for short times and capable of being secured for long periods
Integrity	Watertight and subjected to a static pressure test
Damage protection	Protection against entry or damage from small metal and other durable objects
Installation	All components shall pass through a 26 by 66 in. door and 24 by 24 in. square hatch
Environmental	
Operating environment	Operate in fresh water
Type waste	Sanitary
Temperature	
Maximum	140° F Ambient; 95° F Influent
Minimum	40° F Ambient; 28° F Influent
Service	
Permanent trim	3 deg from normal horizontal plane
Permanent list	15 deg either side of vertical
Pitch	10 deg up or down from horizontal plane
Roll	40 deg either side of vertical (10 sec period)
Discharge	Eject against a 50 ft head
Electrical Power	
Type	Adaptable for following circuits: 440 vac, 3 phase 120/240 vac 120/208 vac, 3 phase 120 vdc

Sanitary

System to remain safe and sanitary and not create offensive or dangerous odors

Materials

Suitable for shipboard operation

TABLE II

SHIPBOARD AFT WASTE TREATMENT SYSTEM SUMMARY

	1972	1973[a]
Total days operated	200	171
Total gallons processed	120,000	100,000
Effluent analysis		
BOD (mg/l)	11-115[b]	15-70[c]
S/S (mg/l)	4-140	6-20
Coliform (mpn/100 ml)	Nil	Nil
Appearance: effluent is clear, has slight hypochlorite bleach odor.		
Influent analysis		
BOD (mg/l)	200-5,680	85-460
S/S (mg/l)	120-8,540	53-350
Coliform (mpn/100 ml)	9×10^6	15,000-600,000

[a] Thru 30 November 1973

[b] Galley and sanitary waste combined

[c] Sanitary waste only

system treated both galley and sanitary waste during 1972 and sanitary waste only during 1973. Grease from the galley (the ship was not equipped with grease traps) caused blinding of the influent screening device during the 1972 operating season causing both operational and treatment problems. As evidenced by the improved quality of the effluent (Table II) improved treatment was obtained during 1973 of the sanitary waste stream when the galley waste was eliminated.

The program demonstrated that shipboard waste streams could be treated to levels which would produce dischargeable effluents in compliance with the goals of the Federal Water Pollution Control Act.

SECTION IV

SYSTEM DESCRIPTIONS

AFT WASTE TREATMENT SYSTEM

The aft waste treatment system is depicted schematically on Figure 2 and in block diagram form on Figure 3. Major components of the system were as follows:

1. A prescreening device, manufactured by C. E. Bauer, Springfield, Ohio, to separate the coarse solids from the influent water.

2. A centrifuge for removing the remaining suspended solids.

3. A Thiokol developed catalyst which accelerated the reaction between the oxidizing agent (calcium hypochlorite) and the organic compounds in the waste stream.

4. A Thiokol developed sludge incinerator and sludge feed system to destroy the solid material removed by the screen and the centrifuge.

Figure 4 provides a photograph of this system undergoing shore test at the Thiokol Wasatch Division.

The sequence of system operation is best understood by referring to the system block diagram (Figure 3). Influent to the system entered through existing ship's piping where it was directed to the influent screen (Hydrasieve) which immediately separated coarse solids and collected them in the sludge tank. The liquid underflow through the screen (with fine solids in suspension) was collected and stored for further processing in the primary tank which contained high and low level sensors. As the liquid entered the primary tank a chemical feeder was energized and deposited the calcium hypochlorite (HTH) oxidizing agent in the tank. When sufficient waste was collected as determined by the high level sensor, the centrifuge feed pump was automatically started and the stored liquid fed to the centrifuge for further removal of suspended solids. This process continued until the liquid level in the primary tank reached the low level sensor which then shutdown the centrifuge feed pump. The collected solids in the centrifuge basket were removed by a combination of skimming

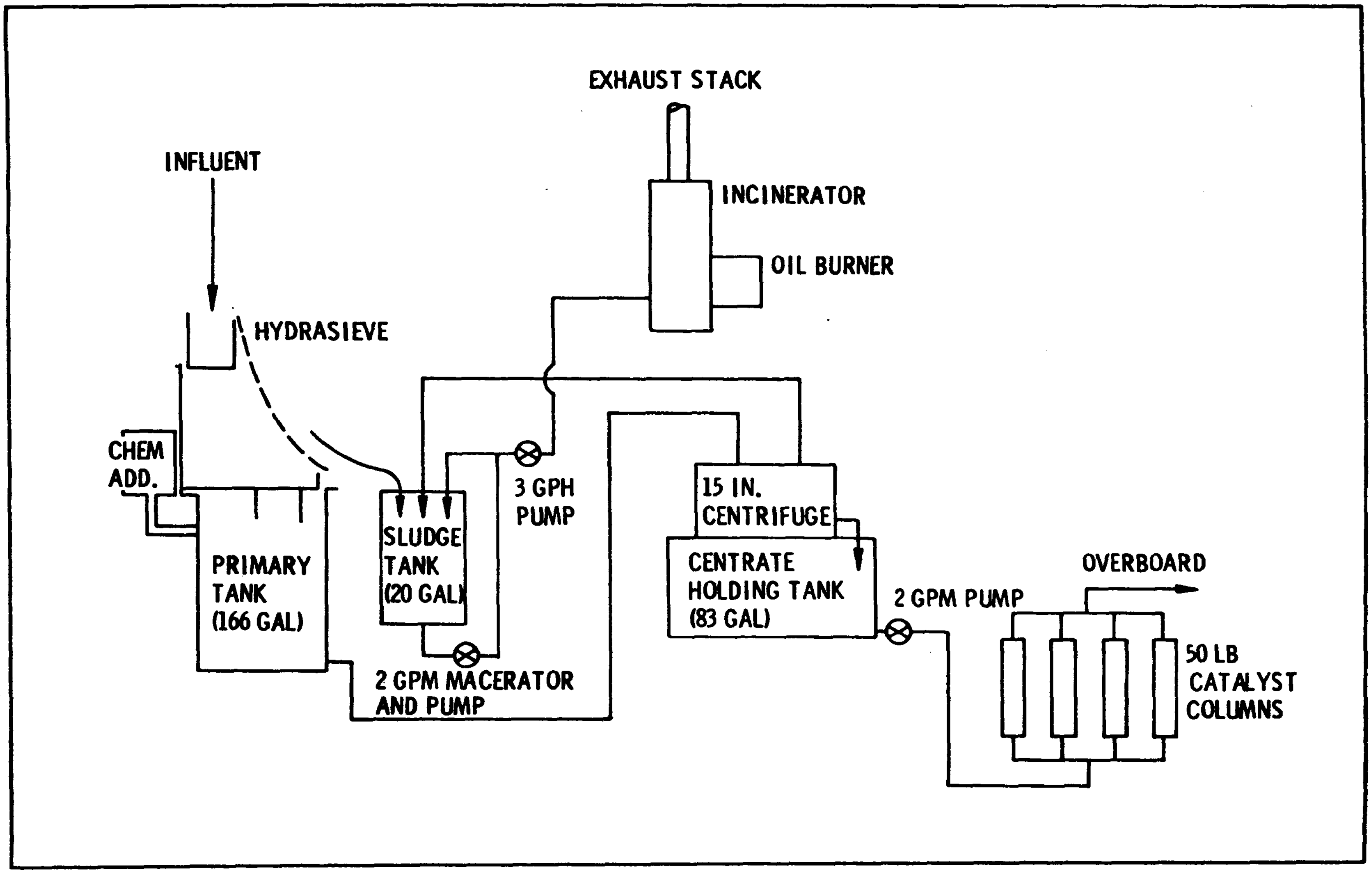


Figure 2. Aft System Schematic

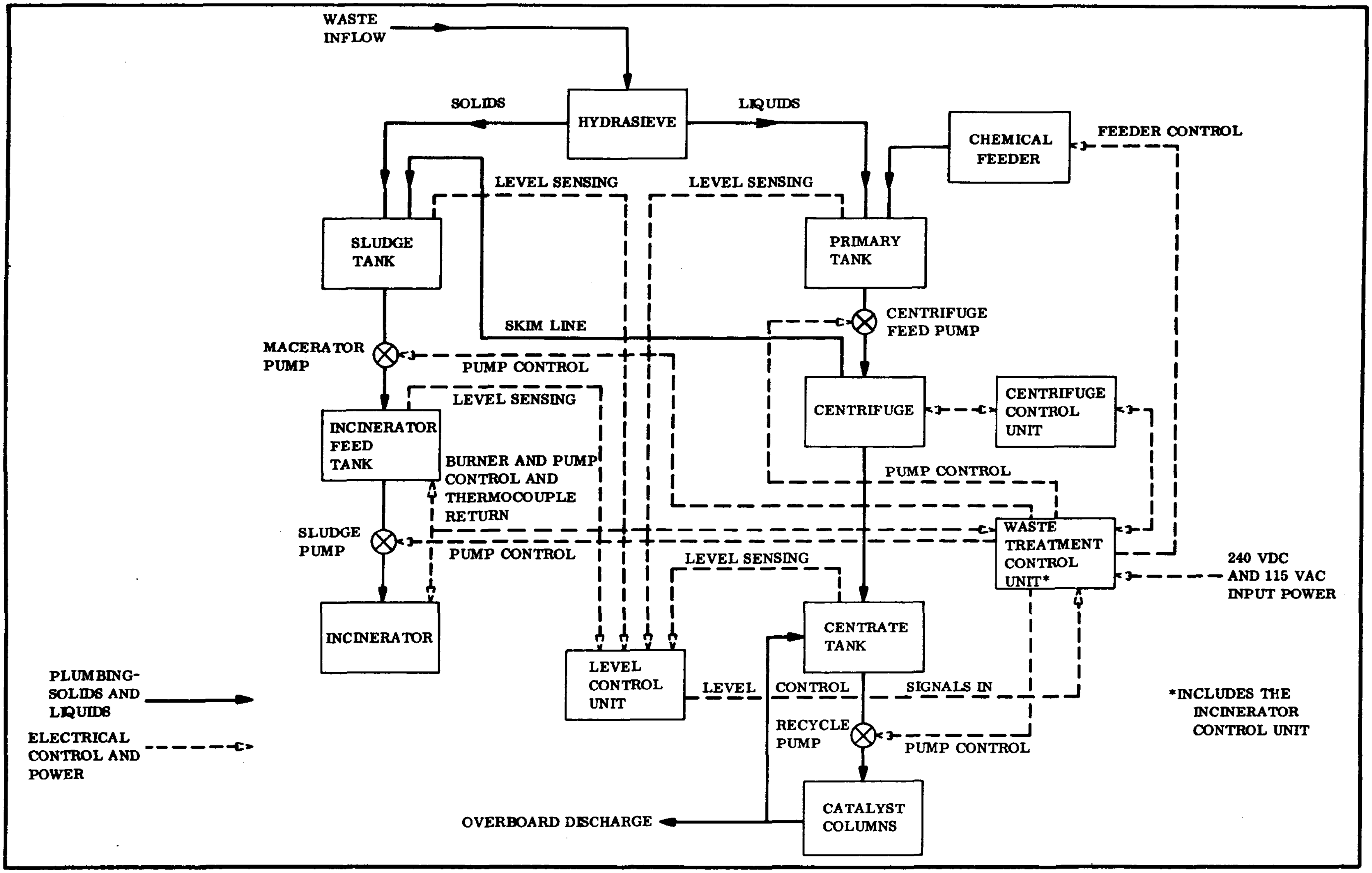


Figure 3. Aft System Block Diagram

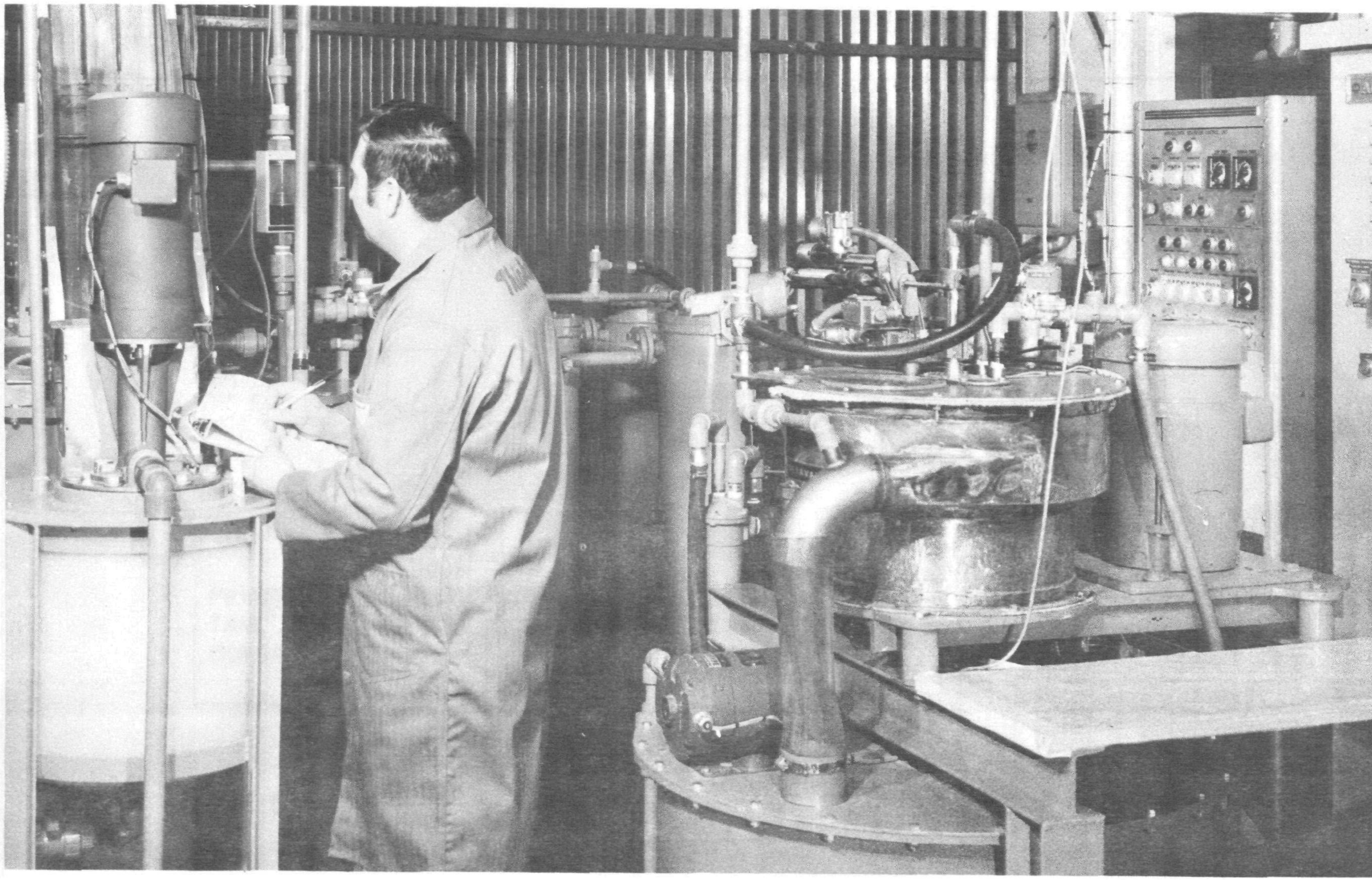


Figure 4. Aft System Shore Test Equipment

and washing controlled by cams on the centrifuge skim arm. These cams were set mechanically for proper switch operation in relation to skim tube penetration. Skimmed solids were also deposited in the sludge tank.

The clarified liquid from the centrifuge dropped into the centrate tank where it was heated to about 125°F by an immersion heater and then recirculated through catalyst columns. The recirculation and overboard dump of waste effluent was controlled by level sensing in the centrate tank. The centrate pump operated continuously during all phases of the waste treatment operation. During the period when the centrate tank was filling, the centrate liquid was in a recirculation mode: through the pump, catalyst columns, and back to the tank. When the centrate level reached the upper level sensing probe, an overboard dump solenoid was energized to cycle treated material overboard. When the level in the centrate tank dropped to the low level, the overboard dump solenoid de-energized and the system returned to the recirculation mode.

The primary tank chemical feeder operation was controlled by level sensing in the primary tank and by a percentage timing control on the side of the feeder. When the level in the primary tank was at the low level, the chemical feeder was energized. The feeder operated continuously for the time period set on the timer. At the end of continuous feeding the operation remotely switched to the feeder percentage control. This control allowed the feeder to operate at a predetermined percentage of each minute. As the level increased in the primary tank, the chemical feeder continued to dump HTH at the set percentage until such time as the level in the tank reached the high level probe. At this point, the feeder ceased all operation as previously described, and the primary pump and centrifuge started operating. The feeder resumed operation after the primary tank was pumped down.

As previously described, sludge from the influent screen and the centrifuge was stored in the sludge tank for disposal in the incineration system. As with the liquid treatment system, the sludge disposal system was level sensor controlled. System operation was initiated by the high level sensor which, in turn, initiated the following events.

- Ignition of incinerator burner
- Startup of macerator pump

The macerator pump transferred the entire contents of the sludge tank to the incinerator feed tank. Since the volumes of both tanks were equal, overflow of the feed tank was automatically prevented. Interlocks prevented the transfer of a new batch of sludge until the feed tank was empty as determined by the tank's low level sensor.

During sludge transfer the incinerator burner was in operation heating the incinerator to the proper operating temperature. Incinerator operation was temperature controlled using thermocouples located as shown on Figure 5. The incinerator was equipped with the following temperature controls.

- A low temperature cutoff set for 900°F. If for any reason the temperature fell below 900°F after once having passed through this set point, the incinerator burner automatically shut down and an alarm system was triggered.

- A low side operating temperature control set for 1150°F. Sludge feed could not be initiated until this temperature was reached. Sludge feed was automatically stopped if the temperature fell below this level.

- A high side temperature control set for 1350°F. If for any reason the temperature rose above this level during normal operation, a burner fuel oil solenoid was energized reducing oil flow to the burner thereby reducing temperature.

- A redundant high temperature safety cutoff set for 1500°F. If temperature reached this level, the burner was shut down and an alarm system triggered.

Under normal operation once the incinerator burner was turned on, temperatures rose to 1150°F and sludge feed was initiated and continued until the feed tank was empty of sludge. Stable operation was achieved after the incinerator was in operation for about 30 minutes.

The end of the normal incinerator burning cycle occurred when the level of sludge in the feed tank uncovered the lower of two probes called low differential probes. These two probes did not regulate levels in the feed tank but served as level indicators for initiating the incinerator time-out sequence. The sequence for shutdown began when the sludge level fell below the low differential probe at which time sludge feed was terminated and after a time-out period (set for 10 minutes) the burner and exhaust fan shut down.

One additional safety feature was provided in the incineration system. A flame detection device was provided to sense burner ignition. If the burner failed to ignite, the detection system caused a disruption of

TC-3: THERMOCOUPLE FOR LOW-SIDE TEMPERATURE CONTROL DURING CONTINUOUS OPERATION (1,150°).
TC-3A: THERMOCOUPLE FOR HIGH-SIDE TEMPERATURE CONTROL DURING CONTINUOUS OPERATION (1,350°F).
TC-4: THERMOCOUPLE FOR LOW-TEMPERATURE CUTOFF (900°F).
TC-5: } TC-6: } THERMOCOUPLES (REDUNDANT) FOR HIGH-TEMPERATURE CUTOFF (1,500°F).

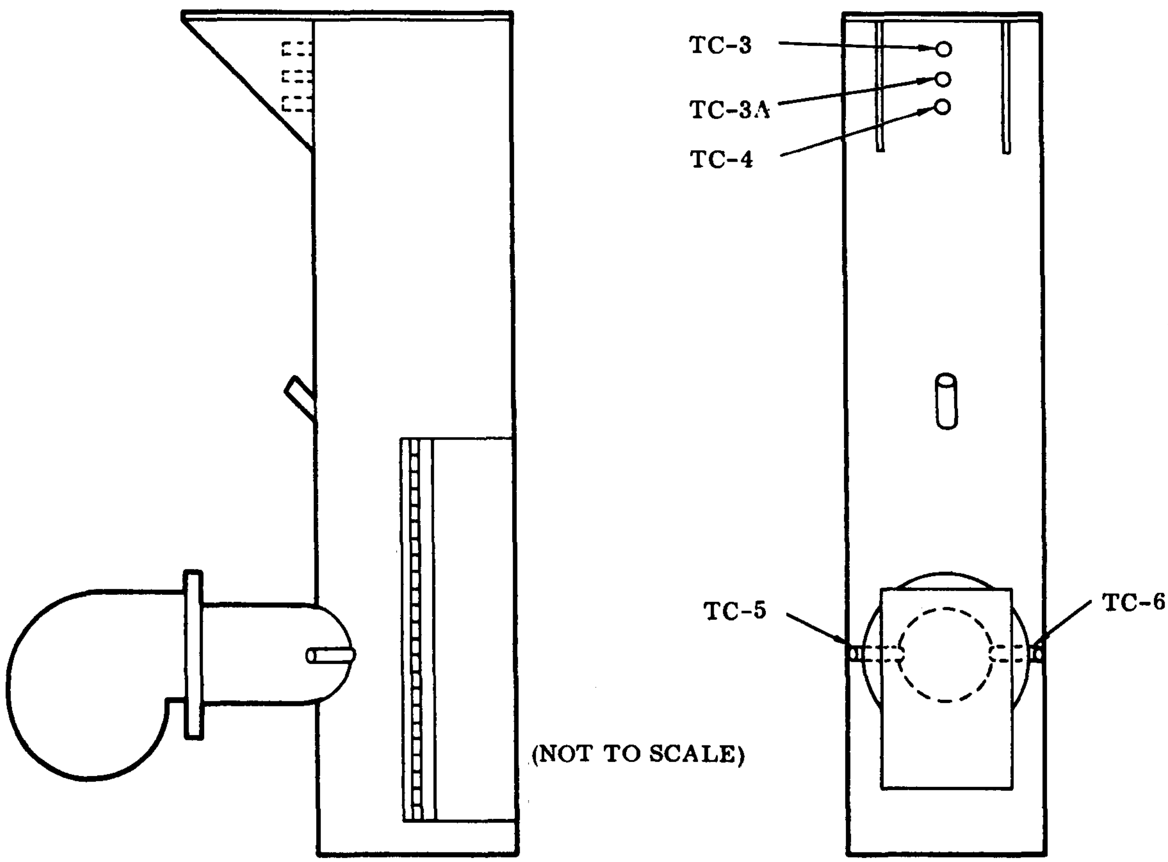


Figure 5. Incinerator Schematic Showing Placement of Control Thermocouples

electrical power to the burner motor after a short delay. At the same time, a signal was sent to the warning light on the incinerator control unit and the alarm bell and lamp. In order to restart the burner after the failure condition had been corrected (no fuel oil, plugged line, etc.), it was necessary to push the reset button on the burner controls. This safety feature complied with Coast Guard requirements for such systems.

SHOWER AND WASHWATER WASTE TREATMENT SYSTEM

The requirement for the disinfection and sterilization of shower and washwater was to maintain a residual chlorine concentration of 0.1 ppm or higher following a contact period of 30 minutes. The chlorine dosage required to achieve proper sterilization depends upon the organic content and chlorine demand of the water and, therefore, is subject to some variation.

The sterilization system design for the Cliffs Victory consisted of a surge tank for flow equalization and salt dissolution, a salt feeder, a chlorine generator, and a final 30 minute chlorine contact tank. Figure 6 provides a simplified block diagram of the system.

The method of water sterilization selected for the Cliffs Victory was unique, in that the chlorine was generated on-site by electrolytic cells. These cells convert salt, present and/or added to the wastewater stream, to hypochlorous acid as shown on Figure 7.

The electrolytic cells were purchased from Pacific Engineering and Production Company of Nevada (PEPCON). These cells consisted of a cylindrical copper cathode and a patented lead oxide coated, graphite anode as illustrated in Figure 8.

Calibration curves obtained for the PEPCON cells are shown in Figure 9 relating equivalent sodium hypochlorite output versus flow rate at salt concentrations of 0.2 and 0.4 percent. Since the chlorine demand of the wastewater on-board ship was unknown, definitions of required salt concentration, flow rates and amperage were not initially optimized.

The shower and washwater system control logic was built around liquid level sensing as the primary control element.

System operation was initiated when the level in the primary tank reached the high level probe (see Figure 6). During the period the tank was filling, salt was added to the tank by a dry chemical feeder which was automatically sequenced on by the tank low level sensor. The shower and washwater with dissolved salt was pumped through two parallel PEPCON cells where

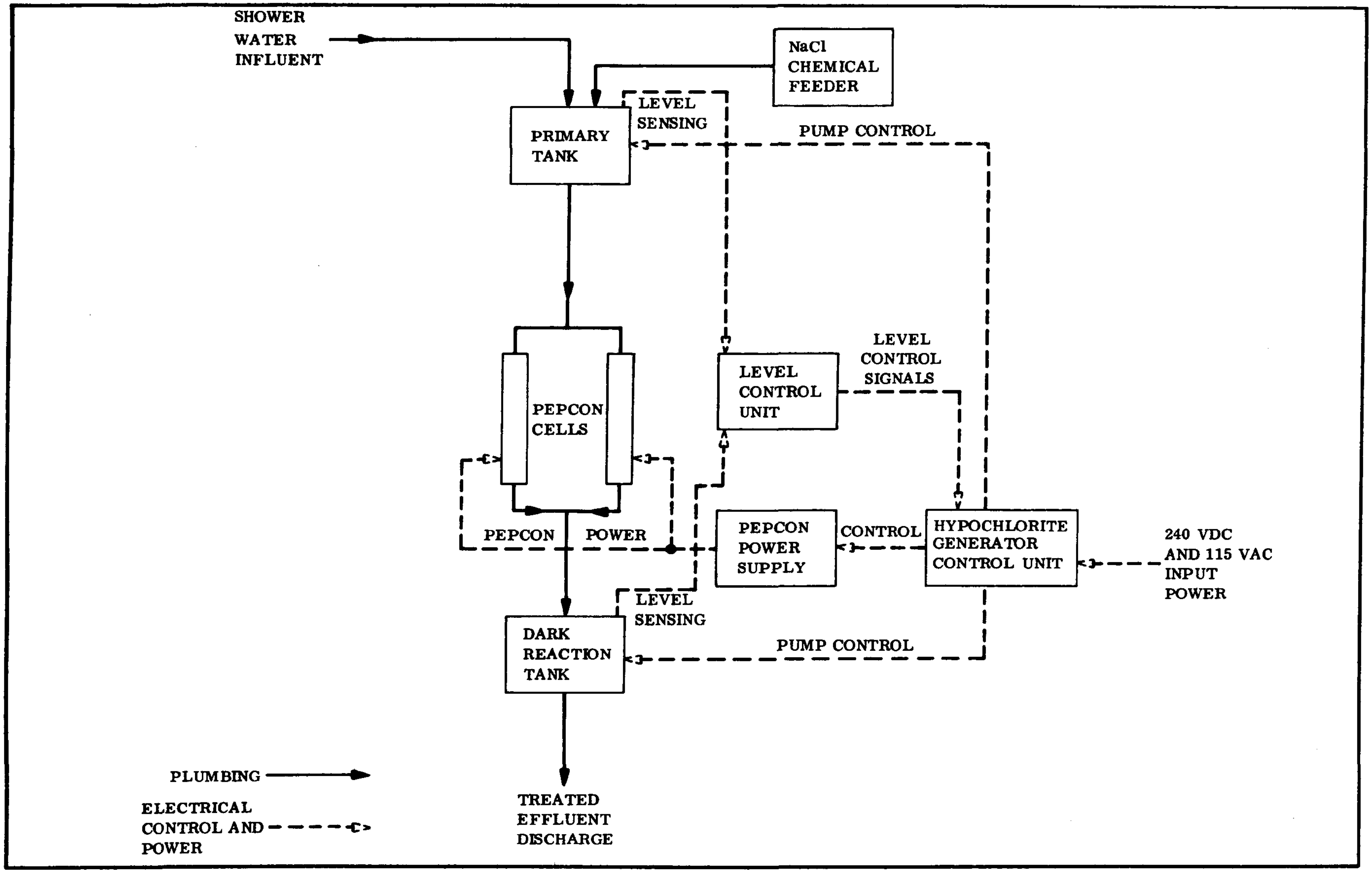
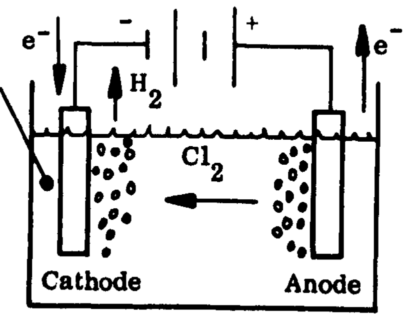


Figure 6. Shower Water Treatment System Block Diagram

Electrolytic Cell



Electrochemical Reactions

Anode

$$2NaCl \longrightarrow Cl_2 + 2Na^+ + 2e^-$$

Cathode

$$2e^- + 2H_2O \longrightarrow H_2 + 2OH^-$$

Electric Circuit

Overall Reaction

$$2NaCl + 2H_2O \xrightarrow[\text{Current}]{\text{Electric}} Cl_2 + H_2 + 2NaOH$$

Chemical Reactions

Anode Region

$$Cl_2 + H_2O \longrightarrow HOCl + HCl$$

Cathode Region

$$HCl + NaOH \longrightarrow H_2O + NaCl$$

$$HOCl + NaOH \rightleftharpoons H_2O + NaOCl$$

In Solution

$$HOCl \rightleftharpoons H^+ + OCl^-$$

H_2 and HOCl are the major end products of the cell. H_2 (hydrogen gas) is discharged into the vent system. HOCl (or OCl^-) is the chief oxidizing agent in the system and is the species which destroys the dissolved waste organic materials and assures disinfection of the recycle liquid (bacteria kill and virus inactivation).

Figure 7. Chlorine Chemistry of Thiokol Waste Treatment System

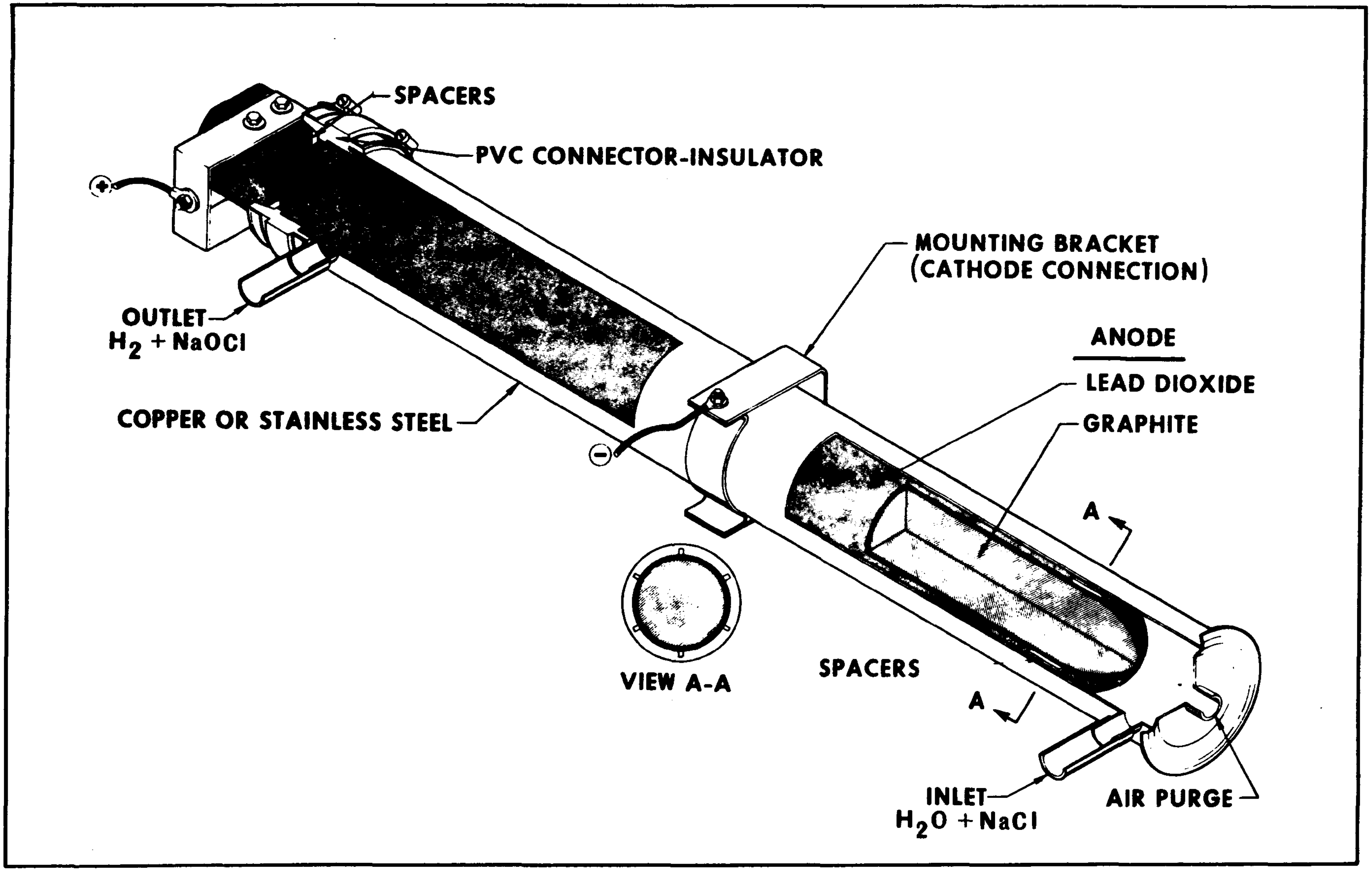


Figure 8. Standard PEPCON Cell

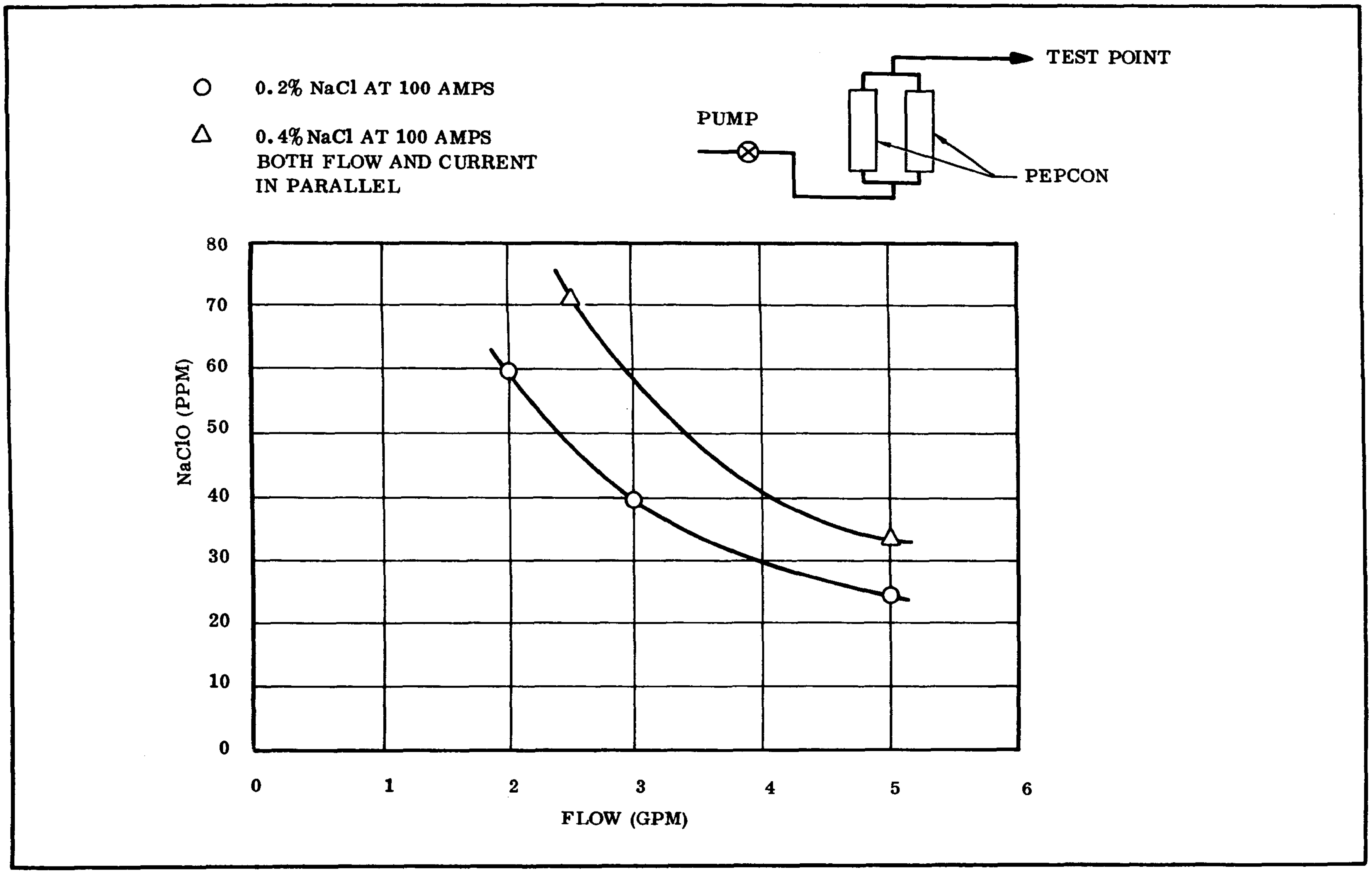


Figure 9. Hypochlorite vs Flow Curves, Forward and Aft Shower and Wash Water Tests

the hypochlorite was generated. The treated shower and washwater was then piped to the secondary or dark reactor tank. The dark reactor tank operation was also under level sensor control. As the tank received the hypochlorite-treated wastewater, the level increased to the high level probe. At this point a timer was energized to allow sufficient time for reaction of the hypochlorite with dissolved organics in the waste stream. When the timing cycle was complete, the overboard pump was started, continuing until the level in the tank was lowered to the low level probe. At this point the pump was shut down.

SECTION V

SHORE TEST PROGRAM

OBJECTIVES

Installation and operation of the waste treatment systems aboard the Cliffs Victory ore carrier were preceded by a series of shore tests at Thiokol's Wasatch Division waste treatment test facility. These tests were conducted to calibrate the systems and to check operation and maintenance requirements prior to shipboard installation. Major emphasis was placed on the aft waste treatment system since calibration data already existed on the hypochlorite generation rate of the PEPCON electrolytic cells used in the shower water systems. The aft waste treatment system was installed in a configuration which simulated the proposed shipboard installation and was operated for a period of five months. Operational tests were preceded by calibration tests and subsequent sections of this report describe the details of these tests.

CALIBRATION TESTS

Subscale pilot tests were conducted to calibrate the aft waste treatment system. A flow schematic of the subscale system is shown on Figure 10. Varying amounts of commercial hypochlorite (HTH) were added to an agitated influent tank. The contents of this tank were metered to a 20 in. dia basket centrifuge for suspended solids removal. The centrate was heated to 130-140°F using an indirect emersion-type steam heat exchanger and passed through an upflow column containing 50 lbs of Thiokol WNC-1 catalyst. The flow rate through the pilot system was 0.5 gpm. The results of these tests are presented in Table III.

A relatively high reduction in BOD, COD, and suspended solids was observed in the solids removal (centrifuge) phase of the process. The solids removed by the centrifuge contain a large portion of the materials responsible for the BOD and COD of the wastewater. A beneficial effect was also realized because of the combined action of the oxidizing agent, calcium hypochlorite, and the flocculating agent, calcium hydroxide, present in the HTH additive. A further BOD and COD reduction was observed in the catalytic phase of the process due to the catalyzed reaction of hypochlorite with the dissolved organic material in the waste stream.

As noted in the table, HTH dosages were varied from 250 to 1400 grams per 45 gal of influent. The results of variations in this dosage are

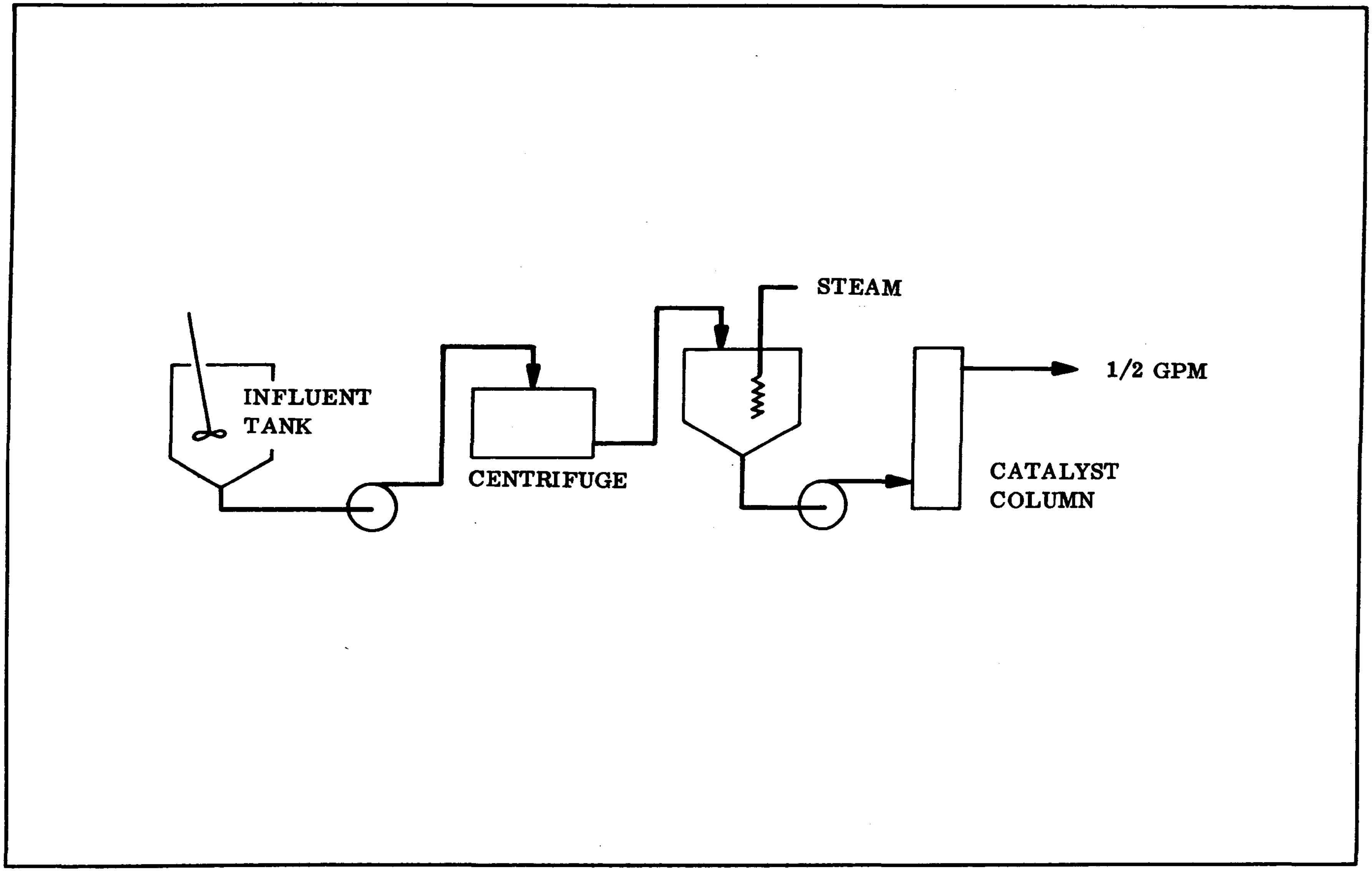


Figure 10. CCI Waste System: Subscale

TABLE III
EVALUATION OF CCI WASTE STREAM: SUBSCALE

Sewage Batch	Test	Sample	HTH (grams/45 gal)	pH	Temp (°F)	SS (mg/l)	COD (mg/l)	BOD (mg/l)
M85-085	A	Influent	1,400	8.4	79	422	1,191	N/R
		Centrate		8.2	104	23	333	
		Effluent		6.1	122	Nil	132	
M85-085	B	Influent	1,400	8.1	80	422	1,191	N/R
		Centrate		8.3	83	70	332	
		Effluent		6.8	125	10	98	
M85-086	A	Influent	1,000	-	-	268	438	150
		Centrate		8.0	132	Nil	124	-
		Effluent		6.1	127	Nil	44	43
M85-086	B	Influent	500	7.6	75	268	438	150
		Centrate		7.8	132	Nil	160	93
		Effluent		6.5	126	Nil	64	49
M85-087	A	Influent	250	7.8	76	353	717	148
		Centrate		7.4	134	38	424	115
		Effluent		6.5	126	13	324	58
M85-094	A	Influent	1,000	7.5	75	355	1,262	364
		Centrate		7.9	81	Nil	401	122
		Effluent		6.3	130	Nil	201	65
M85-094	B	Influent	500	7.7	76	355	1,262	364
		Centrate		7.7	82	Nil	442	129
		Effluent		6.3	127	Nil	311	80

illustrated in Figure 11. The BOD and COD reductions are observed to be nonlinear functions of HTH dosage. Large initial reductions are observed with comparatively small HTH dosages. Increased dosages, however, are shown to result in less significant reductions. The final BOD approached the 50 mg/l goal established for the system. The optimum HTH dosage, based on these tests, was shown to be approximately 500 gm/45 gal or approximately 2-1/2 lb/100 gal and these figures were used to establish initial operating conditions for the system operational tests.

SYSTEM OPERATIONAL TESTS

The full scale prototype of the aft waste treatment system, less incinerator, was assembled in the Thiokol plant for testing and evaluation. The system consisted of the influent screening device, surge tank, dry chemical feeder, centrifuge, centrate tank, catalyst columns and control console. The system received electrical power from an ac/dc motor generator unit to simulate the ship's electrical power. Sewage was collected daily by a tank truck and delivered to the plant for processing.

Figure 12a describes the system as it was tested without a recycle loop and Figure 12b shows the system in its final test configuration with a recycle loop prior to its assembly on board the ship. In all tests the equipment was arranged to simulate shipboard configuration.

A summary of system testing and test results is presented in Table IV.

Excessively high levels of effluent BOD were observed during the first series of tests. The cause was finally determined to be a result of problems in analysis and not in waste treatment system performance. With these problems corrected, the system performance, as described by the runs made 13 March through 29 March, appeared satisfactory. With influent BOD values ranging from a low of 285 mg/l to a high of 650 mg/l and averaging 539 mg/l, the system consistently produced an effluent having a BOD of less than 90 mg/l with the exception of one test run. The average effluent BOD during these tests was 64 mg/l. Based on these values, the system effected an average BOD reduction of approximately 88 percent.

The test runs from 10 April through 19 April were made to check out the system after the refurbishment that was required for shipboard installation had been completed. The main features of this refurbishment included replacing the four steel catalyst tanks with three PVC tanks, adding an air purge to the catalyst columns for periodic purging and cleaning, and replacing the in-line heat exchanger with an indirect

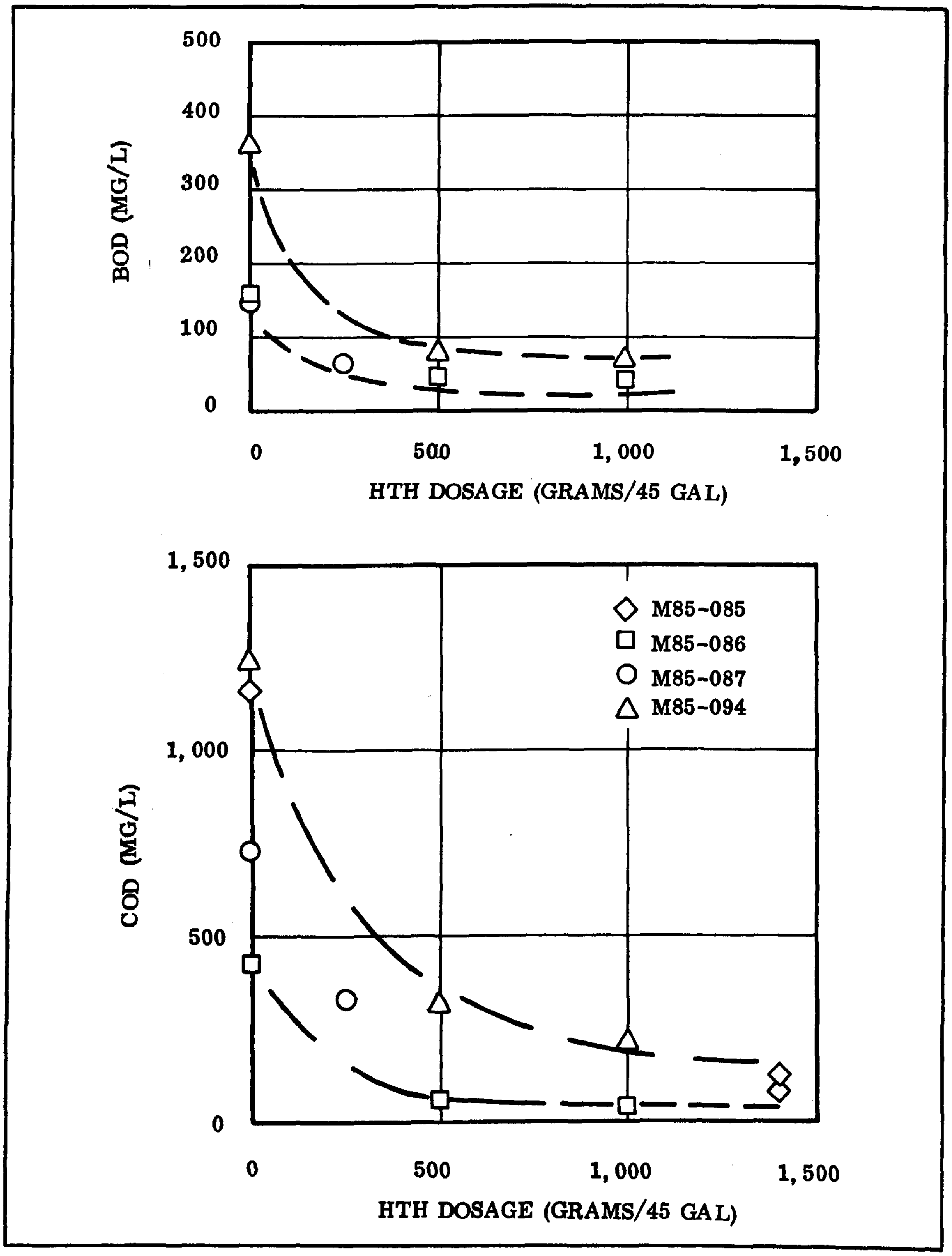


Figure 11. Effect of HTH Dosage on BOD, COD Reduction

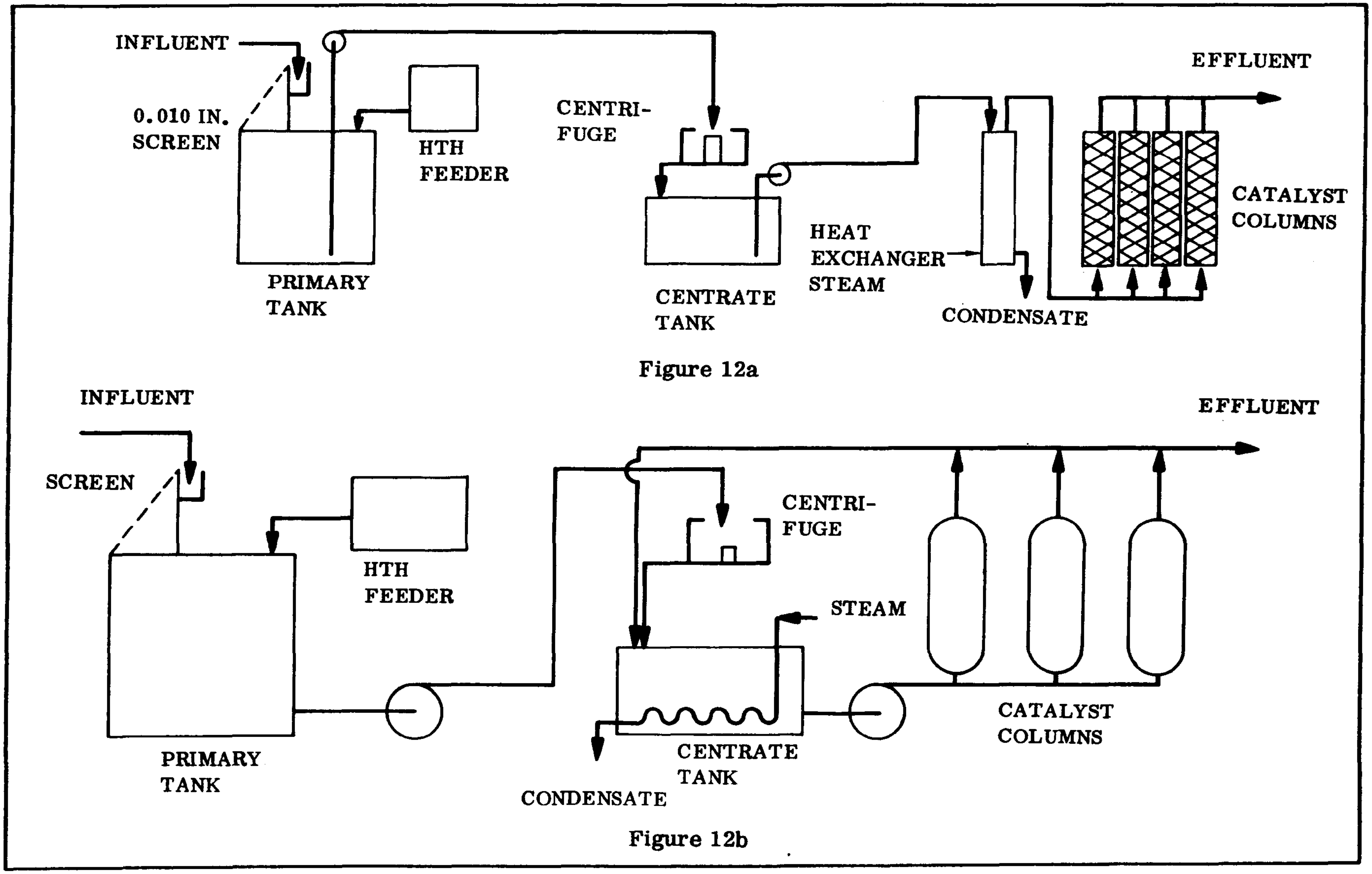


Figure 12. Prototype Schematic Flow Diagram

TABLE IV

SHORE TEST DATA SUMMARY

Configuration	Sewage Batch No.	Date	Flow Rate (gpm)	HTH Dosage (lb)	Influent BOD (mg/l)	Influent S/S (mg/l)	Centrate BOD (mg/l)	Centrate S/S (mg/l)	Effluent BOD (mg/l)	Effluent S/S (mg/l)	Problems Encountered	Corrective Action	Remarks
Original	M-85-196-1	2/29/72	0.5	2.25	N/R	N/R	302	14	212	14	Excessive differential	Replumb to go to	1 day old sewage
			1.0				322	22	272	28	temperature across	concurrent flow of	BOD-S/S test at
			1.75				352	40	302	25	catalytic columns	steam and effluent	Thiokol
	M-85-197-1	3/1/72	1.0	2.25	Old sewage - no samples						Chalky appearing effluent	Vary HTH dosage	
	M-85-197-2	3/1/72	1.0	2.25	Old sewage - no samples								
	M-85-197-3	3/1/72	1.0	2.25	Old sewage - no samples								
	M-85-198-1	3/2/72	1.0	4.50	656	468	388	54	268	24	Lime not removed during skim		Thiokol lab data
	M-85-198-2	3/2/72	1.0	3.375	656	468	368	30	268	27	Primary pump impeller failed	Replace impeller	Thiokol lab data
	M-85-198-3	3/2/72	1.0	2.25	656	468	358	20	258	24			Thiokol lab data
	M-85-202-1	3/8/72	0.5	2.25	336	667	173	19	101	26			Thiokol lab data
			1.0										Thiokol lab data
							{154	24	134	26}			
	M-85-202-2	3/8/72	1.0	2.25									
	M-85-203-1	3/9/72	1.0	2.25	No samples								
	M-85-204-1	3/9/72	1.0	2.25	810	920	180	42	72	2			Ford laboratory
	M-85-204-2	3/9/72	1.0	2.25	No samples								
	M-85-204-3	3/9/72	1.0	2.25	No samples								
	M-85-204-4	3/9/72	1.0	2.25	No samples								
	M-85-204-5	3/10/72	1.0	2.25	No samples						HTH feeder discharge caked with HTH	Relocate vent line to eliminate	
	M-85-204-6	3/10/72	1.0	2.25	No samples								
In Line Heat	M-85-205-1	3/10/72	1.0	2.25	578	560	N/R	N/R	193	28	Centrifuge would not start	Switched to man. then auto.	Thiokol lab data
Exchanger Installed											Impellers failed	Install new impellers	
	M-85-205-2	3/13/72	1.0	2.25	No samples (old sewage)								
	M-85-206-1	3/13/72	0.5	2.25	530	389	120	38	55	11	(Thiokol lab data effluent only BOD = 81, S/S = 32)		Ford lab data
		3/13/72	1.0	2.25	530	389	137	84	81	66			Ford lab data
	M-85-206-2	3/13/72	1.75	2.25	530	389	110	73	88	56			Ford lab data
	M-85-206-3	3/13/72	1.0	2.25	No samples								
	M-85-206-4	3/13/72	1.0	2.25	No samples								
	M-85-206-5	3/13/72	1.0	2.25	No samples								
	M-85-206-6	3/13/72	1.0	2.25	No samples								
	M-85-206-7	3/14/72	1.0	2.25	No samples								
	M-85-207-1	3/14/72	1.0	4.50	285	376	127	93	70	55			Ford lab data
	M-85-207-2	3/14/72	0.75	3.75	285	376	98	67	57	41			Ford lab data
	M-85-207-3	3/14/72	0.75	2.25	285	376	91	79	53	43			Ford lab data
	M-85-207-4	3/14/72	0.75	3.75	No samples							New impeller in centrate pump	
	M-85-207-5	3/14/72	1.0	3.75	No samples								
	M-85-207-6	3/15/72	1.0	2.25	1 day old - no samples								

*Recycle 4 gpm; discharge 1

TABLE IV (Cont)

SHORE TEST DATA SUMMARY

Configuration	Sewage Batch No.	Date	Flow Rate (gpm)	HTH Dosage (lb)	Influent BOD (mg/l)	Influent S/S (mg/l)	Centrate BOD (mg/l)	Centrate S/S (mg/l)	Effluent BOD (mg/l)	Effluent S/S (mg/l)	Problems Encountered	Corrective Action	Remarks
Worthington Pumps	M-85-208-1	3/15/72	0.75	2.25	No samples - system shut down to install Worthington pumps								
	M-85-209-1	3/21/72	1.0	2.25	No samples - pump checkout only								
	M-85-210-1	3/21/72	1.0	2.25									
	M-85-210-2	3/21/72	1.0	2.25									
	M-85-210-3	3/21/72	1.0	2.25	610	558	N/R	N/R	118	27	Composite sample		
	M-85-210-4	3/21/72	1.0	2.25									
	M-85-210-5	3/21/72	1.0	2.25									
	M-85-211-1	3/22/72	1.0	1.125	No samples						Heat exchanger tubes blinding with lime	Wash with HCl	
	M-85-211-2	3/22/72	1.0	1.70									
	M-85-212-1	3/23/72	1.0	1.125	616	614	215	92	85	51			Ford lab data
	M-85-212-2	3/23/72	1.0	1.70	No samples								
	M-85-212-3	3/23/72	1.0	1.70	616	614	241	55	74	40			Ford lab data
	M-85-212-4	3/23/72	1.0	2.25									
	M-85-212-5	3/23/72	1.0	2.25	505	990	N/R	N/R	56	61	Composite sample		Ford lab data
	M-85-212-6	3/23/72	1.0	2.25									
	M-85-213-1	3/24/72		1.70	Centrate sampled as follows with corresponding S/S (Influent + HTH = 322 Mg/l S/S)								Remainder of batch ran at 0.5 gpm
					Flow 0.5 gpm	S/S 65 mg/l	Flow 1.0 gpm	S/S 61 mg/l	Flow 1.0 gpm	S/S 77.5 mg/l	Flow 1.75 gpm	S/S 83 mg/l	
			0.5	1.70	630	395	162	39	52	26			Ford lab data
	M-85-213-2	3/24/72	1.0	1.70			170	43	49	23			Ford lab data
	M-85-213-3	3/24/72	1.0	1.125			177	45	44	20			Ford lab data
	M-85-213-4	3/24/72	1.0	2.25			168	35	53	22			Ford lab data
	M-85-213-5	3/24/72	1.0	2.25			190	49	50	23			Ford lab data
	M-85-213-6	3/27/72	1.0	2.25	Old sewage - no samples								
6 Gal Clorox/120 Gal in Lieu of HTH	M-85-214-1	3/27/72	1.0	--	650	334	207	40	48	15			Ford lab data
	M-85-215-1	3/28/72	1.0*	2.25									
	M-85-215-2	3/28/72	1.0	2.25									
	M-85-215-3	3/28/72	1.0	2.25									
	M-85-215-4	3/28/72	1.0	2.25	477	344	180	30	52	20	Cleaned heat exchanger with HCl, added recycle to centrate tank at 4.0 gpm; 1.0 gpm discharge. Design of immersion heat exchanger started. Composite sample		Ford lab data
	M-85-215-5	3/28/72	1.0	2.25									
	M-85-215-6	3/28/72	1.0	2.25									
	M-85-215-7	3/29/72	1.0	2.25	Old sewage - no samples								

*Recycle 4 gpm; discharge 1

steam heat exchanger probe in the centrate tank (see Figures 12a and 12b). The system was operated in this new configuration for a 7-day period. The data that were taken during this checkout period are included in Table V. The higher effluent BOD values were attributed to the reduction in total mass of the catalyst in this configuration. The four steel tanks contained a total of 200 lbs of WNC-1 catalyst whereas the three PVC columns contained 120 lbs. Rather than conducting any further shore tests it was decided to install the system aboard ship and add additional catalyst on board the ship as dictated by shipboard test data.

The effluent BOD data for all system operational tests are shown plotted versus HTH dosage in Figure 13. The general trend of the data as shown by the sketched curve shows a requirement of two or more pounds of HTH per 100 gal of wastewater for satisfactory treatment. The data scatter at 2.25 lbs shows the effect of reducing the volume (mass) of catalyst in the system. Catalyst weight is indicated on the figure.

In summary, the laboratory test data showed that, with proper operation, the system would effectively treat raw sewage and produce an acceptable effluent with low BOD and suspended solids levels and a nil coliform count.

TABLE V

TESTING SUMMARY (WITH SHIPBOARD REFURBISHMENTS)

Sewage Batch	Batch Numbers	Date	Sample	Primary Tank HTH Dosage (lb/100 gal)	Flow (gpm)	Centrate Tank Recycle (gpm)	Avg Temp (°F)	Avg Chlorine (ppm)	BOD (mg/l)	S/S (mg/l)	Lab
M85-222	2-11	4/10	Influent	--	-	-	65	-	350	360	Ford
			Effluent	2-1/4	1	8	130	108	110	26	
M85-223	3-9	4/11	Influent	--	-	-	65	-	490	484	
			Effluent	2-1/4	1	9	132	178	127	31	
M85-224	1-9	4/12	Influent	--	-	-	65	-	560	462	
	1-2		Effluent	2-1/4	1	9	135	50	148	21	
	3-9		Effluent	1-1/2	1	9	133	50	123	20	
M85-225	2-9	4/13	Influent	--	-	-	65	-	420	526	
	2-3		Effluent	3/4	1	8	135	Nil	186	41	
	5-6		Effluent	1-1/2	1	8	133	95	76	30	
	8-9		Effluent	2-1/4	1	8	133	50	74	28	
M85-226	2-10*	4/14	Influent	--	-	-	65	-	518	382	
	2-10*		Effluent	1-1/2	1	10	132	227	175	40	
M85-227	1-9	4/18	Influent	--	-	-	65	-	416	309	
	1-9		Effluent	2-1/4	1	9	133	198	72	44	
M85-228	1-4	4/19	Influent	--	-	-	65	-	419	301	
	1-4		Effluent	2-1/4	1	8	135	128	68	40	

*Continuous run (1,000 gallons)

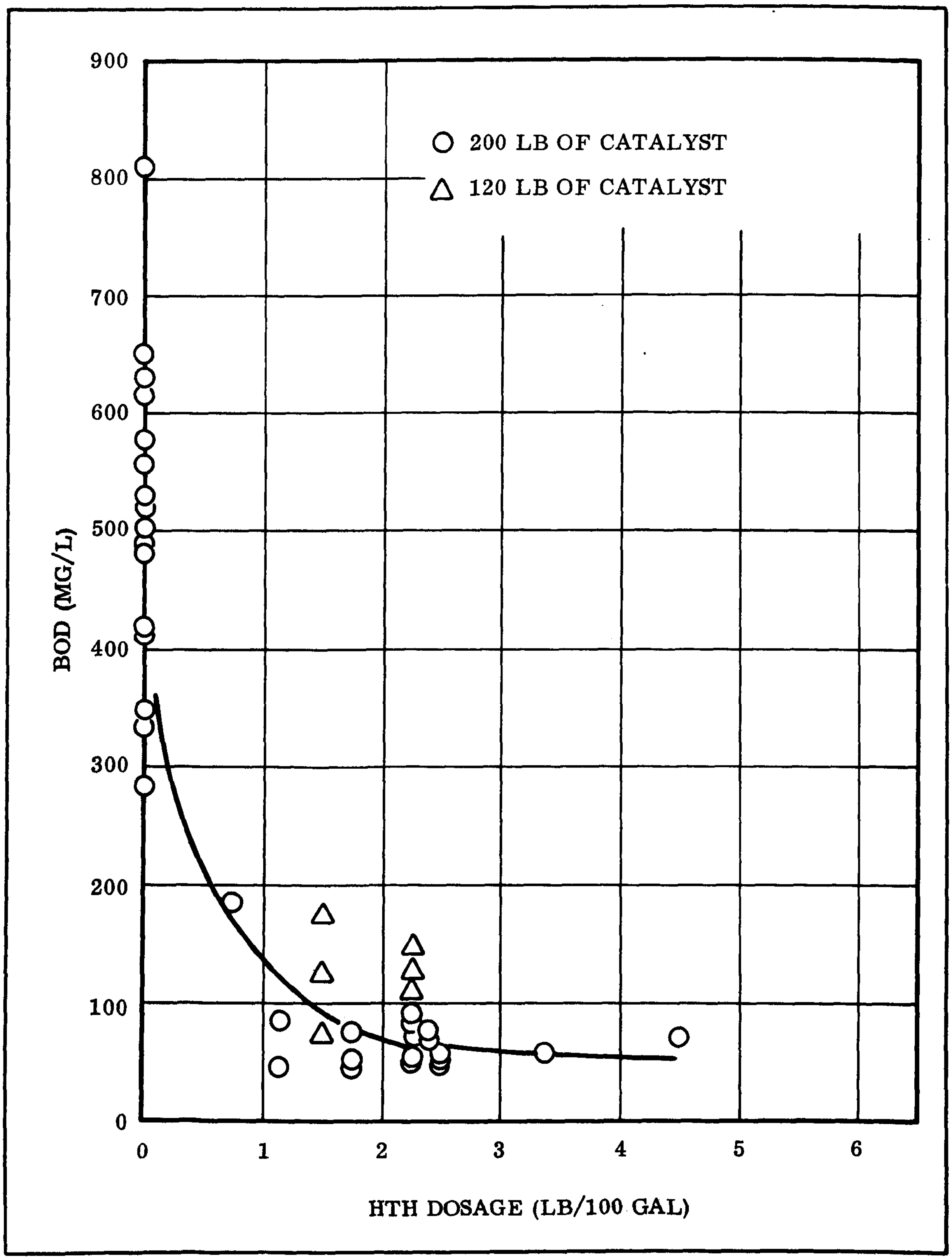


Figure 13. System Performance, BOD vs HTH Dosage

SECTION VI
SHIPBOARD TEST PROGRAM

1972 PROGRAM

Aft Waste Treatment System

Installation of the aft waste treatment system less the incinerator was accomplished in the Spring of 1972. The incinerator became available and was installed in October of 1972. Actual system operation was initiated on 22 June 1972 and the system remained in operation through December 1972. The shipboard test program involved the collection and analysis of influent, centrate, and effluent samples as well as monitoring of equipment performance and reliability. Since laboratory facilities did not exist aboard ship it was necessary to collect samples for analysis by shoreside laboratories. As a result, much of the initial sampling was involved in the development of uniform analytical procedures and methods for obtaining and blending of samples to be analyzed by the various laboratories. Three laboratories were utilized to analyze samples, WAL, Inc., of Independence, Ohio; Ford Laboratories of Salt Lake City, Utah; and the Thiokol Corporation laboratory at Brigham City, Utah. The basic procedures finally utilized after initial sampling are summarized in Appendix A. This procedure dated 1 December 1972 was placed in effect on 9 December 1972.

Data from the 1972 shipboard tests are summarized in Tables VI and VII. Table VI presents the data prior to implementation of the uniform test procedure outlined in Appendix A and Table VII presents the data after this procedure was in effect. It will be noted that the later Table VII data show excellent correlation between the Ford and Thiokol laboratories compared to the earlier data. Only a limited number of samples were analyzed by the WAL Labs and were insufficient to make any correlations.

Several preliminary observations and/or conclusions were made regarding the 1972 shipboard test data as follows:

- Significantly higher influent BOD's and suspended solids were observed in the shipboard waste compared to the shoreside waste. Shoreside waste influent approximated the design influent criteria of 500 mg/l BOD and suspended solids (see Table IV). Shipboard influents showed a

TABLE VI

SHIPBOARD TEST DATA (WITHOUT REVISED ANALYTICAL METHODS)

Sample Date	Laboratory*	Influent BOD (mg/l)	Influent S/S (mg/l)	Effluent (25 min) BOD (mg/l)	Effluent (25 min) % Red.	Effluent (25 min) S/S (mg/l)	Effluent (25 min) % Red.	Effluent (45 min) BOD (mg/l)	Effluent (45 min) % Red.	Effluent (45 min) S/S (mg/l)	Effluent (45 min) % Red.	Remarks
29 Jun 72	WAL	48	124					11	77	30	75	
11 Jul 72	WAL	817	136					27	95	4	97	
12 Jul 72 (1030)	Thiokol							63	--	12	--	
17 Jul 72 (0830)	Thiokol							71	--	26	--	
17 Jul 72 (1130)	Thiokol							76	--	20	--	
22 Jul 72	Thiokol							45	--	20	--	
24 Jul 72	WAL							146	--	35	--	
8 Aug 72	Thiokol							76	--	18	--	Duplicate samples
8 Aug 72	WAL							35	--	22	--	
30 Aug 72	WAL	270	142					241	?	36	--	Analysis questioned
30 Aug 72	WAL	231	188					254	?	26	--	
13 Oct 72	Ford	890	850	188	79	76	91	196	78	52	94	Data inconsistent
13 Oct 72	Thiokol	207	141	190	--	34	--	172	--	28	--	
27 Oct 72	Ford	985	610	210	79	88	91	60	94	65	92	Total galley waste diverted to aft sewage treatment system
29 Oct 72	Ford	327	284	65	80	46	84	52	84	38	87	
30 Oct 72	Ford	1,120	1,650	192	83	216	87	86	92	78	96	
31 Oct 72	Ford	1,080	620	231	79	44	93	135	88	38	94	
31 Oct 72	Thiokol	425	112	229	47	24	73	208	49	Sample Lost		
3 Nov 72	Ford	2,050	1,012	250	88	230	78	216	90	222	78	
3 Nov 72	Thiokol	1,390	748	145	88	242	71	164	78	161	78	
4 Nov 72	Ford	923	660	108	88	58	76	68	93	35	95	HTH dosage increased to 3,750 from 2,500 ppm
5 Nov 72	Ford	1,419	770	108	93	65	92	79	95	53	93	
6 Nov 72	Ford	1,380	985	138	90	160	84	115	92	149	85	
7 Nov 72	Ford	1,350	920	625	54	112	88	105	92	98	89	
8 Nov 72	Ford	998	774	203	78	75	90	87	91	48	94	
8 Nov 72	Thiokol	780	218	165	79	68	69	205	74	45	78	
9 Nov 72	Ford	1,210	834	480	60	46	94	90	93	50	94	
10 Nov 72	Ford	1,642	5,060	318	80	55	99	216	88	36	99	
10 Nov 72	Thiokol	790	375	558	29	79	80	500	37	55	87	
11 Nov 72	Ford	1,050	630	284	73	47	92	78	93	39	94	

*WAL, Inc Pollution Control Consultant, Independence, Ohio
Ford Chemical Laboratory, Inc, Salt Lake City, Utah
Thiokol/Wasatch Division Laboratory, Brigham City, Utah

TABLE VI (Cont)

SHIPBOARD TEST DATA (WITHOUT REVISED ANALYTICAL METHODS)

Sample Date	Laboratory*	Influent BOD (mg/l)	Influent S/S (mg/l)	Effluent (25 min) BOD (mg/l)	Effluent (25 min) % Red.	Effluent (25 min) S/S (mg/l)	Effluent (25 min) % Red.	Effluent (45 min) BOD (mg/l)	Effluent (45 min) %Red.	Effluent (45 min) S/S (mg/l)	Effluent (45 min) % Red.	Remarks
12 Nov 72	Ford	870	664	228	74	78	88	63	93	60	90	
12 Nov 72	Thiokol	2,350	432	330	85	107	68	300	85	92	68	
13 Nov 72	Ford	1,962	868	252	88	115	87	112	94	108	57	
14 Nov 72	Ford	652	483	602	--	774	?	400	--	382	--	
15 Nov 72	Ford	915	325	140	74	110	66	70	92	54	84	
16 Nov 72	Ford	3,290	2,030	276	92	74	96	96	97	69	97	
16 Nov 72	Thiokol	505	10,560	610	--	77	--	640	--	63	--	Data not consistent
17 Nov 72	Ford	513	140	113	78	93	33	58	89	43	71	
18 Nov 72	Ford	926	558	336	63	194	65	94	90	85	85	
19 Nov 72	Ford	885	434	113	85	101	78	59	63	65	85	
20 Nov 72	Ford	1,043	988	212	80	67	93	88	92	64	93	
21 Nov 72	Ford	800	595	210	75	80	86	60	92	48	92	
21 Nov 72	Thiokol	275	224	180	--	75	--	241	--	54	--	Data not consistent
22 Nov 72	Ford	820	610	135	84	113	82	81	90	102	82	
23 Nov 72	Ford	750	452	230	69	70	84	114	85	57	89	
24 Nov 72	Ford	826	260	89	89	55	78	64	92	46	78	
24 Nov 72	Thiokol	204	160	700	--	48	--	790	--	43	--	Data not consistent
25 Nov 72	Ford	912	280	130	84	216(?)	18	61	93	78	71	
26 Nov 72	Ford	698	274	330	54	250(?)	9	117	83	95	65	
27 Nov 72	Ford	650	156	130	80	96	38	114	83	73	51	
28 Nov 72	Ford	660	270	135	79	61	78	83	88	45	83	
29 Nov 72	Ford	970	864	200	79	84	90	59	94	69	93	
29 Nov 72	Thiokol	2,188	575	1,628	--	50	--	1,668	--	50	--	Only one dilution yielded data on each BOD
30 Nov 72	Ford	715	260	183	74	75	73	110	85	60	77	
1 Dec 72	Ford	883	254	270	58	88	64	117	82	73	70	
2 Dec 72	Ford	634	460	148	76	99	78	93	86	87	79	
3 Dec 72	Ford	414	216	199	51	58	73	80	80	44	82	
3 Dec 72	Thiokol	337	200	111	67	42	80	164	51	70	65	
4 Dec 72	Ford	750	236	210	72	112	54	113	85	107	54	
5 Dec 72	Ford	870	285	123	86	63	79	78	90	42	86	

*WAL, Inc Pollution Control Consultant, Independence, Ohio
Ford Chemical Laboratory, Inc, Salt Lake City, Utah
Thiokol/Wasatch Division Laboratory, Brigham City, Utah

TABLE VII

SHIPBOARD TEST DATA (WITH REVISED ANALYTICAL METHODS)

Sample Date	Laboratory	Influent		Centrate				Effluent (4 min)				Effluent (40 min)			
		BOD (mg/l)	S/S (mg/l)	BOD (mg/l)	% Red.	S/S (mg/l)	% Red.	BOD (mg/l)	% Red.	S/S (mg/l)	% Red.	BOD (mg/l)	% Red.	S/S (mg/l)	% Red.
9 Dec 72 (0800)	Ford	535	804	243	60	105	88	150	80	95	88	70	88	60	92
9 Dec 72 (0800)	Thiokol	634	758	248	52	138	83	162	75	102	87	77	88	88	85
9 Dec 72 (1300)	Ford	750	510	285	40	150	70	144	80	66	90	75	83	40	97
9 Dec 72 (1300)	Thiokol	778	620	294	48	188	50	140	82	36	95	82	89	42	94
10 Dec 72	Ford	1,380	638	350	72	74	89	218	84	80	87	162	88	60	91
10 Dec 72	Thiokol	1,400	492	360	71	78	86	213	86	40	92	164	88	49	90
11 Dec 72 (0830)	Ford	5,830	6,570	279	95	71	99	95	98	30	99	60	98	27	99
11 Dec 72 (0830)	Thiokol	5,900	5,800	334	95	60	99	140	96	32	99	55	99	32	99
11 Dec 72 (1200)	Ford	420	193	530	--	180	--	110	75	35	73	100	75	83	57
11 Dec 72 (1200)	Thiokol	514	140	768	--	280	--	100	80	13	93	92	80	54	64
11 Dec 72 (1800)	Ford	1,736	2,920	703	59	285	88	155	90	56	98	126	92	88	98
11 Dec 72 (1800)	Thiokol	3,730	144	1,556	60	154	--	424	89	38	70	952(?)	75	287(?)	--
12 Dec 72 (1400)	Ford	5,680	8,536	590	89	294	96	246	95	69	99	160	97	78	99
12 Dec 72 (1400)	Thiokol	3,450	(sample lost)	630	82	131	--	252	93	48	--	120	97	52	--
12 Dec 72 (1800)	Ford	1,790	685	744	58	278	58	250	86	75	89	160	91	78	89
12 Dec 72 (1800)	Thiokol	1,625	870	630	61	160	80	260	84	144	84	160	90	175	80
14 Dec 72 (0800)	Ford	895	694	360	59	157	77	240	71	155	76	286	68	145	76
14 Dec 72 (0800)	Thiokol	982	360	353	64	66	83	227	77	42	89	253	74	44	89
14 Dec 72 (1500)	Ford	790	486	380	52	204	57	216	72	177	62	290	63	134	73
14 Dec 72 (1500)	Thiokol	826	195	330	60	508(?)	--	234	72	49	75	314	60	32	75

wide variation and generally exceeded the 500 mg/l design condition by significant amounts (influents in the 1,000 mg/l range were not unusual).

- The higher influent BOD and suspended solids resulted in correspondingly higher effluent values for these parameters exceeding the design goals of 50 mg/l. This was to be expected since the same level of treatment was used for the shoreside and shipboard waste. Effluent samples were taken after 25 and 45 minutes of treatment on the early tests (Table VI) and after 4 and 40 minutes on the later tests (Table VII). This change in sampling time was made to provide data at the beginning of the overboard discharge time as well as at the end. Although higher than design effluent values were experienced, percentage removals were generally good. Average BOD removal (see Table VII) was 83 percent after 4 minutes and 88 percent after 40 minutes.

- The high influent BOD and suspended solids levels were attributed to the fact that the shipboard system treated both the sanitary and galley wastes. Only limited quantities of galley wastes were included in the shore test influent. The wide variation in influent was attributed to the fact that galley waste entered the system on a sporadic basis and was not present in all samples and to problems in obtaining a representative influent sample. These tentative conclusions were later verified in 1973 when the galley waste was diverted from the system.

Shower Water Treatment Systems

The aft shower water treatment system was installed and activated in July 1972. As previously mentioned, this system was designed to provide sufficient hypochlorite to sterilize the discharge stream. Only limited BOD and suspended solids data were obtained from this system. These data obtained during the week of 9 to 12 December are summarized in the following listing:

Date	Effluent BOD	Effluent SS
12/9	36	17
12/10	100	105
12/11	70	33
12/12	26	22

The limited data were not sufficient to draw any final conclusions regarding system performance.

Component Performance

During 1972 several changes and modifications were made to the shipboard installation to improve system performance and reliability and to correct design deficiencies. These changes were as follows:

1. Size of discharge pipe on the dry chemical feeders (salt and hypochlorite) was increased from 1 in to 1-1/2 in. to prevent caking of these chemicals at the pipe discharge where the feed was subject to contact with moisture.

2. The high moisture content in the ship's compressed air supply necessitated the installation of traps in the air supply lines to the pneumatic actuators on the centrifuge skimmer to prevent corrosion of this actuator.

3. An effluent catalyst column was added to the system to reduce the concentration of hypochlorite in the effluent stream.

4. The initial flexible impeller centrifugal process pumps proved unsatisfactory due to a high impeller failure rate. These pumps were replaced with stainless steel fixed impeller centrifugal pumps.

5. Problems were experienced with the conductivity probe level sensors due to condensate, splashing, etc., causing short-circuiting. A plastic sheath was added to correct this condition.

6. A temperature controller was added to control steam in the centrate tank heating coil and hence temperature in the recycle liquid stream.

The shore test installation did not include the treatment of galley wastes in the solids waste treatment system. The galley drains on the ship were changed to divert this waste into the treatment system. This change created several unexpected problems. One of the first problems experienced was the accumulation of grease in the primary and sludge tanks. The floating grease layer in the primary tank interfered with the mixing of the calcium hypochlorite powder with the wastewater. The hypochlorite would pile up and float on top of the grease layer until a large accumulation would break through. The grease buildup in the tank also caused the conductivity level probes to short out, indicating false levels.

The variable liquid flow rate from the galley was also a problem. At times during a sudden large discharge of water, the Hydrasieve screen would overrun. This would result in an increased quantity of liquid in the sludge tank, placing an extra burden on the incinerator to dispose of this excess liquid.

Galley waste contained considerable abrasive material such as egg shells, bones, broken glass, kitchen utensils, etc. This abrasive material caused excessive and rapid wear on the rubber pump stators. This abrasive material also caused some scratching and gouging on the stainless steel pump rotors.

At the end of the 1972 operating season a detailed inspection of the waste treatment systems was conducted and the following observed.

1. A shipboard modification to relocate the temperature control in the centrate tank destroyed the protective plastic coating resulting in severe local corrosion of this tank in the modification area.

2. The metal (304 stainless) steam heating coils in the centrate tank failed. The chemical reaction between the hot stainless steel and the calcium hypochlorite sewage centrate caused the two coils to corrode and fail. Raw steam was being injected directly into the centrate tank solution, through the deteriorated coil, at the close of the operating season.

3. The incinerator liner fabricated from Inconel 625 was severely eroded and warped. The fused silica insulation was in excellent condition.

4. Egg shells, scouring pads, broken glass, etc., caused excessive wear of stators and rotors in the sludge macerator pump and sludge feed pump in the incineration system.

5. The PEPCON cell anodes in the aft shower water system were eroded due to bridging of the annular gap between the anode and cathode as a result of buildup of cigarette butts, hair, string, etc.

6. Centrifuge bearings required replacement.

After review of the above system, modifications and/or repairs were recommended and implemented prior to placing the system back in operation for the 1973 season. This system refurbishment is summarized on Tables VIII, IX, and X.

Refurbishment also included reactivation of the system catalyst by an acid wash. Data relating to the catalyst activity before and after acid treatment are summarized in Table XI indicating the effectiveness of the reactivation procedure. These data are presented graphically on Figure 14 relating hypochlorite concentration as a function of catalyst volume and flow rate.

1973 PROGRAM

System Description

In 1973 the aft waste treatment system was modified as previously discussed, with emphasis on improving the effluent quality and system performance by eliminating the introduction of galley waste. The basic aft system was the same as the 1972 system being comprised of an influent screen, influent holding tank, hypochlorite feeder, centrifuge, centrate tank, catalyst system, and incinerator system.

The shower water systems were identical to the 1972 systems except for the incorporation of a screen to trap and prevent foreign objects from entering the system.

TABLE VIII

MAINTENANCE SUMMARY,
SHIPBOARD AFT WASTE TREATMENT SYSTEM,
1973 OPERATING SEASON

1. Hydrasieve	2. Chemical Feeder	3. Primary Surge Tank	4. Process Pump
a. Clean	a. Replace feeder b. Enlarge feed spout	a. Repair tank bottom and coat with plasite b. Repair air manifold c. Clean conductivity level sensor probes d. Wash out and clean tank	a. Replace packing

5. Centrifuge	6. Centrate Tank	7. Recycle Pump	8. Recycle Catalyst Columns
a. Replace bearings*	a. Repair corroded area and repair Plasite coating b. Replace steam coil with titanium probe c. Replace steam control valve and added Thermowell* d. Clean conductivity sensor probes	a. Replace packing b. Replace belt	a. Acid wash and reactivation

Notes
*Incorporated during operating season

TABLE VIII (Cont)

MAINTENANCE SUMMARY,
SHIPBOARD AFT WASTE TREATMENT SYSTEM,
1973 OPERATING SEASON

9. Effluent Catalyst	10. Sludge Tank	11. Macerator Pump	12. Incinerator Feed Tank
a. Add air purge*	a. Wash out and clean tank b. Clean conductivity level sensing probes	a. Rebuild pump	a. Wash out and clean tank b. Clean conductivity level sensing probes

13. Incinerator Feed System	14. Incinerator	15. Miscellaneous	
a. Replace incinerator feed pump b. Replace three-way valve (less operator) c. Replace three-way valve operator*	a. Replace combustion chamber b. Replace feed nozzle c. Replace thermocouples	a. Replace solenoid valve in effluent line b. Replace float and orifice in flow meter c. Substitute gate valves for ball valves	

Notes
*Incorporated during operating season

TABLE IX

MAINTENANCE SUMMARY, SHIPBOARD FORWARD SHOWER TREATMENT SYSTEM, 1973 OPERATING SEASON

1. Primary Surge Tank	2. Primary Pump	3. PEPCON Cells	4. Effluent Holding Tank
a. Clean conductivity level sensor probes	a. Replace impeller b. Replace motor	a. Add silicone oil b. Drain and flush	a. Clean conductivity level sensor probes

5. Overboard Pump	6. dc Power Supply	7. Salt Feeder	8. Miscellaneous
a. None	a. Transferred to aft system as replacement*	a. Enlarge feed spout	a. Added inline screen*

Notes
*Added during operating season

TABLE X

MAINTENANCE SUMMARY, SHIPBOARD AFT SHOWER TREATMENT SYSTEM, 1973 OPERATING SEASON

1. Primary Surge Tank	2. Primary Pump	3. PEPCON Cells	4. Effluent Holding Tank
a. Clean conductivity level sensor probes	a. Replace impeller	a. Replace anodes b. Drain and flush c. Add silicone oil	a. Clean conductivity level sensor probes

5. Overboard Pump	6. dc Power Supply	7. Salt Feeder	8. Miscellaneous
a. Replace impeller	a. Removed for repair*	a. Enlarge feed spout	a. Added inline screen*

Notes
*Added during operating season

TABLE XI

WNC-1 CATALYST ACTIVITY SUMMARY,
SHIPBOARD AFT WASTE TREATMENT SYSTEM
(CATALYST COLUMN = 0.9 FT^3)

Date	Column Number	Temp (°F)	Infl Cl_2 Conc (ppm)	Effluent Cl_2 Conc (ppm) 2 gpm	1 gpm	0.5 gpm	0.25 gpm	0.125 gpm
Before Acid Rinse								
14 Feb 1973	1	120	950	800	800	688	-	-
			975	850	800	675	-	-
	2	120	1,100	950	900	813	-	-
			1,075	975	913	800	-	-
	3	120	1,013	900	845	800	525	350
			1,000	900	845	775	575	338
After Acid Rinse								
9 Jun 1973	1	120	970	600	500	362	175	-
	2	120	1,200	600	475	325	162	-
	3	120	912	537	500	337	137	-

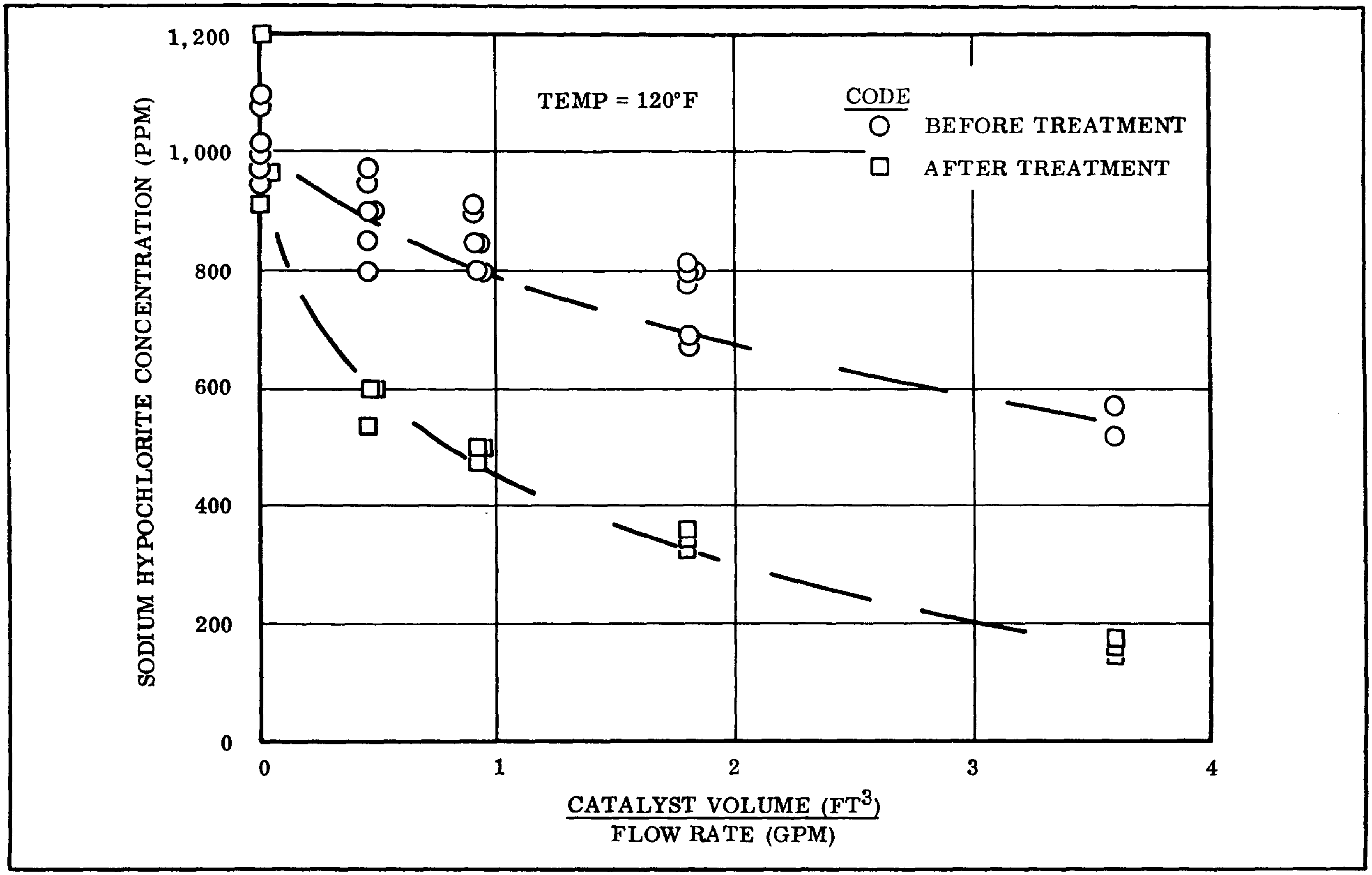


Figure 14. Shipboard Catalyst Activity Summary

Test Results

The aft waste treatment system was placed on stream on 21 June 1973. The forward and aft shower treatment systems were operational on 23 and 20 June 1973, respectively. The performance objective for the shower treatment systems was to maintain a measurable concentration of residual chlorine in the effluent following a 30 minute detention period. This is achieved by the addition of salt to the shower wastewater, and metering the resulting solution through two small electrolytic cells for the conversion of the chloride ion to chlorine. Following startup of the aft shower treatment system, residual chlorine concentrations were monitored. These data are presented in Table XII. The initial concentrations of 30 to 40 ppm chlorine were considered excessive. The salinity of the water was, therefore, reduced as noted by the decreased salt feeder settings to produce chlorine concentrations of approximately 15-20 ppm.

The aft waste treatment system was intended to produce an effluent containing less than 50 mg/l of BOD and suspended solids and less than 240 mpn coliform. Influent and effluent samples were taken periodically throughout the operating season for analysis. The samples were submitted to one of four laboratories, depending upon the ship's location, for analysis. The results of these tests are presented in Table XIII. Average suspended solids concentrations of 14.3 mg/l for the 25 minute effluent sample and 10.6 mg/l for the 40 minute effluent sample were observed. A range of suspended solids concentrations from $<$1 to 54 mg/l was observed. BOD concentrations averaged 32.6 mg/l and 30.2 mg/l for the 25 and 40 minute effluent samples, respectively. A range of BOD concentrations from $<$1 to 78 mg/l was observed. All coliform tests were negative.

A comparison of the data from the 1972 operating season and the 1973 season for the aft system reveals a significant drop in BOD and suspended solids for both the influent and effluent streams. The improved performance is attributed to the elimination of galley wastes into the aft waste treatment system. The resulting average BOD of 30.2 and average suspended solids for 10.6 mg/l met the effluent quality design goal objectives for the season. The 1973 data demonstrated the ability of the system to produce effluents meeting proposed standards.

Component Performance

During the 1973 operating season several changes were made to the waste treatment system (Table XIV).

TABLE XII

PERFORMANCE SUMMARY,
SHIPBOARD AFT SHOWER TREATMENT SYSTEM,
RESIDUAL CHLORINE IN EFFLUENT

Date	Residual Chlorine Concentration (ppm)	Salt Feeder Setting	
27 Jun 1973	30	5 min	7 %
28 Jun 1973	35	5	7
	40	5	7
29 Jun 1973	30	5	5
	20	5	5
	15	4	5
30 Jun 1973	20	4	5
	15	3	5
2 Aug 1973	15	3	7

TABLE XIII

SHIPBOARD PERFORMANCE SUMMARY; AFT WASTE TREATMENT SYSTEM

	Suspended Solids (mg/l)			Biochemical Oxygen Demand (mg/l)			Coliform/100 ml		
Date	Influent	Effluent-25 min	Effluent-40 min	Influent	Effluent-25 min	Effluent-40 min	Effluent-25 min	Effluent-40 min	Laboratory
20 Jul 73	28.4	9.2*	--	270	<5*	--	0*	--	Ruble
	53.6	3.2*	5.6*	460	20*	5*	0*	0*	Ruble
21 Jul 73	--	9.4*	--	--	15*	--	0*	--	Ruble
22 Jul 73	393	380**	399**	74	3	0	--	--	WAL
23 Jul 73	390	369**	392**	27	0	0	--	--	WAL
25 Jul 73	47.6	--	5.2*	85	--	30*	--	0*	Ruble
	109	3.6*	4.8	250	7.5*	5	0*	0	Ruble
	--	5.2	5.8	--	<5	5	0	0	Ruble
28 Jul 73	61	41	18.5	290	62.5	70	0	0	Ruble
	47	15	18.5	175	40	60	0	0	Ruble
31 Jul 73	8	29.5	22	70	52.5	52.5	0	0	Ruble
	31	17.5	17.5	260	42.5	55	0	0	Ruble
3 Aug 73	422	10.4	--	490	74	--	0	--	Ruble
5 Aug 73	270	54	--	160	27.5	--	0	--	Ruble
23 Aug 73	100	5.5	6.4	290	30	1	--	--	Ruble
	24.5	6.0	10.8	120	<1	1	--	--	Ruble
27 Aug 73	54	9.2	5.6	185	78	78	--	--	Ruble
8 Oct 73	167	7	9	375	41	23	--	--	ECO-Labs
18 Oct 73	302	1	2	550	30	38	--	--	ECO-Labs
26 Oct 73	140	<1	<1	525	3	2	--	--	ECO-Labs
13 Nov 73	1,128	21	26	1,030	28	32	--	--	Buffalo
15 Nov 73	196	7	8	470	59.4	29.4	0	0	Ruble
22 Nov 73	193	27	25	201	42	52	--	--	Buffalo
25 Nov 73	115	3	10	180	78	60	0	0	Ruble
28 Nov 73	362	46	10	256	39	1	--	--	Ruble
1 Dec 73	268	10	11	300	23.7	29.4	0	0	Ruble
6 Dec 73	213	12.5	12	61	14	15	--	--	Buffalo
7 Dec 73	40	5	4	300	42	53	0	0	Ruble
12 Dec 73	118	12	5	185	39	45	0	0	Ruble
17 Dec 73	356	15	10	530	43	22	0	0	Ruble
Avg***	201.3	14.3	10.6	292	32.6	30.2	0	0	

*Samples taken at times other than 25 and 40 minutes.
**Suspect data, not included in averages.
***Maximum values of data reported as "<x" were used in averages.

TABLE XIV

PROCESS IMPROVEMENTS,
AFT WASTE TREATMENT SYSTEM,
1973 OPERATING SEASON

1. Process Pump

   a. Substituted positive displacement pump to prevent flow variations.

2. Centrifuge

   a. Allow centrifuge to run continuously with skim cycle based on cumulative process time in order to reduce frequency of skim cycles and volume of sludge to be incinerated.

3. Conductivity Level Sensing Probe

   a. Substituted titanium probes for Monel to preclude corrosion.

4. Flush Valves

   a. Substituted Dolphin marine valves to preclude sticking and non-functioning due to contaminants in flush water.

A positive displacement pump was installed in the centrifuge feed line, replacing the centrifugal pump. This was done to assure a uniform flow rate independent of suction head condition. It also eliminated the need for a flow meter or flow control valve.

A major change was also made in the operation of the centrifuge cycle. Operating personnel had reported that excessive quantities of liquid were being generated for incineration. This was the result of having the centrifuge programmed to skim after each 50 gal batch is processed. It appeared that a more practical approach was to let the centrifuge operate continuously and base the skim cycle on the hours of primary pump operation. Accordingly, a change in the control logic was made which resulted in a reduced, equal and controlled delivery of sludge to the incinerator. Measurements made during a typical skim cycle showed that 4.75 gal of sludge to the incinerator were generated per cycle, as follows:

First part of skim	3.5 qts to sludge tank
Second part of skim	11.0 qts to centrate tank
Third part of skim	4.5 qts to sludge tank
Washout cycle	11.0 qts to sludge tank

Inspection of the incinerator several times during the year revealed evidence of erosion and hairline cracks developing in the area of welds on the dispersion disk. In general, however, appearance of the liner, plenum, and feed nozzle was good.

APPENDIX A
SAMPLING AND TEST PROCEDURES

1.0 Sample Handling

1.1 WAL, Inc., of Independence, Ohio, will be responsible for the splitting and distribution of all samples, especially the influent sample used for seed preparation, which are dropped in the Cleveland area. Personnel aboard the ore carrier will obtain one large volume of each sample, and WAL, Inc., will obtain these samples, blend them if necessary, and forward aliquots to Ford Laboratories of Salt Lake City, Utah, and the Thiokol laboratory at Brigham City, Utah. All samples will be properly refrigerated and will be sent by air to the Utah laboratories. All samples sent to each laboratory will be approximately one pint in volume except the seed preparation sample which will be approximately one quart in volume.

Because of the logistics problem involved with the handling of samples dropped by the ship up-lake from Cleveland, these samples will be sent directly to the Ford Laboratories in Utah, who will then forward an aliquot of each sample to Thiokol. The WAL Laboratories will not be involved with the testing of these up-lake samples.

1.2 Upon arrival at the laboratory, all samples will be immediately refrigerated at approximately 13°C (41°F) until used.

1.3 All samples will be thoroughly blended (macerated) before analysis. If excessive foaming is encountered during the blending operation, the sample will be thoroughly blended, allowed to settle, and then manually shaken to achieve proper mixing before any aliquot is taken for analysis.

1.4 Just prior to analysis, the pH of the sample will be carefully adjusted to 7 - 7.5 using reagent grade sulfuric acid and sodium hydroxide.

1.5 All chlorine in the sample and all sulfite will be quantitatively neutralized in accordance with the procedure found on page 491 of "Standard Methods for the Examination of Water and Waste Water," 13th Edition.

2.0 Seed Preparation

2.1 Draw a one-quart sample of raw domestic sewage and incubate it for 24 hours at 20°C.

2.2 Pour off about 500 ml of the sample after the 24 hour incubation period.

2.3 Replace this 500 ml by adding to the sample bottle 300 ml of fresh domestic sewage and 200 ml of influent sample from the ore carrier. Incubate this total sample for 24 hours at 20°C. This is now ready to be used as seed.

2.4 Use the supernatant (or filtrate) liquid from Step 3 above as seed for the BOD analysis.

2.5 Pour off sufficient liquid from that remaining after Step 4 to bring the seed bottle to the "minus 500 ml level" of Step 2 and repeat Steps 3, 4, and 5.

2.6 Prepare a new bottle of seed (and discard the old) each week from a new influent sample.

3.0 Biochemical Oxygen Demand (BOD) Analysis

3.1 The standard method as described on page 489 of "Standard Methods for the Examination of Water and Waste Water," 13th Edition, will be followed. All dilution water will be either double distilled, or deionized, with special attention paid to the removal of toxic substances such as copper. All BOD analyses will be run precisely five (5) days.

4.0 Dissolved Oxygen Analysis

4.1 The azide modification for dissolved oxygen determination will be used. This procedure is found on page 477 of "Standard Methods for the Examination of Water and Waste Water," 13th Edition. DO probes will not be used in this testing program, except possibly to compare the DO value with the titration value.

5.0 Suspended Solids Analysis

5.1 The standard method for determining the total suspended matter in aqueous systems, as described on page 537 of "Standard Methods for the Examination of Water and Waste Water," 13th Edition, will be followed.

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

MAILING ADDRESS:
U.S. COAST GUARD (G-MMT-3/83)
400 SEVENTH STREET SW.
WASHINGTON, D.C. 20590
PHONE: (202) 426-1444

5946/159.12/18
12 MAY 1975

Mr. P. E. Lakomski
Wasatch Division
Thiokol Corporation
P. O. Box 524
Brigham City, Utah 84302

Dear Mr. Lakomski:

Review of your submission of 10 April 1975 and the additional data supplied by Mr. Billovits on 5 May 1975 has been completed. The information supplied is accepted as evidence that the effluent from the Thiokol "aft waste treatment system" aboard the S.S. Cliffs Victory meets the standards of section 159.53(b) of the U. S. Coast Guard Marine Sanitation Device Regulations (33 CFR, Part 159). Accordingly, the Thiokol "aft waste treatment system" installed aboard the S.S. Cliffs Victory is hereby certified as a discharge type marine sanitation device under 33 CFR 159.12.

Sincerely,

C. E. MATHIEU
Captain, U. S. Coast Guard
Acting Chief, Merchant Marine Technical Division
By direction of the Commandant

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

A research and development program to develop a waste treatment system for a 30-50 man commercial vessel was conducted. The program included evaluation of the system for two operating seasons (1972 and 1973) aboard the Cleveland - Cliffs ore carrier "Cliffs Victory".

The results of the Thiokol checkout and shipboard testing are presented in depth with supporting data, data and systems analyses and pertinent conclusions.

A summary of problems and recommended corrective action are also presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Sewage treatment *Sludge disposal *Ships *Incineration *Chlorination	Great Lakes Marine sanitation device Waste characterization Physical/chemical treatment Waste water recycle	13B

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