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NAVY ADVANCED WASTE TREATMENT SYSTEM
PHASE I FINAL REPORT

Contract N00024-71-C-5332 NEW
CDRL Item A-001AG

22 December 1971

[redacted]

Thiokol / WASATCH DIVISION
A DIVISION OF THIOKOL CHEMICAL CORPORATION
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FOREWORD

Phase I of the Navy Advanced Waste Treatment System Program was conducted under Contract N00024-71-C-5332 by Thiokol Chemical Corporation, Wasatch Division, Brigham City, Utah. This final report covers the work completed between 20 April 1971 and 22 December 1971. The Navy Project Officer was Greg Harrison.

Wasatch Division personnel who contributed significantly to the development of the advanced waste treatment system and to the preparation of this report are as follows.

Paul D. Nance
Tom O'Grady
Howard McIntosh
Larry Poulter
O. Daugherty
W. Holmes

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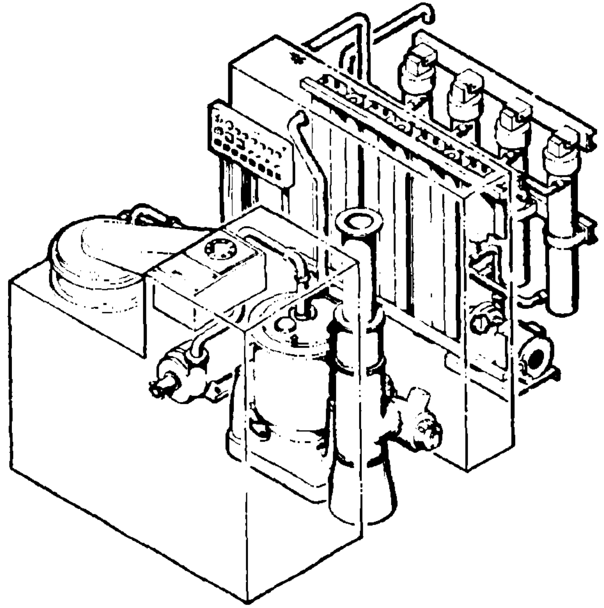
1.0 INTRODUCTION AND SUMMARY

Thiokol Chemical Corporation received a contract from the Navy to develop an advanced waste treatment system on 20 April 1971. This report covers Phase I research and development effort which has demonstrated the feasibility of Thiokol's advanced photochemical waste treatment system. The Phase I system utilizes chemical and physical processes to achieve rapid treatment with a highly compact system. A full scale system for a 200 man vessel has been fabricated and tested under Phase I. This approach eliminates the necessity to scale data from laboratory prototypes to the larger systems. Data is presented in this report on a 200 man Navy prototype system capable of treating 5,200 gal per day of sewage containing 600 mg/l of biochemical oxygen demand and 800 mg/l of suspended solids. Effluent from the sewage has been treated to a level of suspended solids under 80 mg/l, BOD under 50 mg/l, and a coliform bacteria count near zero.

Technology applied to the waste treatment system has been jointly developed by Thiokol Chemical Corporation, Pacific Engineering Production Company of Nevada (PEPCON), and Midwest Research Institute. Major components of the advanced waste treatment system include:

1. Pretreatment to remove large solids and foreign objects.
2. A high efficiency centrifuge to remove suspended solids.
3. An incinerator based upon aerospace combustion technology to destroy collected solids.
4. PEPCON electrolytic cells to generate chemicals for oxidizing dissolved solids and to destroy bacteria.
5. An ultraviolet photochemical cell or chemical catalyst to accelerate the reaction rates between oxidizing chemicals and dissolved solids.

A pictorial view of the above components and the required surge tanks is shown in Figure 1 and a schematic of the system is shown in Figure 2 . The schematic flow includes pretreatment, primary



Thirty minute process time.

Ninety to ninety-five percent total solids removal.

Six thousand gallons per day

PERFORMANCE

	Suspended Solids	Biological Oxygen Demand	Urea	Bacteria
Influent	800 mg/l	600 mg/l	350 mg/l	High
Primary Treatment	50 to 80 mg/l	400 mg/l	300 mg/l	High
Secondary Treatment	<80 mg/l	<50 mg/l	<100 mg/l	<100 mpn/100 ml
Federal Standard	150 mg/l	100 mg/l	No Standard	<240 mpn/100 ml

Figure 1. Nonbiological Waste Treatment System

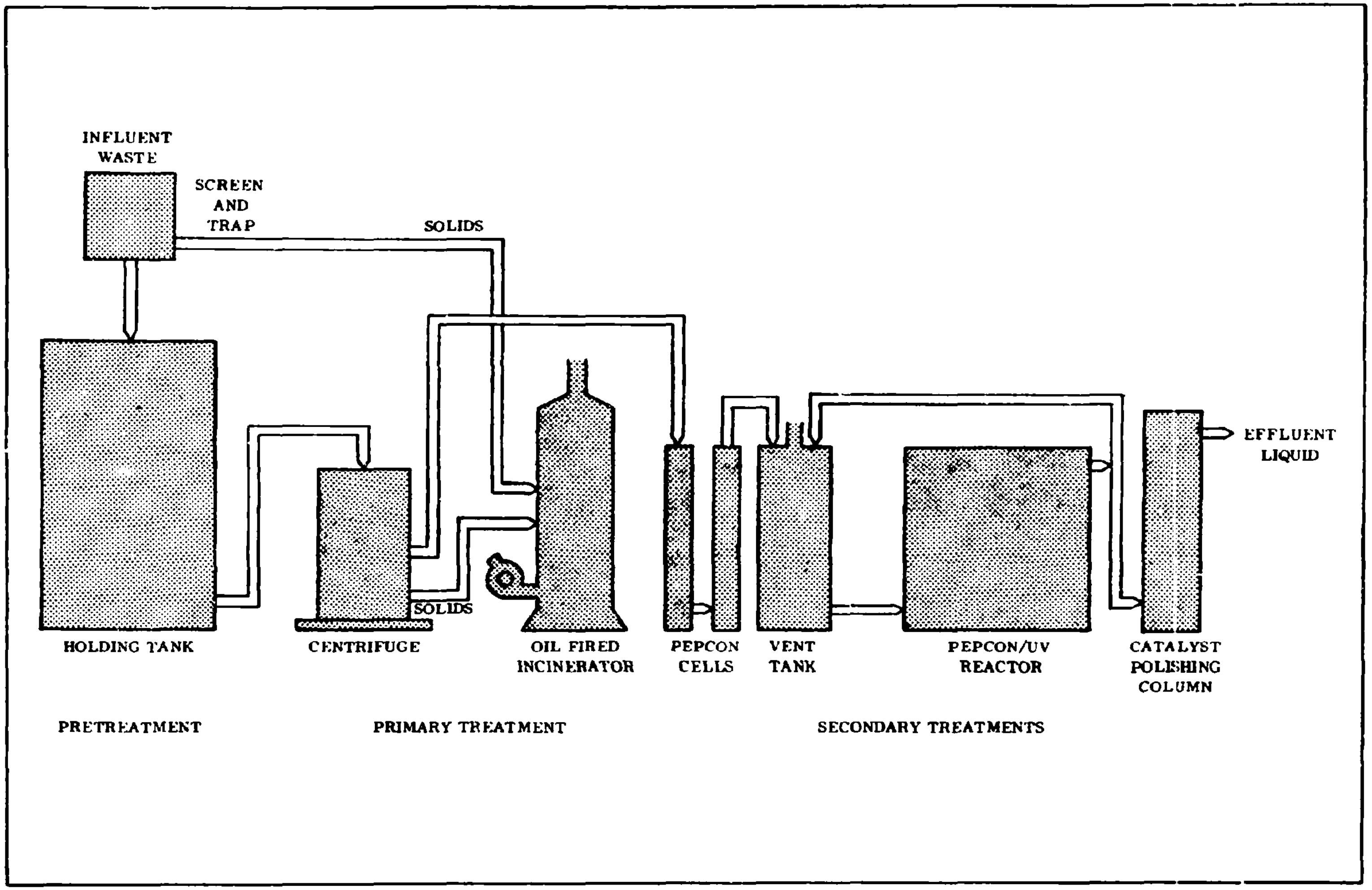


Figure 2. Thiokol Waste Treatment Schematic

treatment, and secondary treatment systems. In the pretreatment step, a combination trap and screening device removes foreign objects and separates off large solids for direct incineration. Liquids which pass through the screen are pumped to a centrifuge where small divided suspended solids are removed for incineration. Effluent from the centrifuge is passed through PEPCON electrolytic cells where hypochlorite is generated and the oxidation of dissolved solids is initiated. Gases from the electrolytic cell are vented in a vent tank and liquids are pumped through a PEPCON/UV reactor for completion of the dissolved solids oxidation. Finally the effluent is passed through a catalyst polishing column to remove last traces of hypochlorite along with continued reduction of BOD.

The results from the Phase I effort substantiated the acceptability of the basic subsystems proposed. The ultraviolet treatment system reduces sewage, suspended solids and biochemical oxygen demand to the level required by Navy standards. However, it was necessary to increase the number of lamps by a factor of two to meet the specification level of 80 mg/l suspended solids and 50 mg/l BOD.

Thiokol has conducted a parallel demonstration program with a catalyst in place of the UV cell. With this system, the Navy effluent specifications were met with four 200 lb catalyst columns in place of 16 UV lamps. Because of the major reduction in system size, complexity, and power consumption with the Thiokol catalyst system, it is recommended that the Navy proceed with Phase II of the program utilizing catalyst in place of the UV light. This system has been fully demonstrated as described in this report and will allow initiation of Phase II with fully demonstrated technology and within contract funding limitations. The Phase II prototype system is scheduled for delivery in June 1972 assuming initiation of the Phase II effort by 1 January 1972.

2.0 PROGRAM DESCRIPTION

A summary of the total Navy program is presented in Figure 3, Program Master Schedule. This schedule defines a 3-phase program effort to design and develop an advanced waste treatment system for a 200 man Navy vessel. Phase I is to conduct research and development for substantiation of previously untested subsystems on a laboratory basis. Phase II includes design, fabrication, and testing of a full scale prototype system in a Navy test facility. Phase III includes design finalization and fabrication of a full scale system for installation and testing aboard a Navy vessel.

The master program schedule indicates that the program started during April 1971 and is scheduled for completion in December of 1973. The master schedule has been revised as follows:

	Months After Phase Authorization	
Milestone	Proposed	Revised
Phase I Report	6 months	7-1/2 months
Phase II Prototype Deliveries	7 months	7 months
Phase II Final Report	9 months	10 months
Phase III Shipboard Installation	12 months	8 months
Phase III Final Report	15 months	13-1/2 months

From the above summary it is concluded that the delivery of the Phase I and Phase II final reports are one-and-a-half months behind schedule.

Phase III systems delivery is four months ahead of schedule and the program final report one-and-a-half months ahead of schedule.

The only portion of this effort currently funded and included in this report is Phase I covering basic research, development, and subsystem demonstration testing.

The schedule shown in Figure 4 depicts the 4-task program included in this final report.

The Task I advanced system trade studies were completed as scheduled in Figure 4 during April and May of 1972. They formed the basis for the subsystem selected for detailed design and evaluation testing under

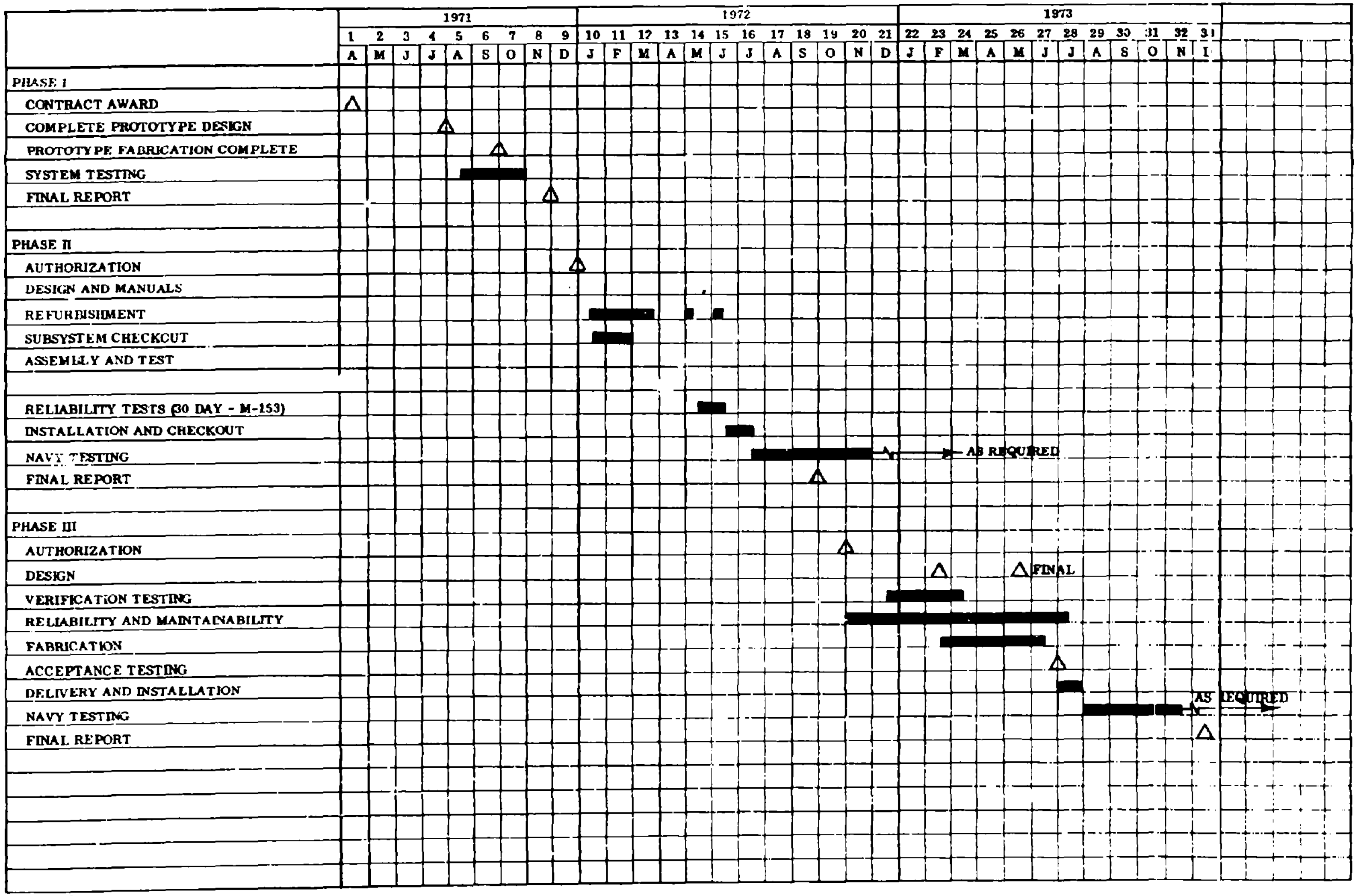
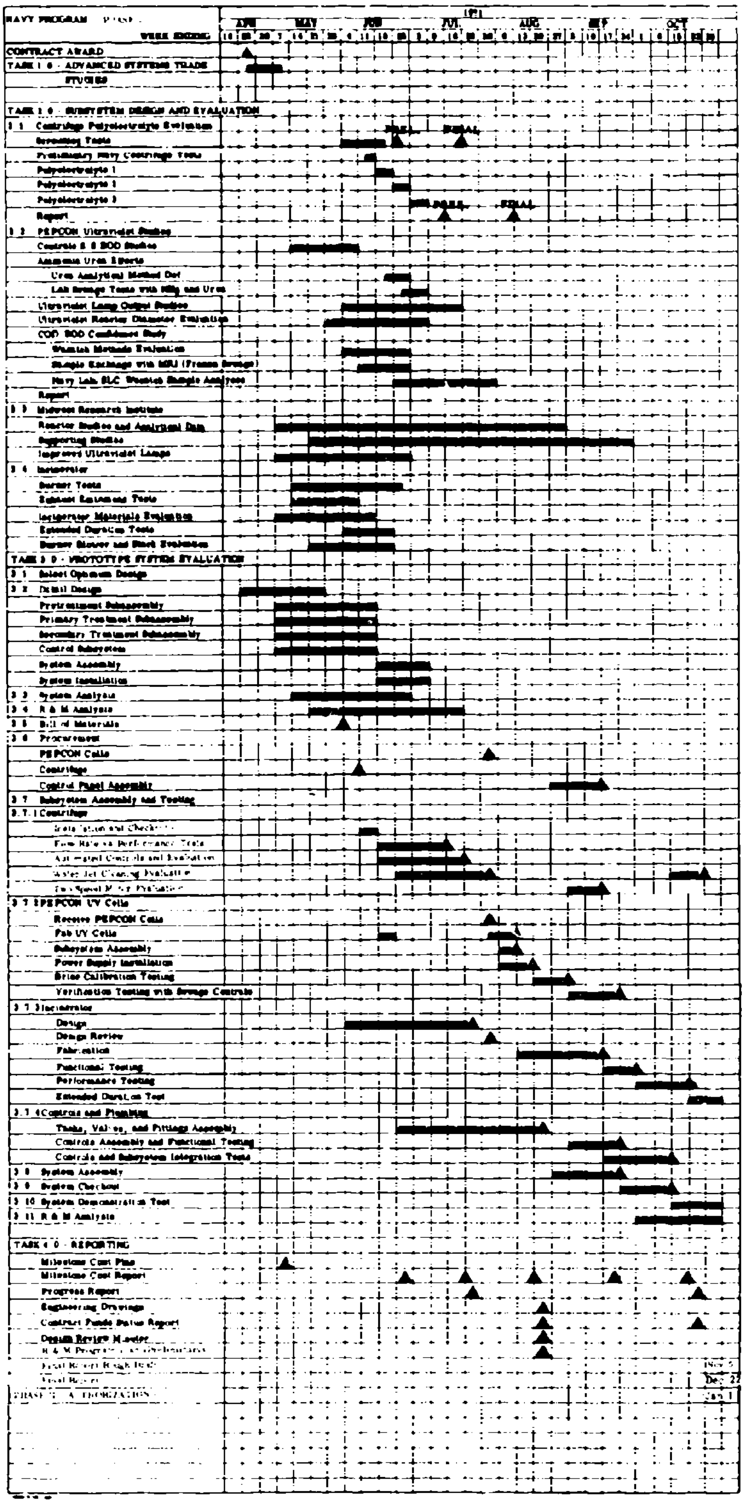


Figure 3. Program Master Schedule

Figure 4. Navy Program Phase I



3.0 TECHNICAL DISCUSSION

This section includes a trade study of candidate systems considered for the advanced waste treatment system under development by Thiokol. Subsystems selected for the candidate waste treatment system including pretreatment system, primary treatment system, solids incineration, and secondary treatment system have been subjected to extensive laboratory testing. Data from this testing is presented in Section 3.2 Subsystem Development and Testing. The results of the subsystem testing were used to prepare a detailed prototype system design. A review of the detailed prototype system design, testing of the prototype subsystems, and finally the demonstration testing of the completed subsystem are presented in this section. Preliminary reliability assessment of the system is also included.

Design requirements used for the Phase I design and devlopment testing effort are listed in Table I . Basically the requirements include the capability to receive an average of 5,200 gal of raw sewage per day containing 800 mg/l suspended solids and 600 mg/l of biochemical oxygen demand. These contaminants must be reduced to a level of 80 mg/l of suspended solids and 50 mg/l of biochemical oxygen demand. In addition requirements include shipboard interfaces and marine engineering aspects of the overall treatment system. These Navy specified design requirements have been used as a guideline in the overall design and development testing effort.

3.1 Advanced Subsystem Trade Studies

The basic approaches to processing sewage waste are summarized on the flow diagram presented in Figure 5 . As indicated, the treatment process generally involves the following basic steps.

- Pretreatment
- Primary Treatment
- Secondary Treatment
- Tertiary Treatment
- Solids Disposal

Within each of the steps, as noted on the flow diagram, several chemical engineering unit operations can be involved. Further, dependent upon the type of system employed, some of the steps may not be required.

In larger municipal systems pretreatment may involve grinding and screening to remove obstructions and to reduce particle size, chlorination, and grit removal, all of which aid the subsequent unit operations.

TABLE I

SUMMARY OF REQUIREMENTS

PERFORMANCE

Influent Physical and Chemical Characteristics	
Suspended Solids	800 mg/l
Biochemical Oxygen Demand (BOD)	600 mg/l
pH	6.7 to 8.4
Temperature	
Maximum	95°F
Minimum	28°F
System Capability (Flow Characteristics)	
No. of Men	200
Maximum Flow	34 gal/day/man
Minimum Flow	22.6 gal/day/man
Average Flow	26.2 gal/day/man
Surge Capacity	300% of average
Effluent Requirements	
Suspended Solids	80 mg/l
BOD	50 mg/l
Coliform (most probable number)	240 mpn/100 ml

PHYSICAL

Weight	Minimum
Height	Not to exceed six feet
Durability	Capable of intermittent operation for short times and capable of being secured for long periods
Damage Protection	Protection against entry or damage from small metal and other durable objects

ENVIRONMENTAL

Shock	Meet requirements of MIL-S-901
Ambient Temperature	
Maximum	140°F
Minimum	40°F
Service	
Permanent Trim	2 deg from normal horizontal plane
Permanent List	3 deg either side of vertical
Pitching	5 deg up or down from horizontal plane
Rolling	30 deg either side of vertical (10 sec period)

SANITARY

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

MATERIALS

Suitable for shipboard operation

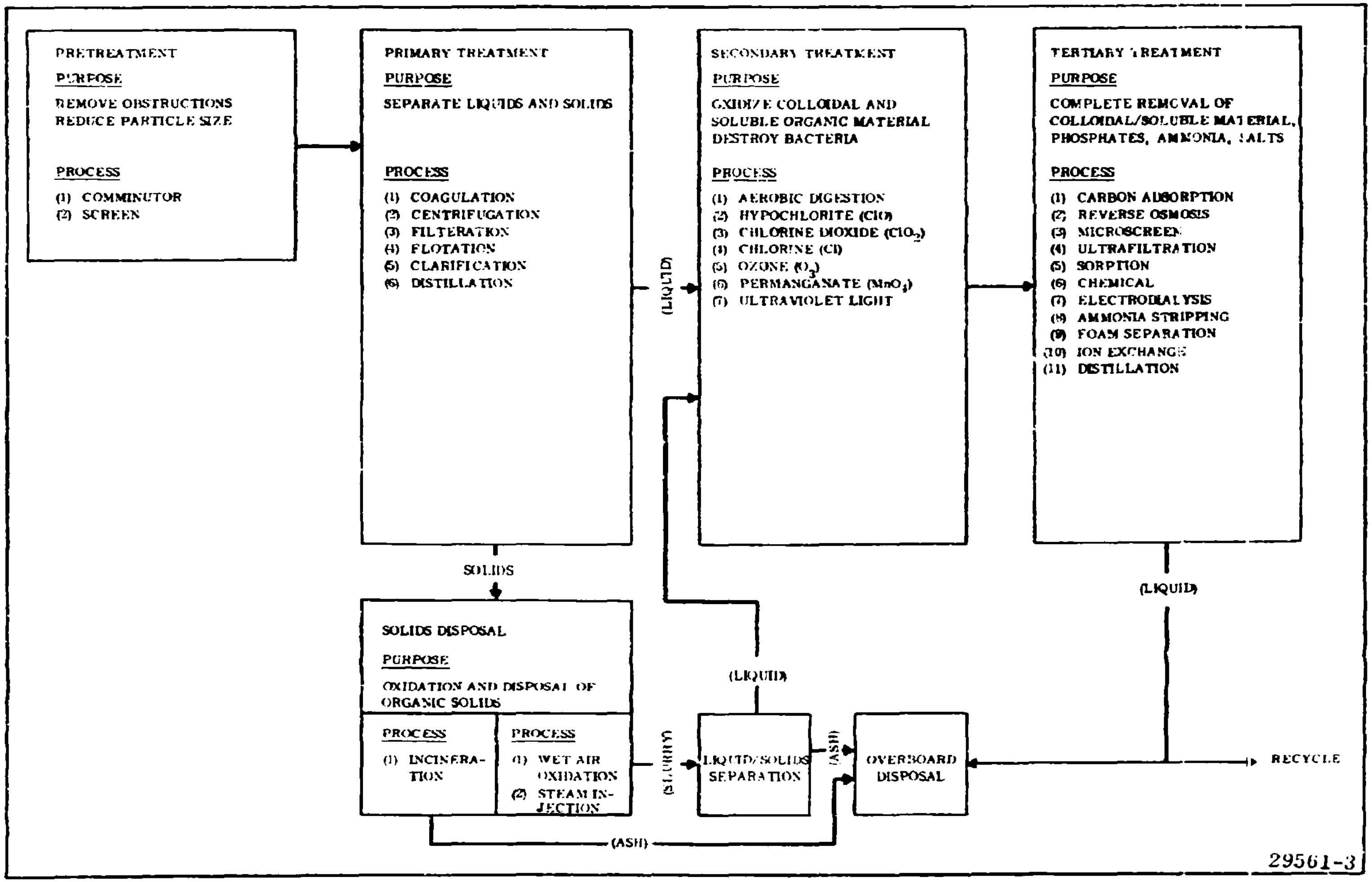


Figure 5. Prepackaged Waste Treatment Plan

The purpose of the primary step in the sewage disposal system is to separate the liquids and the solids and it is generally accomplished by one or more of the following unit operation.

Coagulation
Centrifugation
Filtration
Flotation
Clarification
Distillation

Flotation, centrifugation, and clarification rely on the relative densities of the solids and the liquids and the buoyancy or gravitational loads, while the major process parameters in filtering are particle size and pressure drop around the filter and the filter cake.

Colloidal solids are sometime flocculated with either chemical additives or by electrolytic action. The coagulation process generally is used to make the separation of solids more efficient.

After the liquids and solids have been seperated, there are always some colloidal solids, dissolved solids, and a significant amount of bacteria remaining in the system. The secondary treatment step is designed to reduce these contaminants. The secondary treatment step is usually accomplished by one or more of the following.

Aerobic biological processes
Chlorine or hypochlorite
Ozone
Permanganate
Ultraviolet light
Chlorine dioxide

In each of the unit operations, the basic function is to reduce chemical and biological oxygen demands and disinfect the effluent.

After receiving secondary treatment, generally the treatment plant effluent can be discharged into rivers, lakes, streams, or the ocean. If it is intended that the treated water be used for culinary purposes, or the control of eutrophication, it must receive tertiary treatment which removes collodial and soluble materials such as phosphates, ammonia, and objectionable salts, such as iron and magnesium sulphates.

Tertiary treatment is usually accomplished by one or more of the following unit operations.

Distillation
Ion exchange
Adsorption
Reverse osmosis
Electrodialysis
Microscreening
Sorption
Foam stripping

The major process parameters for distillation are relative differences in vapor pressure of the water and various organic compounds in the sewage. Ion exchange requires activated ion exchange resins or media which can remove dissolved solids. Reverse osmosis also is used to remove dissolved solids through the use of high pressure and permeable membranes.

Adsorption uses activated carbon for removal of dissolved and suspended organic materials.

Tertiary treatment, however, is not a current requirement for shipboard systems.

After the separation in the primary and secondary treatment steps, the solids are generally disposed of by anaerobic digestion, vacuum filtration, incineration, or wet air oxidization followed by incineration or air drying.

The candidate subsystems selected for Thiokol's advanced waste treatment system include the following.

1. Pretreatment
   - (a) Maceration
   - (b) Prescreening

2. Primary Treatment
   - (a) Screening
   - (b) Chemical Coagulation
   - (c) Centrifuge Solid Separation

3. Secondary Treatment
   - (a) Oxidizing Chemical Addition
   - (b) Electrolytic Generation of Oxidizing Chemical
   - (c) Ultraviolet Light Reaction Rate Acceleration
   - (d) Catalyst Reaction Rate Acceleration

4. Tertiary Treatment (None Required)

Test results presented in the report provide data on the selected subsystems. Briefly the rationale which was use in the selection of baseline waste treatment subsystem follows.

3.1.1 Pretreatment Subsystem

Tradeoff parameters for the pretreatment system investigated were:

- Power Requirements
- Flow Capability
- Cost

The performance requirements for the pretreatment system are:

Removal of Foreign Objects	100%
Solids Removal	30 to 50%
Particle Size Conditioning	0.060 in. dia max

To meet the requirements and match tradeoff parameters, a number of pretreatment macerators and separators were evaluated to determine their suitability for incorporation into the waste treatment system. Equipment evaluated include:

Nomenclature	Manufacturer	Brief Description
Hydraulic Macerator	Thiokol	High pressure jet grinder
Industrial Food Waste Disposal	Gruendler	Rotating blade mechanical grinder
Home Food Waste Disposal	Hotpoint	Flailing hammer grinder
Macerator-Pump	Moyno	Rotating blade mechanical grinder
Macerator-Toilet	Raritan	Small marine toilet with water pump, conical tank, and rotating blade macerator
Belt Conveyor-Separator	Thiokol	Small flatbelt, large particle separator
Tube Screen Separator	Thiokol	High angle longitudinal static bar screen
Hydrocyclone Separator	Borg-Warner	Hydraulic Cyclone
Hydrocyclone Separator	Okla. State U.	Hydraulic Cyclone

Nomenclature	Manufacturer	Brief Description
Pressurized Gravity Sedimentation Column	Thiokol	High pressure settling column
Hydrasieve Screen	Bauer	Static bar screen
Filter Bag System	GAF	5 and 25 micron polypropylene filter bags

All tests were performed at ambient temperature using clean tap water as a carrier for material to be macerated and/or separated.

Basic test media used in these tests consisted of paper and fabric materials such as toilet tissue, paper towels, and sanitary napkins. Also used were vegetables and other foodstuffs, including lettuce, celery, frankfurters, vienna sausages, corn shucks, etc. Raw sewage was used in the pressurized sedimentation tests and the Gaf filter bag tests.

From the subsystem development testing, it was concluded that the hydraulic macerator, the Gruendler disposal, and the hydrasieve screen were candidates for use in the pretreatment system.

The hydraulic macerator could grind solid waste materials into homogeneous sized bits suitable for pumping and subsequent further processing in the waste treatment system. Influent containing the material to be macerated enters the low pressure vortex area of the macerator and is swept into the swirling stream generated by the high pressure (1,000 psid) jets. As the material spins in the cylinderical chamber, it is repeatedly passed through the jet streams and is cut into progressively smaller bits by the slicing action of the jet streams.

The hydraulic jet macerator is relatively insensitive to influent flow variations within the maximum flow capability for a particular size unit. This feature evolves from the capability of the unit to release free water (or other liquid) at the same rate as recieved, retaining only the solid matter in the chamber. Free water flowing through the unit does not degradate the maceration process.

The macerator is directly scalable to large or small sizes, and jet pressure may be varied upward or downward as required by a particular application. A full size 20 gpm hydraulic jet macerator was subjected to rigorous testing. Overall performance was superior to that of any other type of macerator tested. It was determined that the hydraulic macerator was capable of grinding up to 250 grams per minute, [illegible] weight, of the most difficult materials expected to be encountered in waste disposal systems.

The Gruendler Model C-153 food waste disposer is a direct coupled rigid rotating blade mechanical grinder powered by a 1.5 hp ac motor. This unit is in general use in restaurants and cafeterias and aboard U.S. Naval vessels. The Gruendler unit was tested for determination of: maximum and minimum flow tolerance level, maximum solids tolerance level, consistency of macerated material, and for relative difficulty of feeding solids. It was found that the unit was tolerant of high flows. Up to 55 grams of solids and 60 gpm of water were passed through the unit successfully. Macerated material was finely chopped and of good consistency.

The Bauer hydrasieve is a static bar screen separator in general use as a slurry thickener and sludge dewatering device. The bar screen consists of specially shaped transverse bars with 0.060 in. slot widths. The screen is angled from the vertical at three progressive slopes; beginning at 25 deg at the upper level, 35 deg through the center section, and approximately 45 deg in the lower section. The headbox is fitted with a shallow weir to provide even flow distribution. The individual bars of the screen are contoured to present a curved surface to the lower side of the thin stream, whereupon the stream attaches, producing a laminar flow hydraulic shear which tends to bend the stream around the curved surface and discharge the free water through the slots. This phenomenon is a fluidic principle known as the Coanda effect.

A 6 in. wide laboratory type, demonstration model, Figure 6, was subjected to flow testing using finely macerated toilet tissue and paper towels in clean water.

Overall results were excellent. Very little blinding occurred and self-cleaning action was good. Most of the free water was separated satisfactorily at flow rates to 10 gpm.

The full scale hydrasieve will have an 18 in. wide screen and flow baffles. It will be capable of separating solids at flow rates up to 30 gpm, when subjected to the following conditions:

Temperature: 40° to 120°F

Roll: ± 30 deg for 10 sec duration

Pitch: ± 5 deg

Permanent Trim: ± 2 deg

Permanent List: ± 3 deg

Shock: MIL-S-901

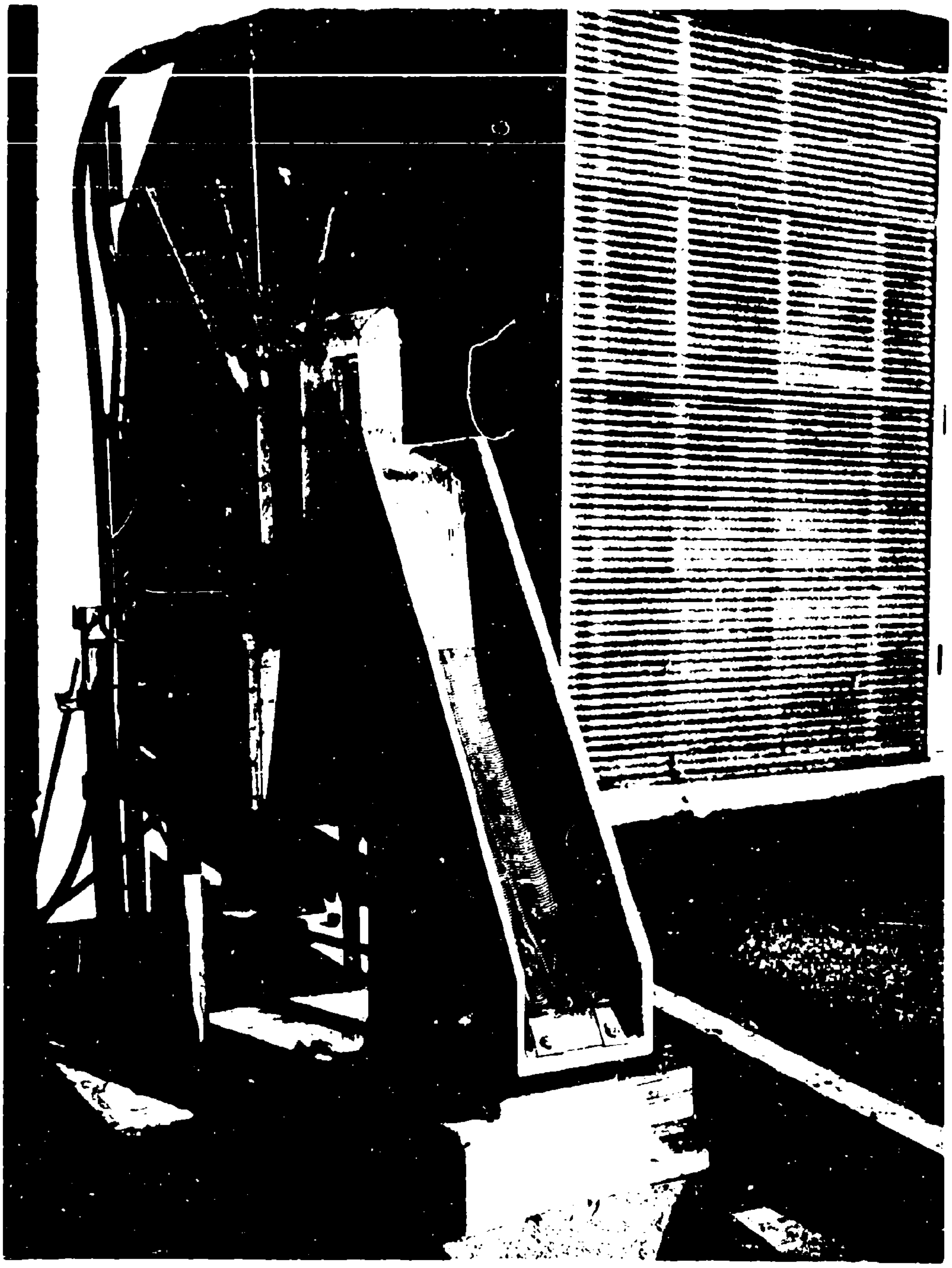


Figure 6. Photo of Hydrasieve

3.1.2 Primary Treatment

Systems evaluated as candidates for primary treatment included filtration, clarification, and combined screening centrifugation. The filtration was eliminated from consideration early due to its tendency to blind following receipt of very small quantities of material. It has inherent problems of high filtration pressures and problems associated with backwashing the filter to remove raw sewage. Several companies manufacturing bed type filters were contacted. In every instance, the filter approach was not recommended as being an available system for treatment of raw sewage.

Clarification is considered a simple and inherently reliable method for treatment of raw sewage. However, it does require the addition of chemicals to achieve the required settling in a short period of time. Also, it suffers from the inherent disadvantage of being subject to shipboard rocking motion. Preliminary screening tests were conducted with sewage chemically treated and settled in laboratory glassware. A slow rocking motion of the container caused sufficient agitation to redistribute the settled solids.

Mechanical methods of solids separation considered included various types of screening devices and centrifuges. Evaluation of available data and Thiokol conducted tests on raw sewage indicates that the centrifuge is inherently capable of removing in excess of 80 percent of solids from raw sewage. The efficiency of the centrifuge can be increased by the use of fine screening devices such as the Sweco vibrating screen in conjunction with the centrifuge. However, this does add to the complexity of the centrifuge system.

As a result of the tradeoff study and the overall goal of obtaining high system reliability, it was decided to limit mechanical separation equipment to a single piece of equipment. Therefore, the data presented was obtained using a basket type centrifuge which received influent from sewage pretreated in such a manner as to feed the centrifuge with an influent which was compatible with the capability of the machine.

The centrifuge was also considered in conjunction with the use of chemical additives. Results presented in Section 3.2.2 of this report indicate that ferric sulfate in combination with various polyelectrolytes can improve the performance of the centrifuge. Other additives such as lime and alum are in routine use in the waste treatment industry to enhance solid separation. However, the use of additives again increase the complexity of the overall system. Based upon the overall waste treatment system objective of simplicity and high reliability it was decided that a slight compromise should be made in the performance of the primary treatment system and that the basic design goal of the system should be to develop a centrifuge technique to remove at least 80 percent of the suspended solids. The balance of the suspended solids required to meet the Navy specification will be removed by the secondary treatment system.

3.1.3 Secondary Treatment System

The secondary treatment considered in this trade study removes finely divided suspended solids and dissolved solids remaining in the waste effluent. In conventional sewage treatment this is accomplished by aerobic digestion in trickling filters followed by clarification. Since a substantial quantity of dissolved solids remain after even 100 percent efficient primary treatment, it is necessary to find a replacement treatment method for the standard biological process. Thiokol actively considered the use of ozone, electrolytically generated hypochlorite, and chemical addition. Chemical addition was discarded due to the overall desire to restrict the size of the system and its operating supplies.

A primary consideration for Navy applications is that waste water always contains at least 7,000 mg/l of sodium chloride. This salt can be electrically converted to sodium hypochlorite which can accomplish the chemical function of oxidizing dissolved solids. Another available raw material is oxygen which can be converted to ozone using commercially available ozone generating equipment. This ozone also possesses the capability to oxidize the solids from available raw materials. Manufacturers of ozone equipment and producers of electrolytic cells to generate hypochlorite were contacted and equipment was compared. The ozone generating equipment was found to be comparatively large and the ozone generating efficiency low compared to the efficiencies that can be obtained in converting salt to hypochlorite electrolytically. Also the ozone was considered to be a highly toxic gas and would require more restrictive safety measures than electrolytic conversion of salt to sodium hypochlorite.

The above considerations led to the selection of electrolytically generated hypochlorite. However, it was determined that the reaction rate obtainable with concentrations of hypochlorite up to 3,000 mg/l were far too slow for the Navy fluid stay time of 30 to 60 min. In fact, it was determined that a period of days may be required to achieve the required oxidation. It was known, however, that the reaction rate can be accelerated several hundredfold through the use of accelerators. Candidate accelerators considered included ultraviolet light and chemical catalysts. The ultraviolet light system was in a comparative high state of development since ultraviolet lamps are available commercially for blueprint machines and highway arc lamps among others. Also the Midwest Research Institute has conducted substantial research which shows that the ultraviolet light can be used efficiently to accelerate the reaction rate between sodium hypochlorite and sewage. This availability of hardware and technology associated with the ultraviolet light as an accelerator led to the selection of the ultraviolet technique in combination with electrolytic generation of hypochlorites for the secondary treatment system. However, Thiokol recognized the potential advantages of the catalyst system and elected to continue exploration of the catalyst system as a potential replacement for the ultraviolet light under Thiokol sponsored research. As of the time of this report the catalyst development has proceeded to the point that it is considered to be a candidate replacement for the ultraviolet light system.

3.2 Subsystem Development Testing

The development testing reviewed in this section was accomplished utilizing the available 50 man waste treatment system. This same system, furnished by Thiokol, was used in furnishing test data supplied to the Navy in support of Thiokol's proposal. Using this equipment, Thiokol obtained early pilot plant test data and design information to be used in fabrication and testing a 200 man prototype system for continued Phase I testing.

3.2.1 Centrifuge Testing

Centrifuge testing in support of the Navy waste treatment system design involved the conduct of screening tests to evaluate the solids separation efficiency of various type machines and evaluation of inorganic and organic flocculating agents to improve solids separation. Results of the testing to date are discussed below. On the basis of the test results, a basket type centrifuge was selected for the Navy system.

3.2.1.1 Screening Tests

There are three basic types of centrifuges commercially available: the disc, the basket, and the solid bowl-scroll conveyor. A brief description and summary of various operating parameters characteristic of these machines is presented in Table II. Preliminary testing of each of these types of machines was conducted in the Thiokol M-85 Pilot Plant. Raw sewage, containing 3 percent sodium chloride, was used in the tests to simulate marine service. The results of these tests, expressed in terms of percent suspended solids removal, are presented graphically in Figure 7. The disc machine is observed to achieve highest centrate clarity followed closely by the basket unit. The scroll conveyor centrifuge produces moderate centrate clarity with scroll movement but is increased significantly with 0 differential scroll speed (intermittent scroll operation). Based on these tests, and because the basket type machine is inherently a reliable simple machine requiring little maintenance (plugging problems were experienced with the disc machine during testing), the basket centrifuge was selected for use in the marine waste treatment system.

A 20 in. diameter basket centrifuge was received and installed in the pilot plant for use in the Navy sewage treatment system. Solids removal tests conducted on the machine and a 14 in. diameter subscale basket centrifuge gave suspended solids removal percentages of 90 to 84 and 88 to 73, respectively, over flow rates of 0.5 to 3.0 gpm, as shown in Figure 6a .

3.2.1.2 Polyelectrolyte Tests

Many inorganic and organic flocculating agents are available to increase the settling rates of waste sludges. Commonly used chemicals include lime, alum, ferric salts, and water soluble polyelectrolytes. Relatively low dosage requirements characteristic of the polyelectrolytes make them somewhat attractive for marine usage to improve suspended solids removal in the centrifuge. Jar tests were conducted with several leading polyelectrolytes including cationic, anionic and nonionic types. A list of the polymers evaluated, the test matrix used, and qualitative results are presented in Table III. It is concluded from the tests that the polyelectrolyte alone does not significantly increase suspended solids removal and that it must be preceded by the addition of a ferric salt to provide hydroxide pin flocs. The polymer then accelerates floc formation and settling.

Preliminary tests were conducted with the basket and scroll conveyor centrifuges to evaluate performance with chemical treatment of the feed. Methods of addition consisted of rapid mix of a ferric salt in a premix tank, and addition of the polymer at (a) the premix tank, (b) the centrifuge inlet and (c) the influent line upstream of the centrifuge. The latter addition method appeared to achieve better results. Although clarification may be improved through chemical addition, the 80% suspended solids removal achieved without chemicals is considered adequate for overall system performance problems.

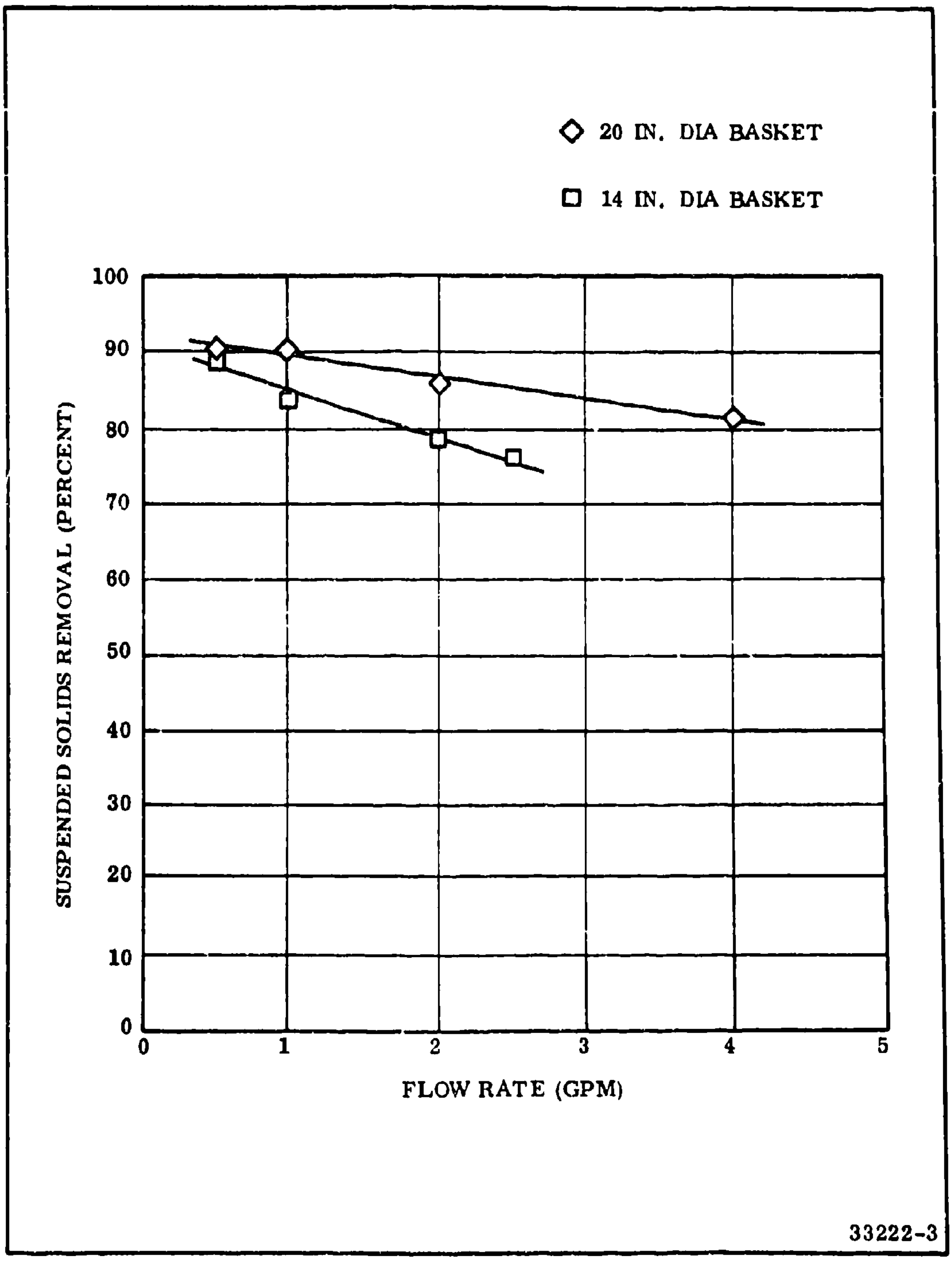
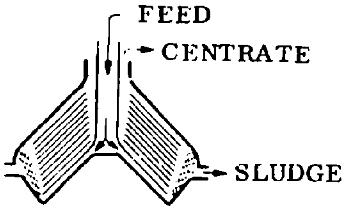
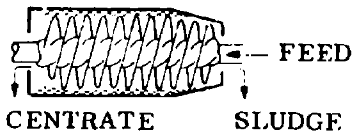


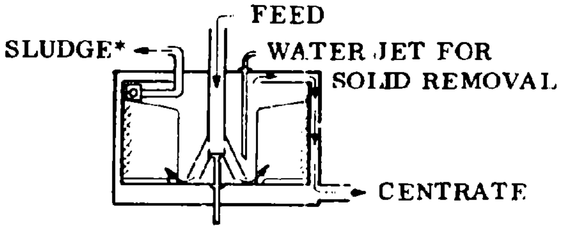
Figure 6a. Suspended Solids Removal

TABLE II

SUMMARY OF CENTRIFUGE CHARACTERISTICS







*SKIMMER SHOWN IN ADVANCED POSITION.

Disc Centrifuge	Solid Bowl-Scroll Conveyor Centrifuge	Basket Centrifuge
1. High speed, high centrifugal force machine.	1. Moderate speed moderate centrifugal force machine.	1. Low speed, low centrifugal force machine.
2. Highly clarified centrate	2. Moderate to medium clarified centrate.	2. Medium to highly clarified centrate.
3. Continuous operation with intermittent or continuous sludge removal.	3. Continuous operation with intermittent or continuous sludge removal	3. Intermittent operation.
4. Requires prescreen of influent material.	4. Accepts coarse feed.	4. Accepts coarse feed.
5. Produces medium solids sludge.	5. Produces dry, high solids sludge.	5. Produces medium solids sludge.
6. Capable of oil/water separation.	6. Oil/water separation not available.	6. Capable of oil/water separation.

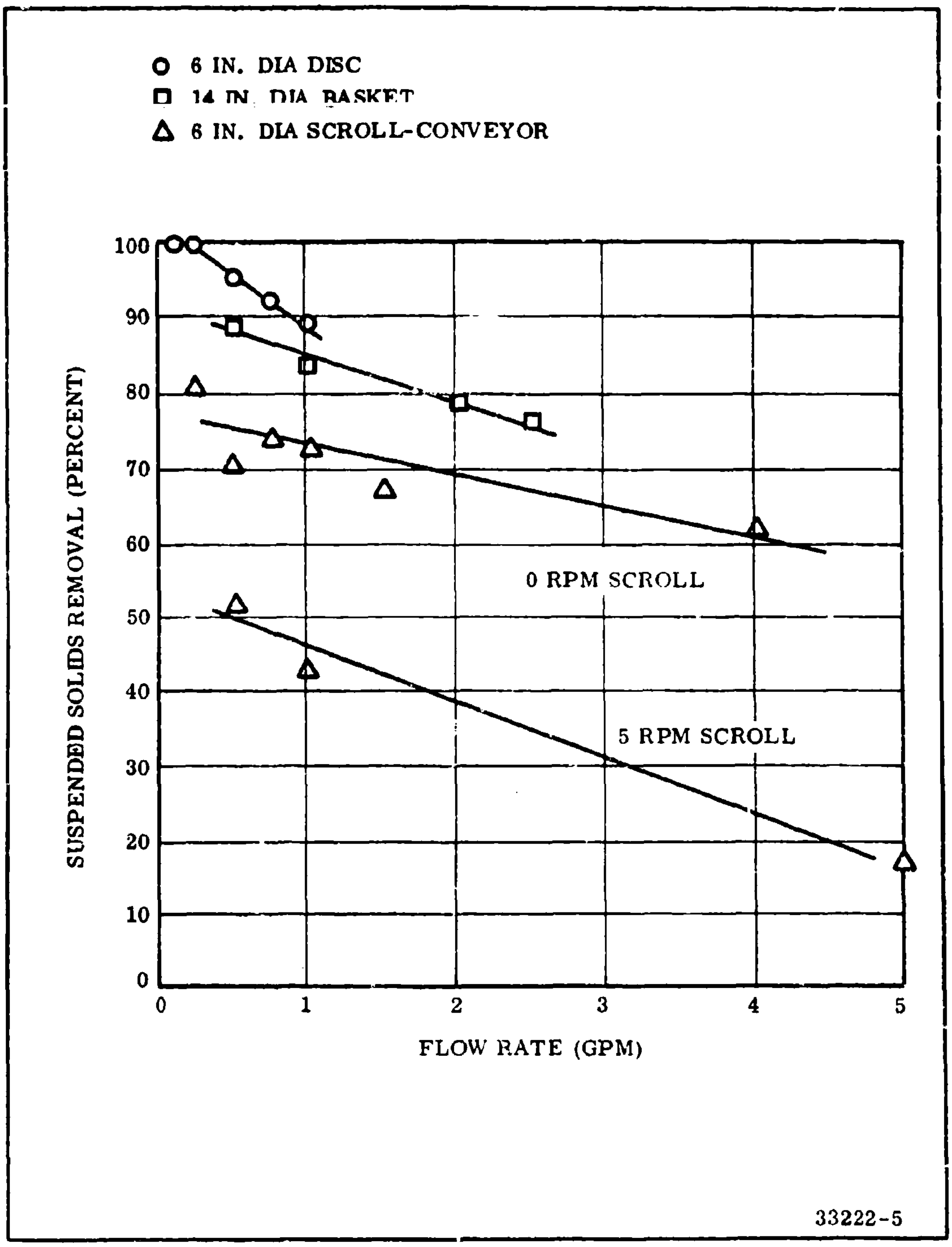


Figure 7. Suspended Solids Removal

TABLE III

SUMMARY OF POLYELECTROLYTE TESTS

Manufacturer	Trade Name	Type	Shipped As	Qualitative Results
Nalco	Nalcolyte 610	Cationic	Powder	Good clarity, moderate rate
Calgon	Wt 2690	Nonionic	Powder	Medium clarity, moderate rate
	Wt 2700	Anionic	Powder	Good clarity, high rate
	Wt 2900	Anionic	Powder	Medium clarity, moderate rate
	WCL 4097	Cationic	Powder	Medium clarity, moderate rate
Hercules	Hercofloc 810	Cationic	Powder	Good clarity, moderate rate
	Hercofloc 814.2	Cationic	Powder	Good clarity, moderate rate
	Hercofloc 828.1	Cationic	Liquid	High clarification, slow rate
	Hercofloc 831.2	Anionic	Powder	High clarification, slow rate
DOW	Purifloc C-41	Cationic	Liquid	Poor clarity, slow rate
	Purifloc A-23	Anionic	Powder	Good clarity, high rate

Test Matrix

Ferric Sulphate Dosage (ppm) (Influent)	Polymer Dosage (ppm) (Influent)
0	1
0	5
0	10
100	1
100	5
100	10
200	1
200	5
200	10

3.2.2 PEPCON/UV Studies

3.2.2.1 Calibration Tests

During this period calibration tests were conducted on the PEPCON electrolytic cells used in the secondary treatment system. The objective of the secondary treatment section of the Thiokol marine waste treatment system is to oxidize dissolved organic compounds and sterilize the effluent without chemical addition. Operation of the waste treatment system in a marine environment provides access to a common raw material sodium chloride, which is easily converted to sodium hypochlorite by electrolytic oxidization. The sodium hypochlorite, properly calalyzed, is capable of performing oxidation and sterilization.

The equipment selected to generate sodium hypochlorite is a PEPCON electrolytic cell produced by Pacific Engineering and Production Company of Nevada. The 500 sq in. anode model cell to be used in the marine waste treatment system was calibrated in the pilot plant for sodium hypochlorite generation. Three percent salt water was used to simulate sea water. Flow rate, current density, and inlet temperature were varied. The results of these calibration tests are presented graphically in Figure 8. The data from the above tests and UV reactor tests are used to size the secondary treatment system.

3.2.2.2 Hypochlorite Utilization

In order to evaluate the utilization of sodium hypochlorite in Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD), reduction tests were conducted generating and catalytically reacting hypochlorite incrementally. Samples were taken and the net change in NaClO concentration, COD and BOD were determined. The theoretical hypochlorite requirement per unit COD reduction is calculated as follows:

$$\frac{\text{NaClO}}{\text{COD}} = \frac{\text{Equiv Wt NaClO}}{\text{Equiv Wt } O_2} = \frac{74.45}{16.00} = 4.65$$

The hypochlorite consumption shown in the Figure 9 closely approaches this value indicating efficient utilization. The amount of BOD reduction for a given hypochlorite reduction appears to be variable from the data obtained.

3.2.2.3 Pilot Plant Performance

Several test runs were accomplished in the pilot plant on a continuous flow basis. Performance of these tests as a function of BOD and COD reduction is summarized in Figure 10. A simulation of the secondary

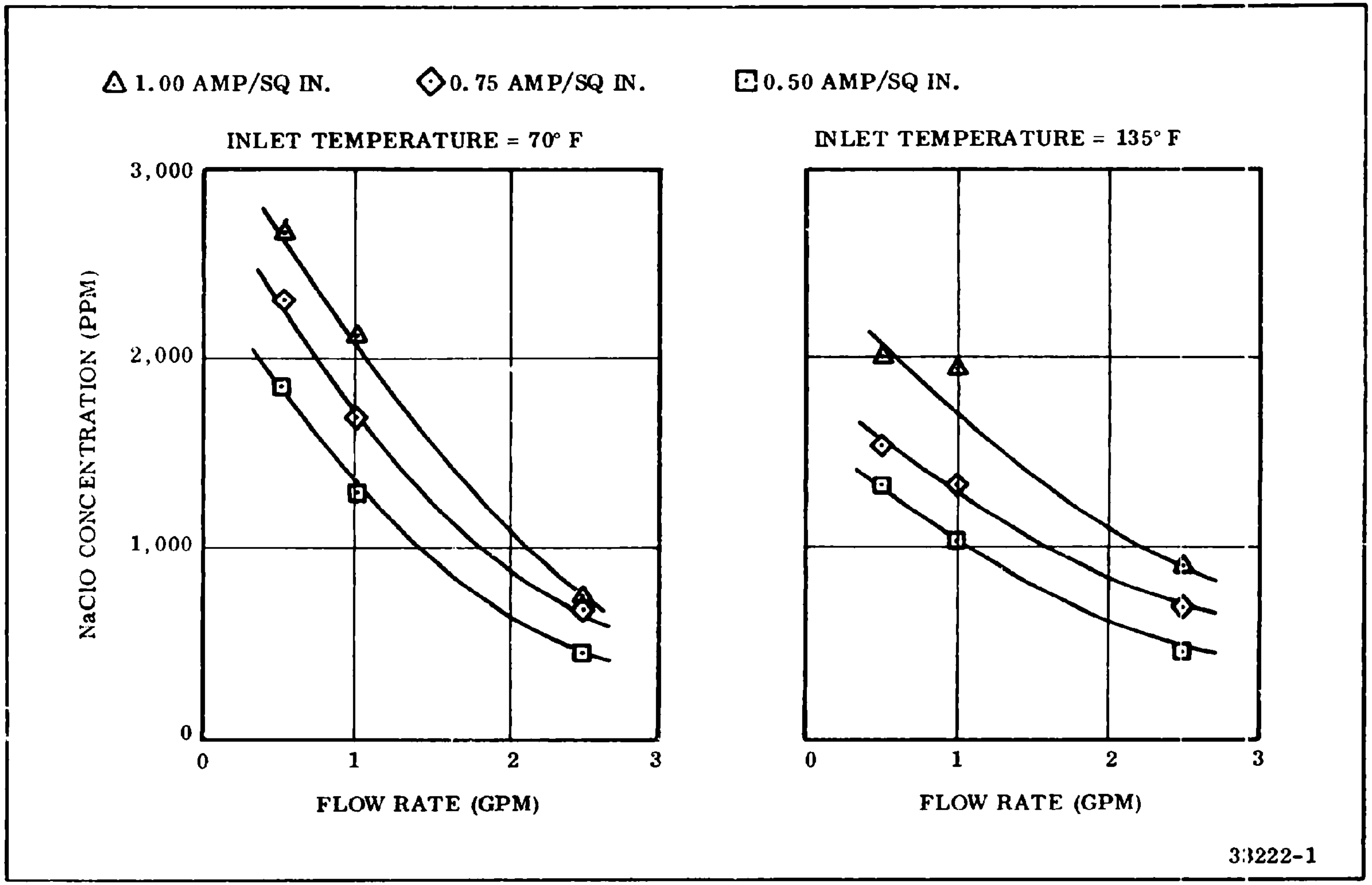


Figure 8. Performance of 500 Sq In. PEPCON Cell in Three Percent Salt Water

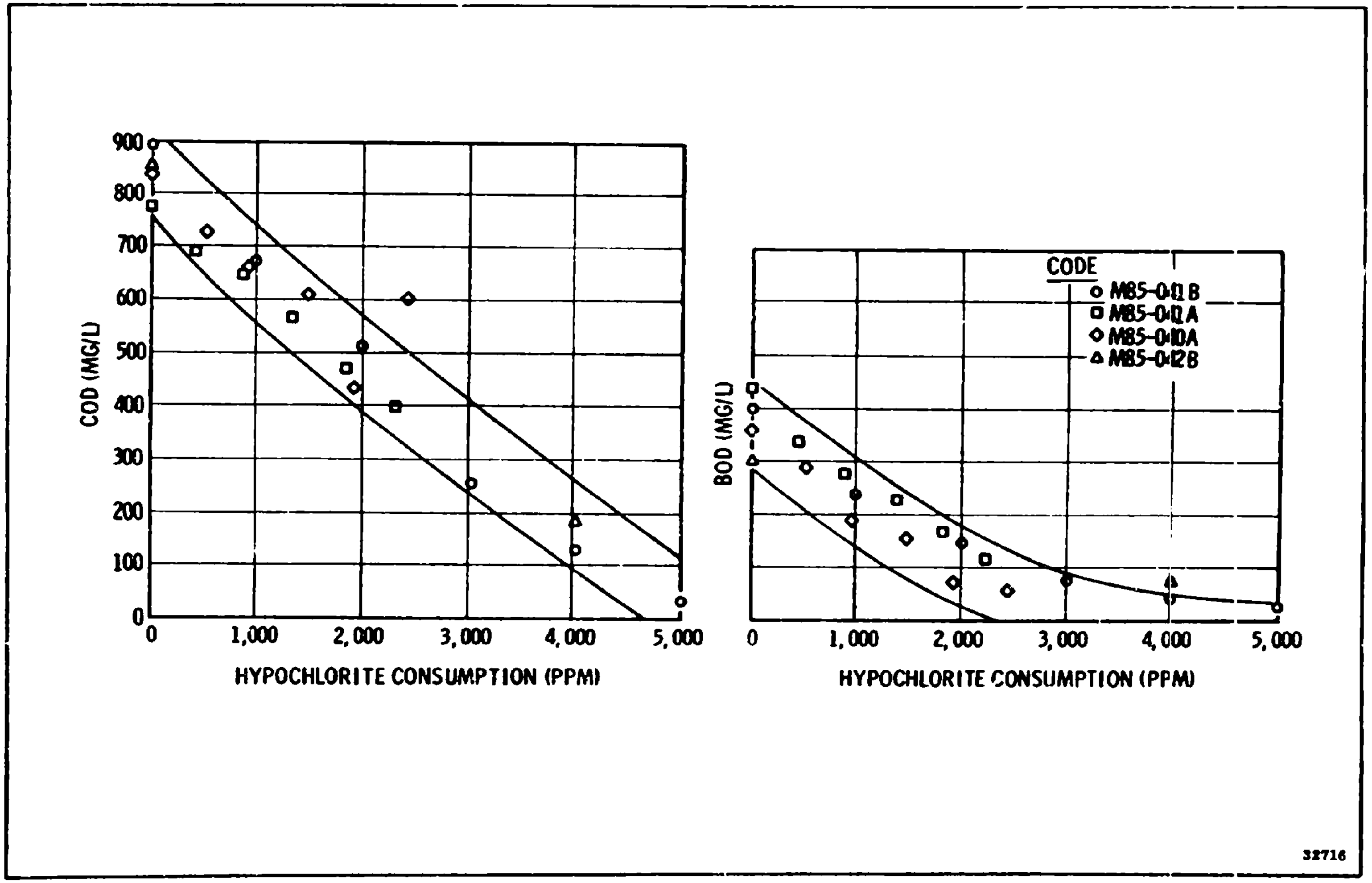


Figure 9. Secondary Treatment, PEPCON and UV Light

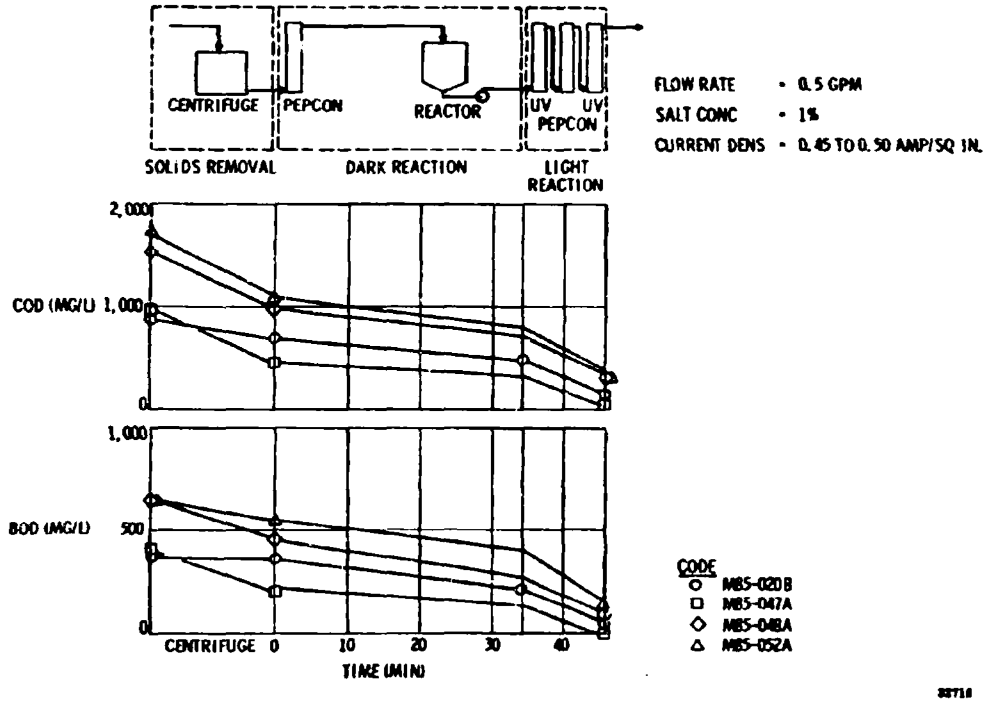


Figure 10. Typical Pilot Plant Performance

treatment system proposed for the Navy was tested and the results are summarized in Figure 11.

Typically, the COD of the influent is reduced by 40 to 50 percent in the centrifuge. The remaining COD is reduced in the secondary treatment by the approximate rate of 0.2 mg/l COD/ppm NaClO consumed.

3.2.2.4 Centrate S/S, BOD Studies

The effectiveness of suspended solids removal during primary treatment on total system performance was evaluated. Duplicate secondary treatment tests were conducted using two different feeds. One feed was prepared in the basket centrifuge and the second feed prepared in a flocculating tank using 200 ppm ferric sulphate and 1 ppm Calgon wt 2700 polyelectrolyte. As shown in Figure 12, the COD reduction in the primary system using the centrifuge amounted to 50 percent and with the polyelectrolytic 71 percent. The difference in COD reduction during primary treatment amounts to 300 mg/l which is equivalent to a NaClO dosage of 1,500 ppm during secondary treatment.

It can be concluded that higher efficiency during primary treatment will reduce the loading on the secondary treatment system. The secondary system is, however, capable of handling the additional COD loading by merely increasing the NaClO dosage.

3.2.2.5 UV Reactor Diameter Studies

In order to catalyze the decomposition of sodium hypochlorite, and therefore, the oxidation rate of dissolved organics in sewage, a photo chemical process has been selected. A concentric reactor containing an ultraviolet light source at the center surrounded by the process liquid will be used. This equipment was characterized in terms of sodium hypochlorite conversion as a function of reactor volume, inlet temperature and flow rate. The results of these characterization tests are shown in Figures 13, 14, and 15 indicating little effect in changing reactor volume (diameter) and a minor temperature dependency. These data were used to construct Figure 16 which defines the sodium hypochlorite conversion rate as a function of residence time (reactor volume/flow rate) in the reactor.

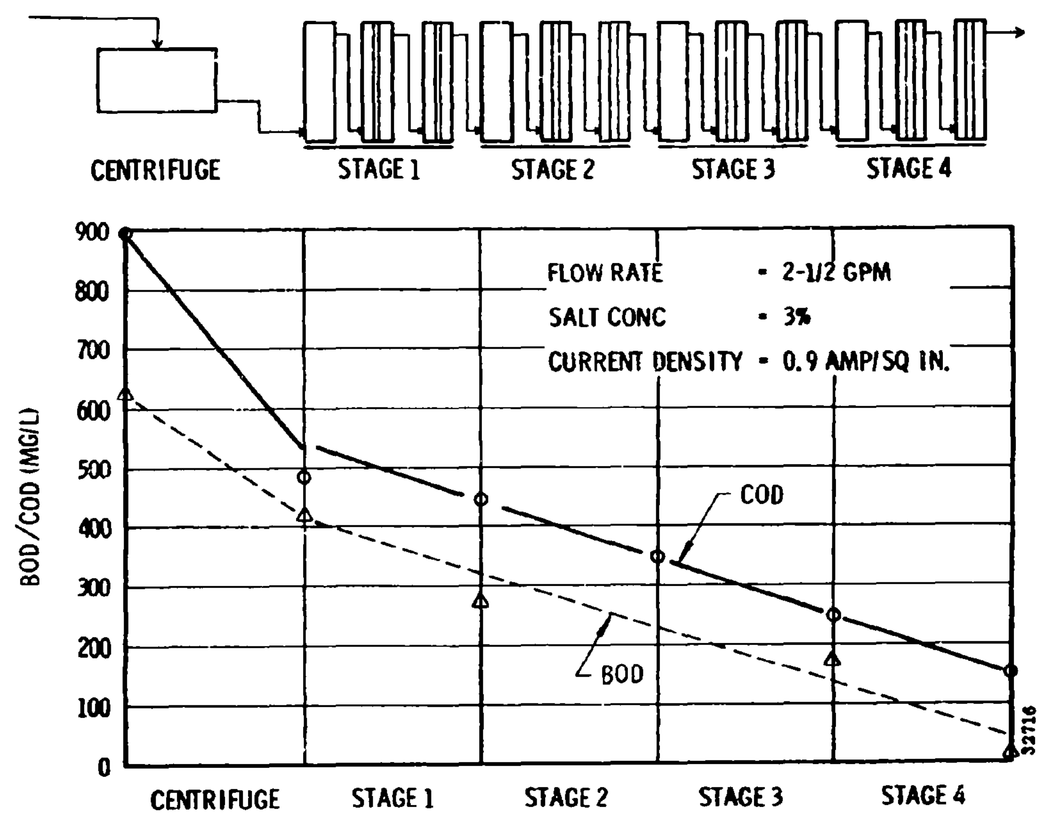
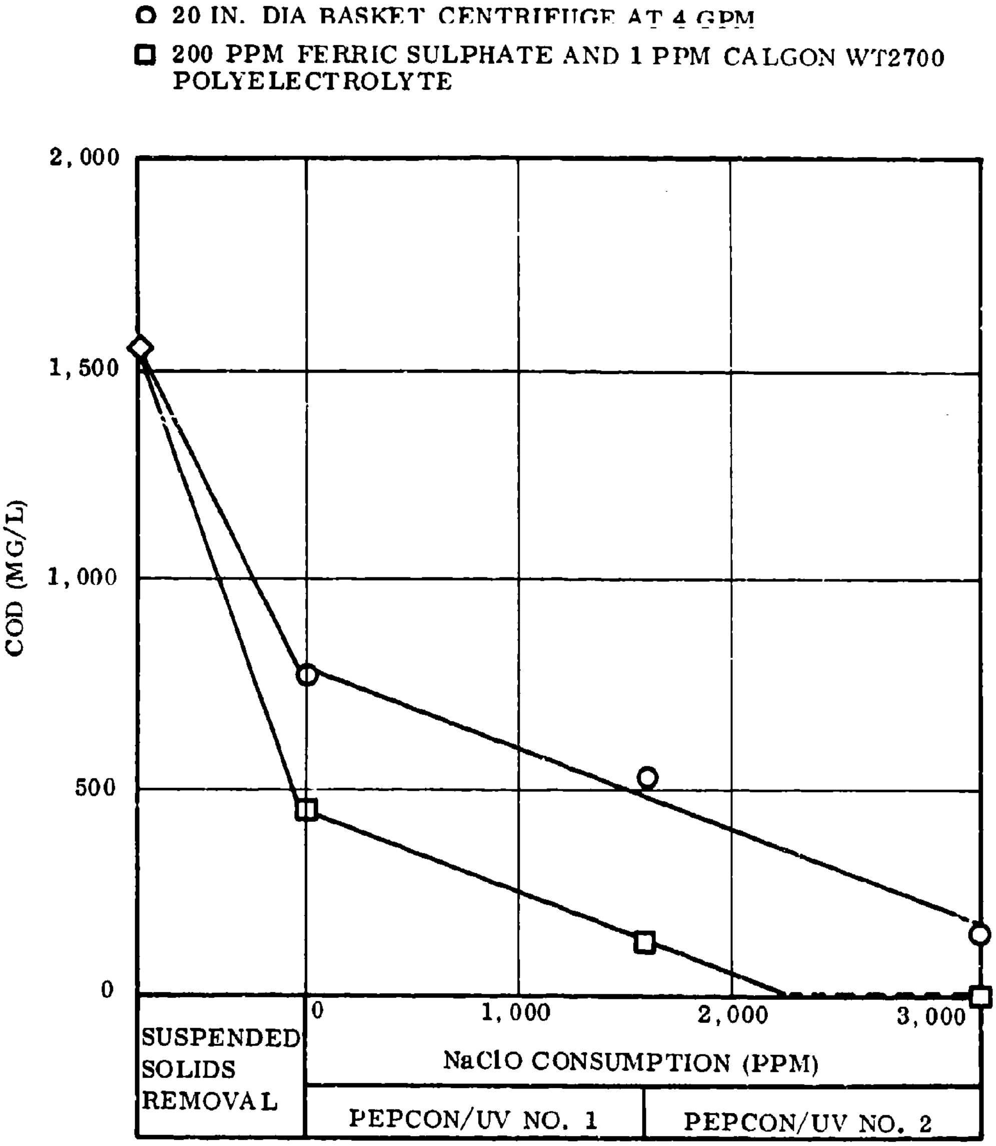


Figure 11. Simulated Navy 200 Man System Performance



FLOW RATE = 0.5 GPM
CURRENT DENSITY = 0.4 AMP/SQ IN.
SALT CONCENTRATION = 3 PERCENT

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Figure 12. Pilot Plant Performance with Variable Primary Treatment

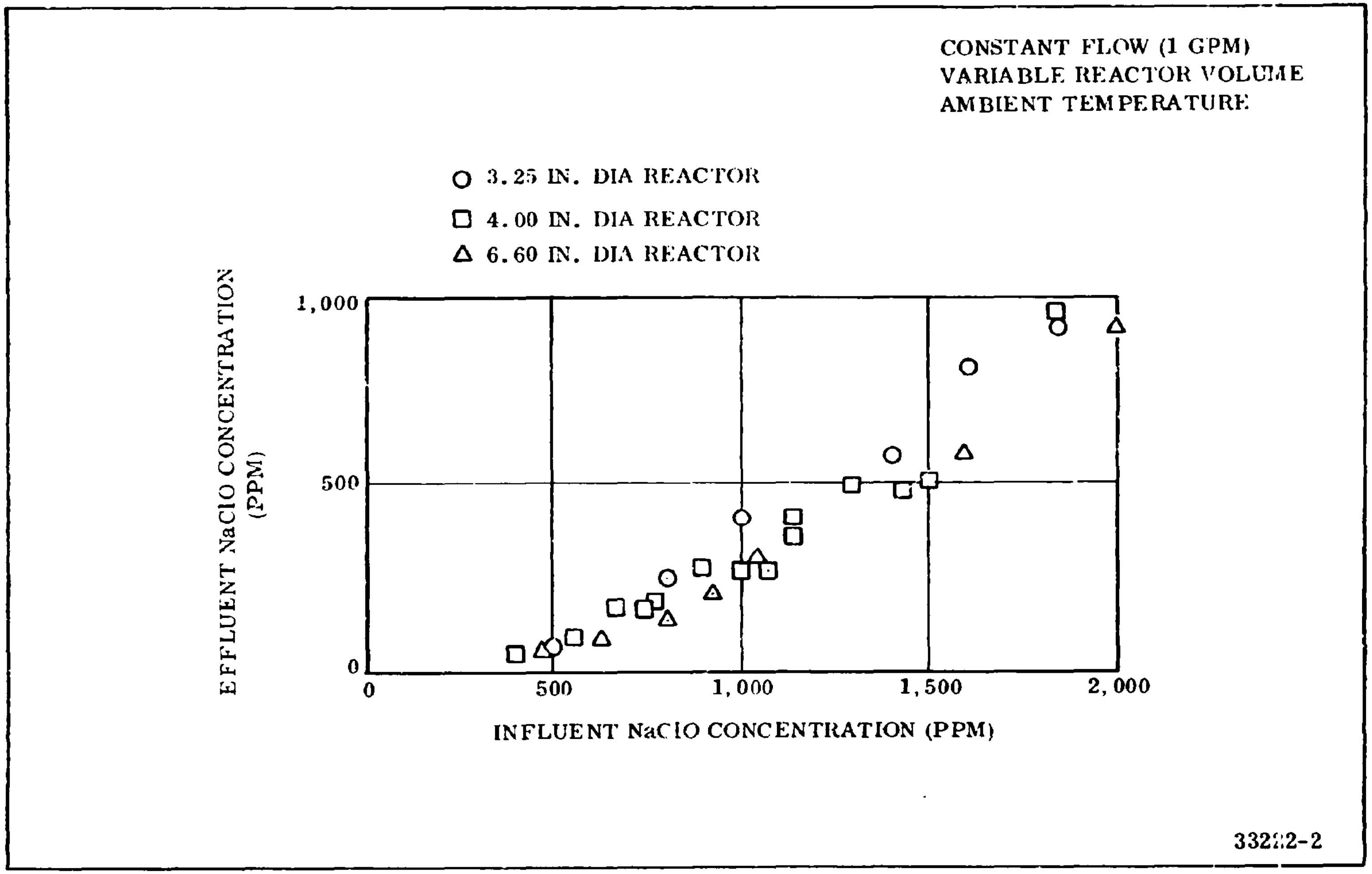

Figure 13. UV Photochemical Reactor Performance

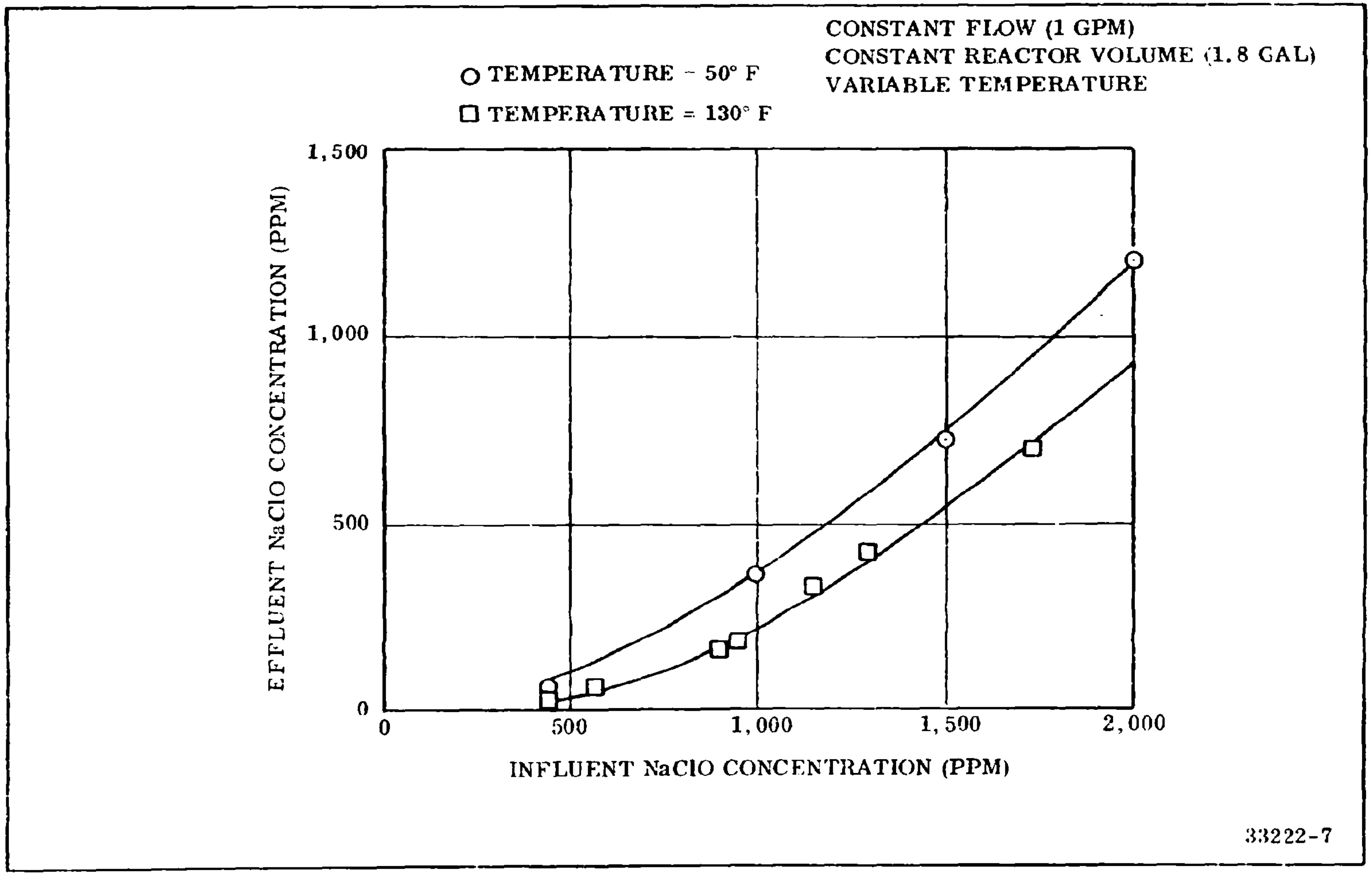

Figure 14. UV Photochemical Reactor Performance

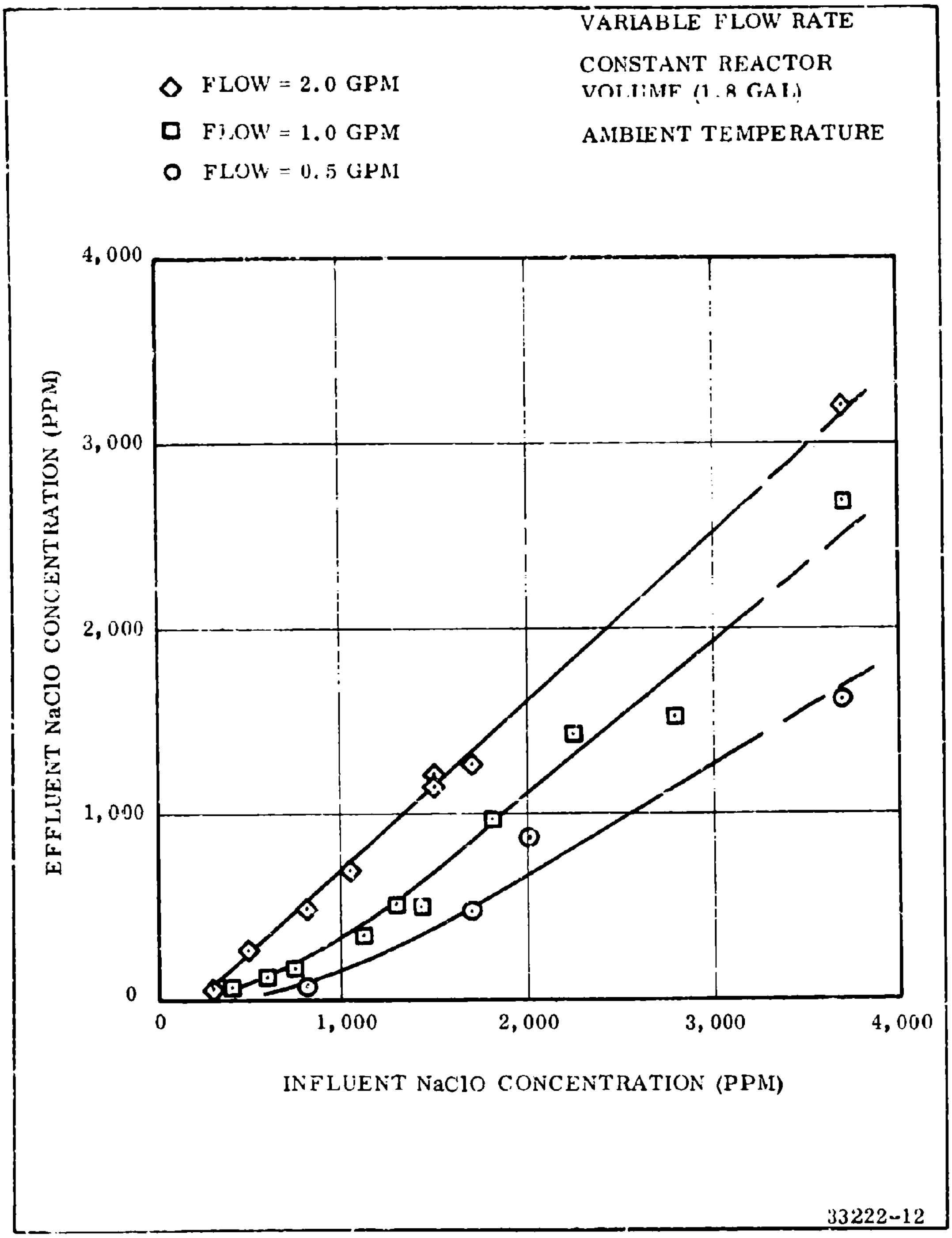

Figure 15. UV Photochemical Reactor Performance

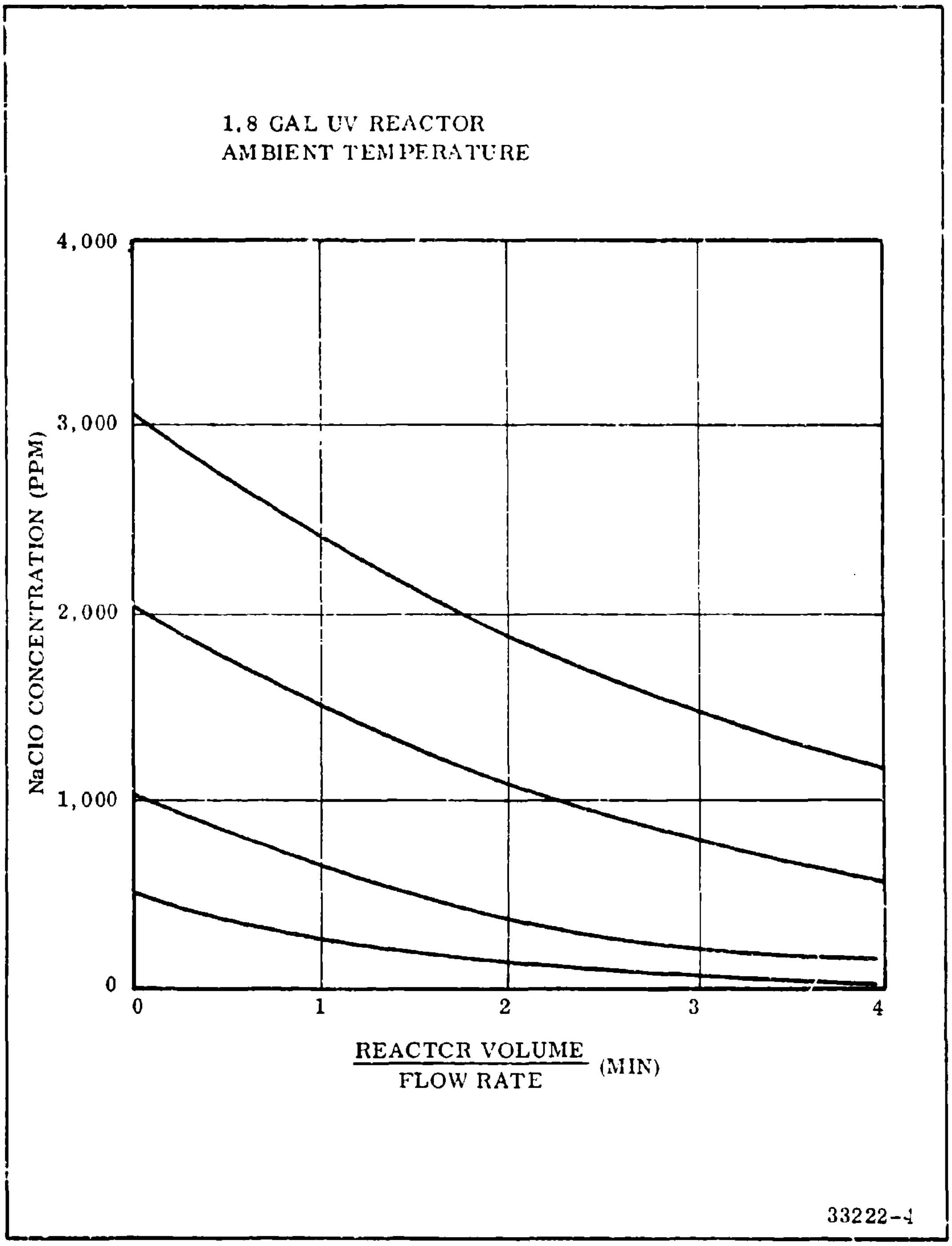

Figure 16. NaClO Concentration Profile

3.2.2.6 Ammonia/Urea Effects

A literature study has indicated that NH_3 is detrimental to the UV catalyzation of the OCl^- reaction with organics. Figures 17 and 18 are from this report and show the effect of 23 ppm of ammonia.

Examination of this data indicates these experiments were conducted under conditions of insufficient OCl^-. This can be seen in the decrease reaction rate at 16 minutes in Figure 17 and the increase in reaction rate at 23 minutes when chlorine was added. As seen on Figure 18, the insertion of the lamp did not catalyze the carbon reaction (slope did not change). This was due to the reaction of the hypochlorite with the NH_4 compounds present. This can be seen in the decrease of chlorine content from 11 to 17 minutes with no COD decrease. After the reaction had taken place, the additional chlorine added at 18 minutes did react with the organics. This study would indicate that ammonia must be eliminated prior to chlorination or sufficient chlorine be available to react with the NH_4 compounds before the organic materials can be decomposed.

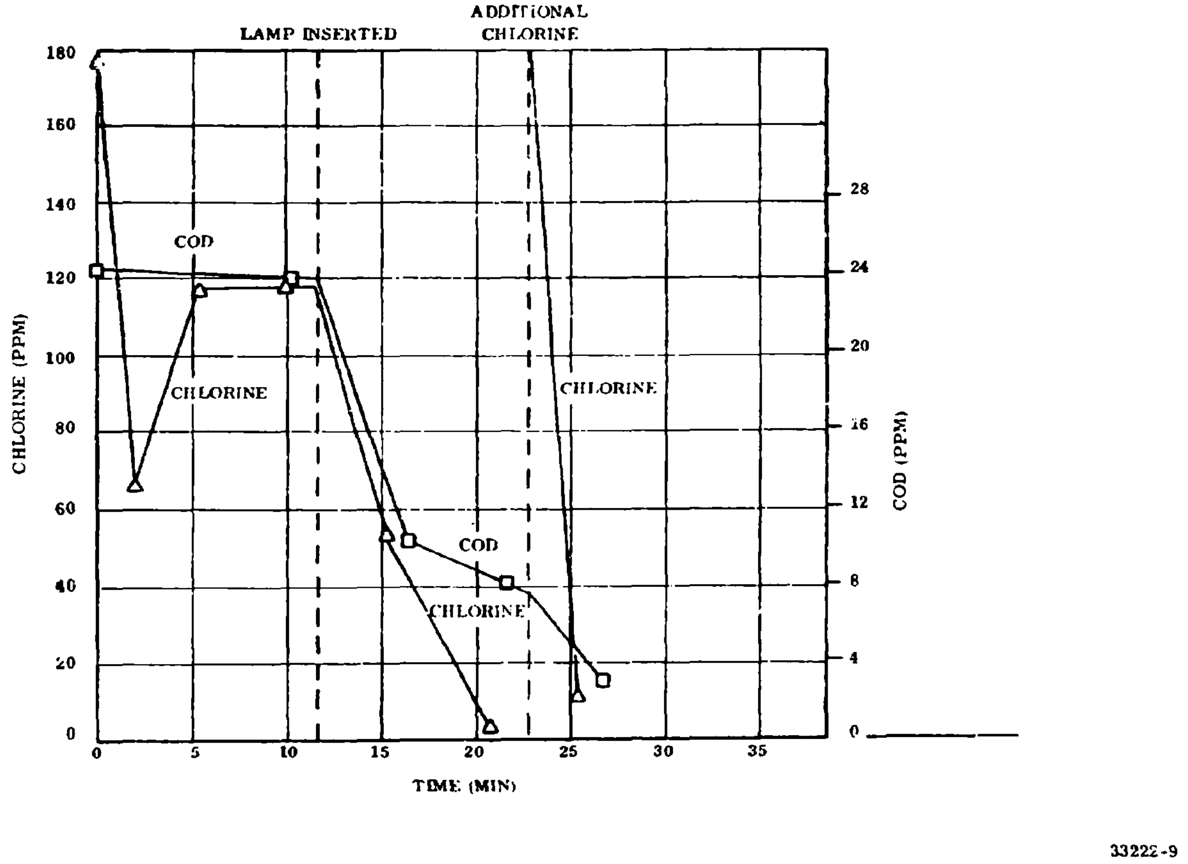

Figure 17. UV-Catalyzed Chlorine Oxidation of Effluent S&L-624-A at pH 5 (Experiment 75)

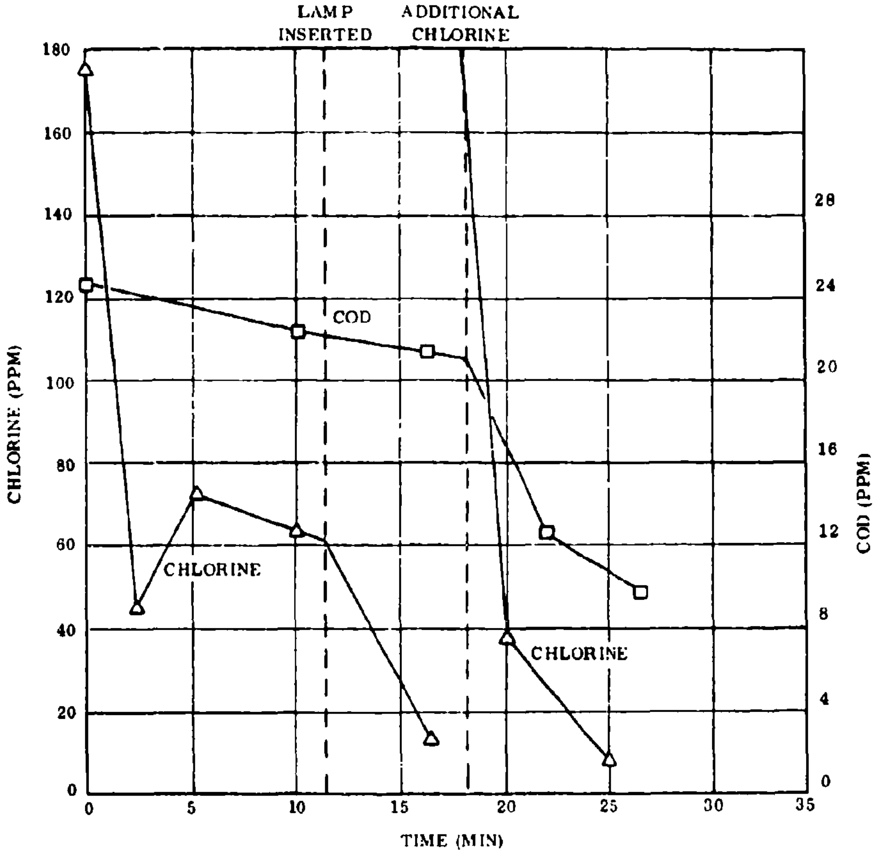

Figure 18. UV-Catalyzed Chlorine Oxidation of Effluent S&L-624-A Containing 23 ppm of Added Ammonia Nitrogen at pH 5 (Experiment 76)

3.2.3 Ultraviolet Oxidation Research

The Midwest Research Institute (MRI) has conducted laboratory research in support of Thiokol's pilot plant testing to optimize the ultraviolet oxidation process. The overall objective of the MRI effort was to firm up operating characteristics of the system applied to treatment of shipboard waste. MRI applied a wealth of information generated under MRI programs and supported by Federal Water Quality Administration research projects. In support of the program a small bench scale unit was set up consisting of one high intensity UV lamp (83.7 watt output) and one small PEPCON electrolytic cell. The system was capable of treating one gallon of centrate at various circulation rates. The centrate treated by MRI was normally shipped frozen by Thiokol and thus the data was directly comparable to Thiokol test results. A number of significant technical areas were evaluated and are briefly described in the following sections of this report.

3.2.3.1 High Pressure Lamp Treatment Efficiency

The General Electric UA-37 high pressure ultraviolet lamp was selected as the baseline lamp for the Navy waste treatment system. This lamp has a power requirement of approximately 3,000 watts and has a UV output ratio to power input of 0.26. A comparison on this lamp to other available lamps is presented in Table IV. A small Hanovia lamp was used for the MRI experiments and is very similar in characteristics to the General Electric lamp. Ultraviolet reactor efficiency is calculated as a relationship between net COD reductions per unit of UV lamp output. For purposes of the MRI investigation, the following equation was used.

$$E = \frac{\Delta \text{COD} \times \text{Flow Rate (liters/minute)}}{\text{Lamp UV Output}}$$

For the Navy system utilizing four 742 watt lamps, the available UV efficiency is:

$$E = \frac{600 \times 2.5 \times 3.785}{4 \times 742} = 1.92 \text{ mg/w-min}$$

A considerable amount of MRI testing was associated with obtaining the operational UV efficiency with the selected high pressure lamp system. Data obtained with Thiokol furnished centrate in five separate runs are summarized in Table V. A review of this data indicates that the UV efficiency varied from 0.12 to 0.34 mg/w-min. These values are of course substantially lower than theoretically obtainable

TABLE IV

CHARACTERISTICS OF CERTAIN HIGH-INTENSITY ULTRAVIOLET LAMPS

	UA-37		UA-11		H23KX		UA-3		Harovia	
Lifetime (hr)	1,000		1,000		6,000		1,000		1,000	
Arclength (in.)	48		17-1/4		12		6		4-5/8	
Burning Position	Any		Any		Horizontal		Any		Any (?)	
UV-Output (w)		%		%		%		%		%
Far (220-280 mμ)	252	32.3	71.6	28.1	189	38.9	10.36	28.7	28.0	33.5
Mid (280-320 mμ)	278	35.7	100.3	37.3	157	32.3	13.72	37.8	26.3	31.4
Near (320-400 mμ)	250	32.1	83.0	32.6	140	28.9	12.23	31.7	29.4	35.1
Total	780		255		486		36.31		83.7	
UV-Output/Arc Length (w/in)	16.3		14.8		40.5		6.05		18.1	
Far UV-Output/Arc Length	5.25		4.32		15.8		1.73		6.19	
Power Requirement (w)	3,000		1,200		1,500		360		450	
UV-Output/w of Electric Energy (w/w)	0.26		0.21		0.325		0.101		0.186	

TABLE V

EXPERIMENTAL SUMMARY

Run No.	Reactor Volume (ml)	Reactor Thickness (in.)	Flow Rate (gpm)	pH	Initial Chlorine (mg/ℓ)	Centrate No.	Initial Volume (ℓ)	UV Efficiency (mg/w min)
3	135	1/4	0.13, 0.07	7-8.5	1,100	M85-054	4.60	0.25
4	135	1/4	0.13, 0.07	7-8.5	1,100	M85-054	4.60	0.22
5	290	1/2	1.0	6.5	2,400	M85-054	4.00	0.34
6	290	1/2	1.8	6.5	1,800	M85-062	3.40	0.12
7	290	1/2	1.8	6.5	1,900	M85-062	3.50	0.22

assuming 100 percent UV efficiency. It is noted that the highest efficiency of 0.34 mg/w-min was a sample which had ammonia removed prior to testing. Other data obtained by Thiokol in experiments M85-041A and M85-056A indicated that UV efficiencies of 0.94 and 0.53, respectively, have been obtained. Review of the circumstances surrounding the Thiokol test indicated that they were conducted at higher flow rates with associated turbulent flow. This led to additional testing by MRI to evaluate the effects of turbulence.

3.2.3.2 Effect of Turbulence on Cell Efficiency

MRI varied conditions in their experimental reactor by varying the flow rate from 1.8 thru 5.2 gpm, as listed in Table VI. This data increased the flow rates in resulting Reynolds numbers in the same range as the Thiokol test data mentioned above. The UV efficiency with the high pressure lamp ranges from 0.15 to 0.18, thus not providing the desired efficiency improvement. BOD and COD removal efficiency is shown in Figures 19 and 20. The flow rates were varied from 1.8 gpm to 5.2 gpm in this data with no substantial difference in the treatment efficiency. It was concluded that this turbulence has no significant effect in improving the treatment efficiency.

3.2.3.3 Low Pressure Lamp Treatment Efficiency

A series of tests were conducted with both high and low pressure lamps and the results are listed in Table VII. A series of glucose oxidation experiments were conducted using various ammonia/urea concentrations and different lamps. It will be noted that the treatment efficiencies vary from 0.14 to 2.70. The highest treatment efficiency was obtained with a low pH and a low pressure lamp system. Ammonia present as either ammonia or urea adversely affected the treatment efficiency during the first 20 min of operation with the high pressure lamp. The data also includes the testing of a new high pressure lamp with a significant improvement in efficiency over the high pressure lamps which have been tested over a period of time. Evidently the high pressure lamp loses some of its output in testing in the wavelengths sensitive to the hypochlorite organic oxidation reaction. It is concluded from this testing that shipboard centrate can be treated much more effectively with hypochlorite and low intensity short wavelength radiation obtainable from the low pressure lamp. However, due to the lower intensity of this lamp, approximately 32 of the lamps will be required to produce the required photochemical decomposition of organics in the Navy system. This compares to 8 tc 12 high pressure lamps.

TABLE VI

EXPERIMENTAL SUMMARY[a]

Run No.	Flow Rate (gpm)	pH	Initial Chlorine (mg/ℓ)	Centrate No.	Initial Volume (ℓ)	Hypochlorite Consumption Ratio (mg OCl⁻/ mg COD)	UV Efficiency (mg/w min)
8	1.8	7.3-8.4	1,500	M85-093	5.0	18	0.18
9	5.2	6.8-7.9	1,700	M85-093	4.5	18	0.19
10	5.2	7.0-8.3	2,000	M85-093	3.5	19	0.15

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a/ Reactor volume, 290 ml; reactor thickness, 1/2 in.

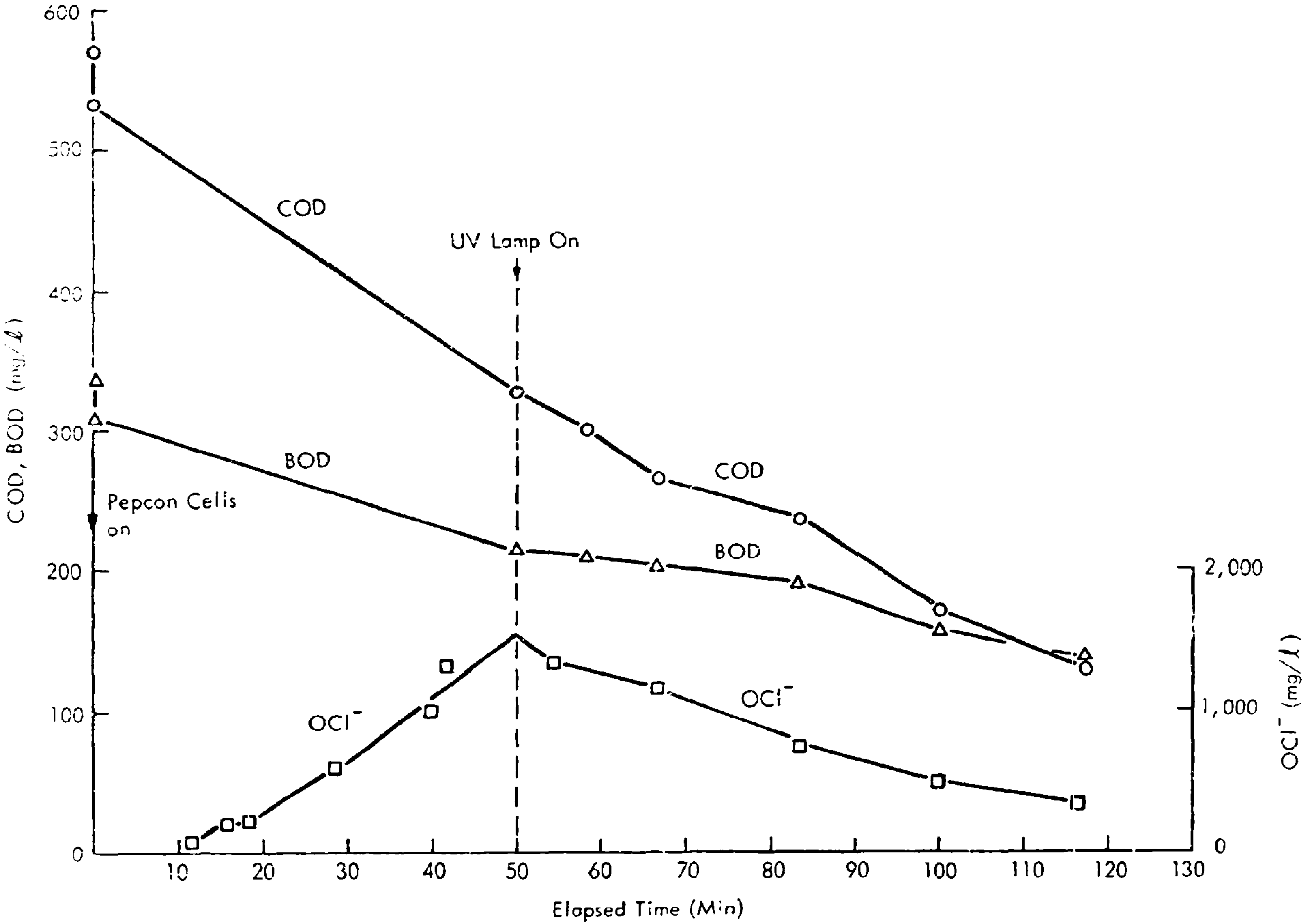

Figure 19. Run No. 8 (Flow Rate 1.8 gpm)

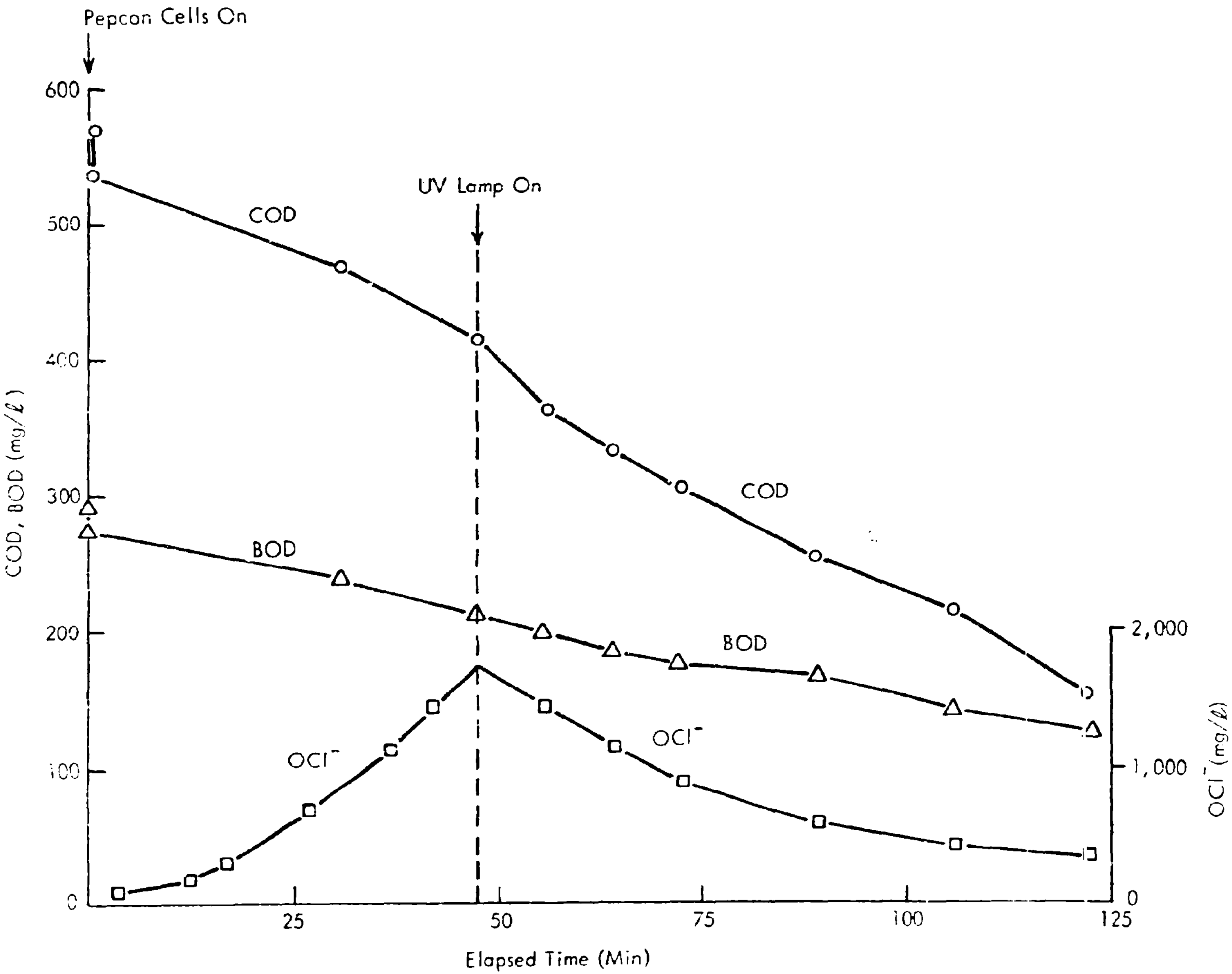

Figure 20. Run No. 9 (Flow Rate 5.2 gpm)

TABLE VII

SUMMARY OF GLUCOSE OXIDATION EXPERIMENTS[a]

Run No.	Conditions	pH Range	Initial Hypochlorite[b] (mg/ℓ)	UV Efficiency (mg/w min) 0-20 min[c]	UV Efficiency (mg/w min) 20-40 min[c]
13	No additive	7.0-8.6	1,900	0.39	0.39
14	50 mg/ℓ ammonia N	7.1-7.6	1,350	0.14	0.44
15	50 mg/ℓ ammonia N	6.6-7.7	1,800	0.22	0.45
16	50 mg/ℓ urea N	6.5-7.7	1,500	0.14	0.35
18	New (high-pressure) lamp	6.5-7.9	1,800	0.34[d]	0.86[d]
19	Low pH, new (high-pressure) lamp	3.0-6.0	1,500	0.97	0.97
21	Low pH, low-pressure lamp	3.3-5.0	1,700	2.70	2.70

---

a/ Reactor volume, 290 ml; reactor thickness, 1/2 in.; flow rate, 5.2 gpm; 2.48 g glucose in 4.0 ℓ; initial NaCl concentration, 1%.

b/ The "initial hypochlorite" concentration is the concentration at the time the UV lamp is turned on.

c/ In 20 min the reaction mixtures reduce about 1,600 wmin/gal; the lamp emits 83.7 w of UV energy and the volume of solution treated is 1.05 gal (4.0 ℓ).

d/ In Run No. 18, the initial period of low UV efficiency lasted only about 16 min (see Figure 9). Since no urea or ammonia was added, we believe that the initial low UV efficiency was the result of using a new lamp. In a subsequent experiment (Run 19) there was no initial period of low UV efficiency.

3.2.3.4 Chlorate Formation

Another data point obtained was the degree and effect of chlorate formed by the PEPCON electrolytic cell in conjunction with the UV lamps. The glucose oxidation experiments were continued varying pH and the type of lamp used in the oxidation step. Data is summarized in Table VIII. A series of six tests resulted in chlorate formation rates ranging from 2.8 to 4.3 mg/l-min from the PEPCON cell alone and was as high as 23 mg/l-min using the high pressure lamp and the PEPCON cell. The rate was substantially lower with no significant increase in the chlorate formation rate using the low pressure lamp. The presence of chlorate has been shown to have an influence on the COD analytical methods. As indicated in Figure 21, the chlorate concentration of 1,000 mg/l will result in a COD value which is about 125 mg/l lower than actual. Duplicate BOD determinations on samples containing 50 and 100 mg/l of chlorate indicated no significant effect on the chlorate analysis.

3.2.3.5 MRI Test Results Summary

1. The urea and/or ammonia present in fresh centrifuged sewage water temporarily inhibits UV hypochlorite oxidation of organics diminishing the efficiency of UV radiation.

2. Organic matter in the centrate is oxidized by UV hypochlorite but less efficiently than are substances such as glucose and formic acid. There is no fundamental reason why the oxidation of organic matter in sewage cannot be accomplished in an efficient manner.

3. Low intensity of lamps which deliver a relatively high proportion of short wavelength radiation gives a substantially higher yield or efficiency than do the higher intensity lamps presently incorporated in the shipboard system design. The possibility of using the low pressure lamps in the system should be explored. It must be recognized that approximately 32 of the presently available low pressure lamps will be required. They would require a reactor approximately 20 in. by 20 in. by 54 in. high. Also, there is a possibility of obtaining higher intensity low pressure lamps which radiate light in the same wavelength.

TABLE VIII

CHLORATE FORMATION RATES

Run No.	Experiment	pH Range	Chlorate Formation Rate (mg/ℓ/min) In The Dark	Chlorate Formation Rate (mg/ℓ/min) UV Irradiation
15	Glucose oxidation (50 mg/ℓ NH_3)	6.6-7.7	4.3	23
16	Glucose oxidation (5 mg/ℓ urea N)	6.5-7.7	4.2	15
18	Glucose oxidation (new high-pressure lamp)	6.5-7.9	3.8	14
19	Glucose oxidation (new lamp, pH 5)	3.0-6.0	2.8	10
20	Centrate oxidation (new lamp, pH 4)	2.9-4.0	3.6	11
21	Glucose oxidation (low-pressure lamp, pH 4)	3.3-5.0	3.7	0[a]

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[a] The Pepcon cells remained on continuously during the experiments, except for the irradiation step in Run No. 21.

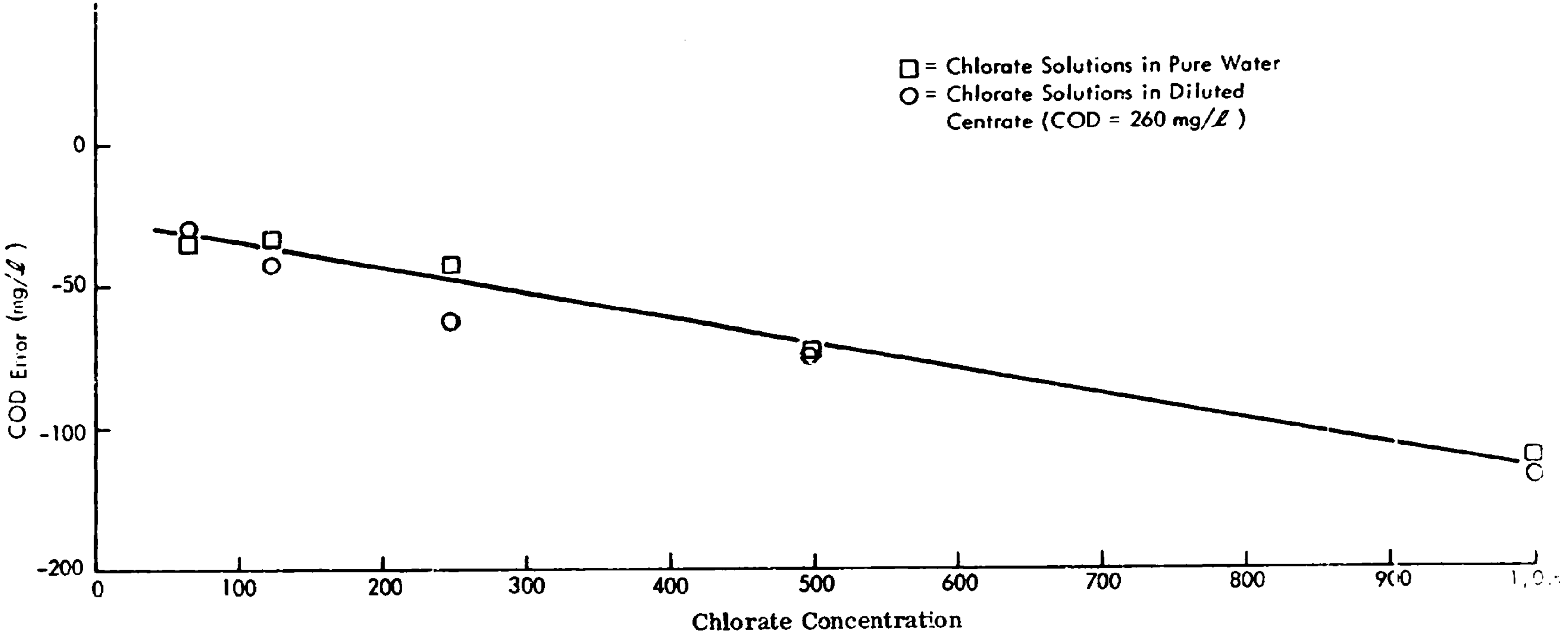

Figure 21. The Effect of Chlorate Concentration on the COD Analysis

4. Data indicates that new lamps performed more efficiently than old high pressure lamps. This also suggests that the low pressure lamp having a higher percentage of the desired wavelength could have better aging characteristics.

5. Chlorate is generated at moderate rates with the PEPCON electrolytic system. This chlorate will have an affect on the COD analytical method and it will also require additional energy output from the PEPCON cells. The rate of chlorate formation is accelerated by the use of high pressure ultraviolet lights.

3.2.3.6 Secondary Treatment Conclusions and Recommendations

The experimental data described in this section of the report on the UV system has been confirmed by full scale data obtained from the Navy prototype system. It indicates that the high pressure UV lamp system utilizing GE UA37 lamps has UV efficiencies varying from .12 to .34 milligram per watt-minute compared to 1.9 milligram per watt-minute design goal to obtain the desired COD removal by the Navy system with four lamps. The efficiency level can be raised to around one milligram per watt-minute using low pressure UV lamps. However, low pressure lamps with sufficient intensity are not currently commerically available. Based upon these considerations it was decided to initiate a comparative evaluation of Thiokol catalyst versus the high pressure UV lamp system. This testing is reviewed in Section 3.3 of this report and indicates that the catalyst system will meet the Navy treatment requirement with four 200 lb catalyst columns replacing the UV high pressure lamps. Data also indicates that the Navy treatment requirements can also be met by increasing the number of UV lamps from 8 to 16. It is recommended that the Navy select the catalyst system for the 200 man advanced waste treatment application. This selection will allow smaller overall system size, decreased weight, and lower power consumption. Thiokol has demonstrated catalyst performance during the past year as summarized in Section 3.3.2.6. The catalyst is based upon the use of technology developed in the chemical and petroleum industries and this has a strong basis for success. It has been demonstrated to have a life of over 6 months and a commercial source, Union Carbide, is being developed to manufacture the catalyst for under $2.00 per lb.

3.2.4 Solids Decomposition

3.2.4.1 Burner Evaluation

Two types of burners have been evaluated to date. The first type is an ordinary heating furnace natural draft burner. This burner performed very well when converted to a forced draft unit by the use of blowers available in the laboratory. The burner has a blower which is an integral part, but is too small to supply enough excess air for the incinerator. The burner operates and fires very easily and is not sensitive to a wide range of air to fuel ratios. Since it is not a specialty item and is widely used as a heating furnace burner, it is relatively inexpensive.

The second burner evaluated is a high pressure, high velocity burner. This burner has no integral blower or fuel pump and, therefore, these items must be supplied as separate items. Because it is a high pressure, high velocity burner, it is very effective for fluidized bed incineration tests. At small excess air rates, it seemed to be more efficient because of the highly turbulent flame. Since this burner requires extra controls, it is about 3 to 4 times as expensive as the heating furnace burner. Another disadvantage is that the burner will not operate in a wide range of air to fuel ratios.

It was determined that the ordinary heating furnace burner along with an exhaust blower would be used in the final design such that the incinerator will be operated under a negative pressure and all leakage would be into the incinerator.

3.2.4.2 Exhaust Emission Evaluation

To evaluate the combustion and exhaust emission of the incinerator, several thermodynamic equilibrium calculations have been made on the products of combustion to determine the amount of each product and the flame temperatures. These calculations are accurate if equilibrium can be assumed to be in effect in the combustion chamber. It is believed because of concentration gradients of the sludge in the combustion chamber, that equilibrium conditions do not exit, however, these calculations can be used as a guideline for incineration performance. In the region of the burner, where the sludge has little or no effect on the fuel combustion, equilibrium calculations should be quite accurate and can be used to predict the flame temperatures and the amount of nitrogen oxides formed for different mixture ratios of air to fuel. Table IX shows the results of some of the calculations. The flame temperature as a function of air to fuel ratio is shown in Figure 22.

TABLE IX

EQUILIBRIUM COMPOSITION

Air to Fuel Ratio	15	30	40	100
Equilibrium Temperature (°F)	3,450	2,120	1,675	770
	Mole Fractions			
CO	0.0063	--	--	--
CO_2 (G)	0.12	0.067	0.05	0.02
H (G)	0.00019	--	--	--
HO (G)	0.0028	0.000025	--	--
H_2 (G)	0.00097	--	--	--
H_2O (G)	0.1	0.053	0.04	0.016
NO (G)	0.0039	0.00067	0.00015	--
N_2 (G)	0.74	0.769	0.77	0.78
O (G)	0.0004	--	--	--
O_2 (G)	0.017	0.11	0.13	0.18
SO_2 (G)	0.00053	0.00027	0.00019	--
SO_3 (G)	--	--	0.00002	0.00008

Studies have shown that oxides of nitrogen produced by the combustion of fuel in air at these high temperatures are very close to the predicted values as calculated assuming equilibrium conditions. The oxides of nitrogen are quite stable, however, and the amount formed near the burner is "frozen" after the addition of the sludge influent. The amount of nitrogen oxides formed as a function of air to fuel ratio is shown in Figure 23.

Sulfur emissions from the stack are dependent on the amount of sulfur in the fuel and sea water. The amount of sulfur which is contributed from human waste is small. Assuming the fuel has 1 percent sulfur

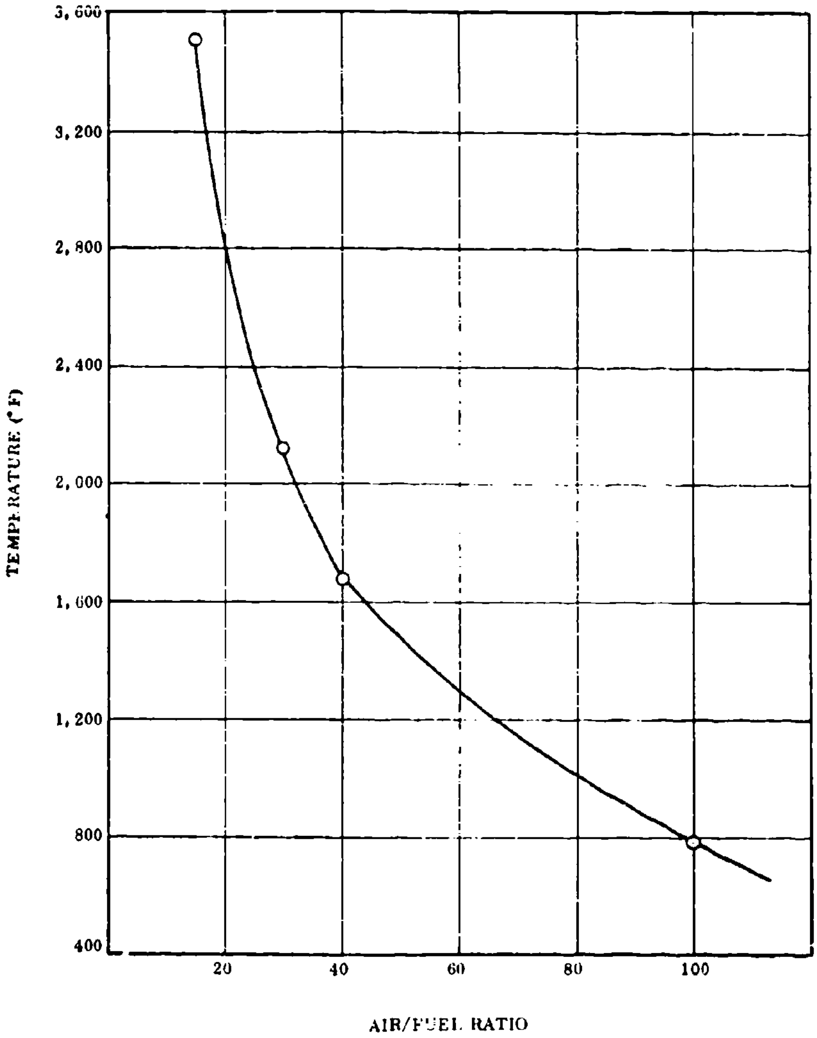

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Figure 22. Equilibrium Flame Temperatures vs Air to Fuel Ratio

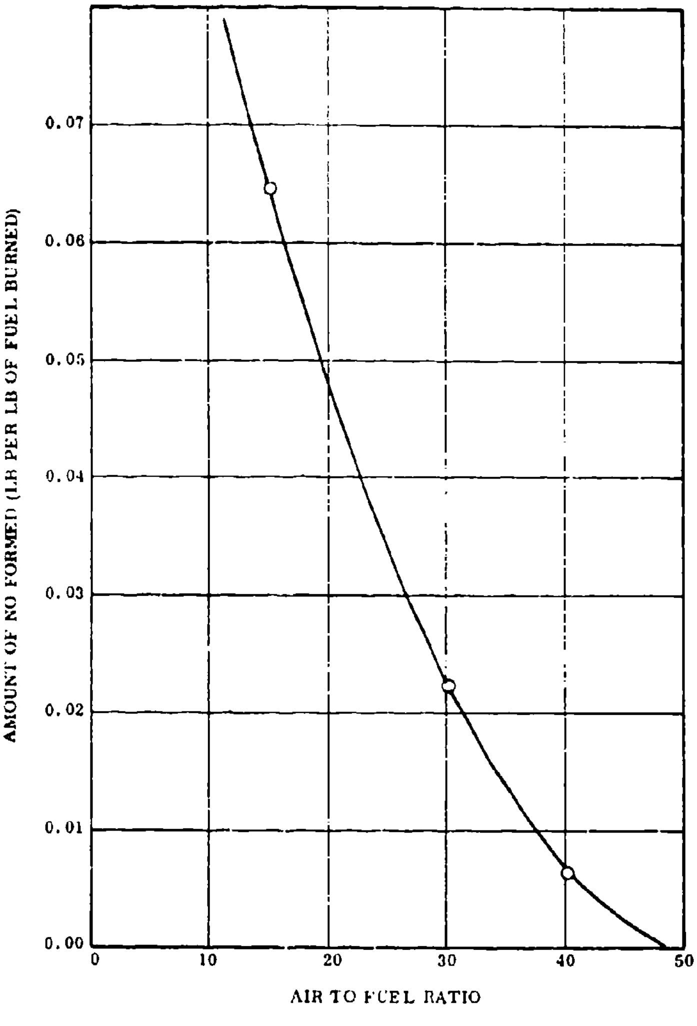

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Figure 23. Nitrogen Oxide Formation as a Function of Air to Fuel Ratio

content and the sea water has the amount of sulfur as published in the Handbook of Physics and Chemistry the amount of sulfur as SO_2 per hour is 0.30 lb when burning at the rate of two gallons of fuel per hour.

Other pollutants in the flue gases which must be considered are the different salts that are precipitated when the sea water is evaporated from the sludge in the incinerator. Because of the high velocities attained in the incinerator, 80 percent or more of the salts which are precipitated in the incinerator are fluidized and blown out the stack.

Equilibrium calculations show that very little NaCl solid is formed in the incinerator, however, because of concentration gradients and the short residence time in the incinerator, it is believed that equilibrium conditions are not a good assumption for the calculation of the amount of the different salt species in the flue. If the influent could be sprayed into the combustion chamber without nozzle plugging, then the amount and types of species formed by the different salts would be closer to the values as calculated assuming equilibrium conditions. It is believed that most of the ionized species in the sea water are precipitated as sodium chloride solid, magnesium chloride liquid and magnesium sulfate solids, however, an analysis of the flue gas particulate matter or the solids remaining in the incinerator has not been made when using sea salt in the influent.

It has been concluded that to reduce the amount of pollutants in the incinerator flue, the following criteria are necessary in the design and operation of the solid separation and incineration system.

1. Flame temperature must be kept as low as possible and still maintain adequate combustion of sewage solid material to reduce nitrogen oxide pollutants.

2. To reduce sulfur oxide pollutants it is necessary to use a low sulfur content fuel.

3. Reduction of salt particulate matter can be accomplished by increasing the efficiency of the solids separator and thus reducing the total salt which is processed by the incinerator.

4. To prevent the precipitated salts from melting and also to reduce the oxides of nitrogen which are formed, an air to fuel ratio of approximately 40:1 is needed. This also allows a high enough temperature for good evaporation and combustion of the sludge.

3.2.4.3 Incinerator Operating Performance

The performance of an incinerator can best be evaluated by the following criteria.

1. The amount of sludge consumed per gallon of fuel burned.
2. The qualify of the stack emissions from the incinerator.
3. The frequency and amount of salt and ash removal.

To evaluate the amount of sewage sludge which can be vaporized and combusted per gallon of fuel, a look at a summary of test data should be made. Table X shows a summary of the data from a series of runs totaling 30 hours incineration operating time. The series of runs shows an average of 4.67 gal of sludge per gal of fuel burned. The incinerator test apparatus is shown in Figure 24. Generally it can be stated that a ratio of between 4 and 5 gal of sludge per gal of fuel is how the incinerator has performed for most of the tests to date.

The quality of the stack emissions is difficult to measure without precise measuring equipment, however, a reasonably good evaluation can be made by visual observation and detection of odors. Generally, it has been observed that if the exhaust from the combustion chamber is above 900°F that the stack emissions appear to be quite clean, and no odors are detected. Analyses of the stack gases have been made, but because of the very small concentrations of pollutants, it is difficult to measure. Therefore, stack gas analyses are used primarily for material balance calculations and the amount of air being used. A stack gas analysis is shown in the test run, Table X. This analysis was on a dry basis and if the amount of water is calculated from the hydrogen content of the fuel and sludge, the resultant analysis would be:

N_2	61.5%
O_2	5.77%
CO_2	5.93%
H_2O	Balance

The amount and type of particulate matter in the flue has not been measured.

TABLE X

TYPICAL INCINERATOR TEST RUNS

Summary of Results

Incinerator Operating Time (hr)	31.2
Sewage Feed Time (hr)	25.05
Number of Runs	9
Time of Runs (hr)	0.75 to 6.25
Volume of Sewage Feed (gal.)	96.5
Volume of Fuel Oil (gal.)	21.1
Ratio of Sewage to Fuel (avg)	4.67
Chamber Exhaust Temperature Range (°F)	950 to 1,600
Temperature Range Near Distribution Plate (°F)	925 to 1,250
Temperature Range at Bottom of Chamber (°F)	1,200 to 1,800
Air Flow (cfm)	50 to 80
Feed Suspended Solids (lb)	13
Feed Total Solids (lb)	37
Total Salt in Feed (lb)	24
Total Salt in Incinerator After 25 Hours (lb)	3
Total Ash in Incinerator After 25 Hours (lb)	Less than 0.1

Stack Gas Analysis:

	Percent
N_2	84.4
O_2	7.9
CO_2	8
CO	0

NOTE: Gas analysis did not consider water vapor.

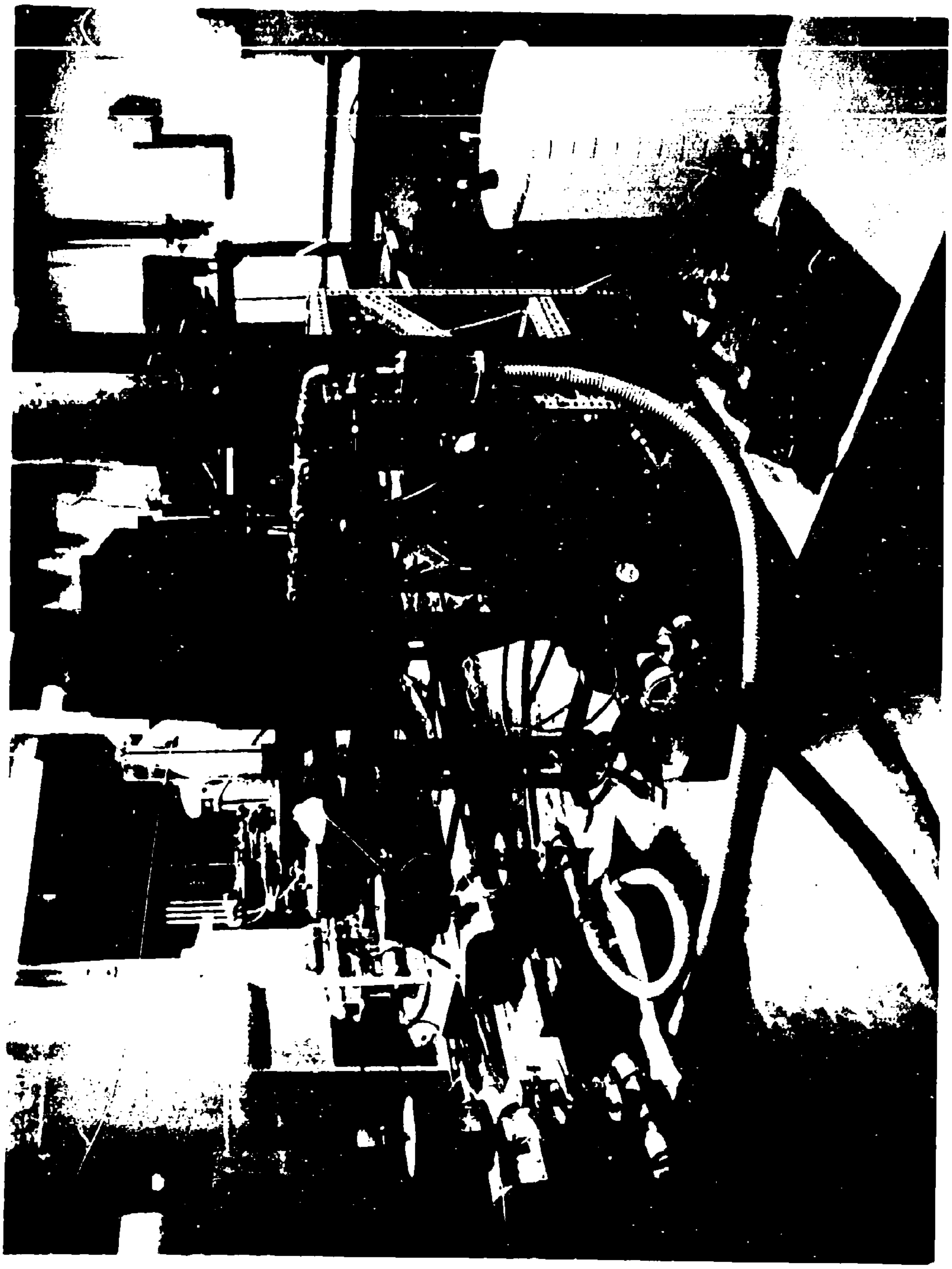

Figure 24. Pilot Incinerator Test Apparatus

It has been found that most of the salt is fluidized and is blown out the stack along with the ash. This minimizes the frequency and amount of salt that will be required to be cleaned from the incinerator. A 25 hour test showed that of 24 lb of salt that was fed to the incinerator only 3.4 lb were retained. Figures 25 and 26 show the salt buildup after the 25 hour period. One section in Figure 25 has been washed to show the liner material. The salt was easily cleaned out after the test with water. It is believed that even less salt would have been retained if the air flow in the latter part of the test was not restricted because of salt buildup in the excessively small holes in the distribution plate. Table XI summarizes the total operating test results on the pilot incinerator from May through August.

The test results proved to be quite meaningful, however, because during this period of testing it was confirmed that if the incinerator could be operated at relatively high velocities the chamber and stack could be kept relatively free of deposits of salt and other particulate matter.

A steel baffle section was designed such that it did not restrict the gas flow substantially. This baffle section performed reasonably well for vaporizing and burning the sludge when the sludge was poured into the baffled section. A sketch of the baffle used during the testing is shown in Figure 27. Table XI lists the results of this baffle design evaluation test.

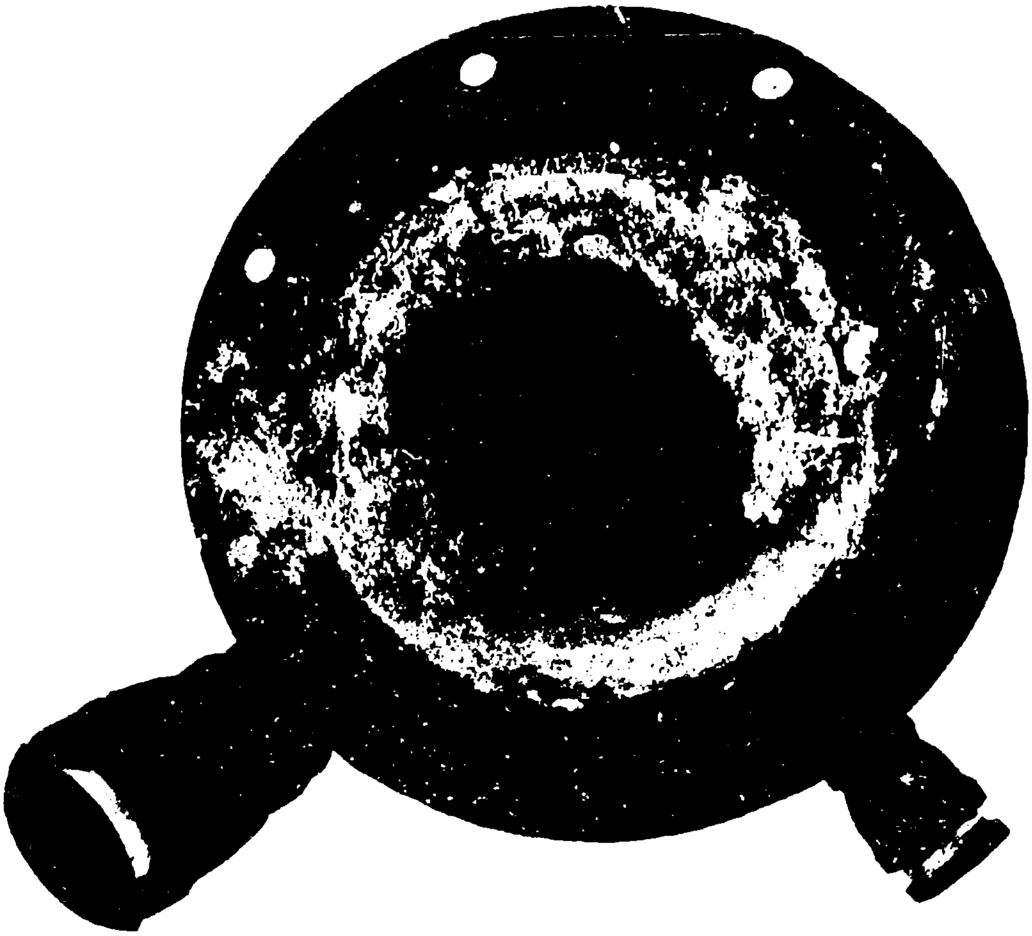

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Figure 25. Salt Buildup After 25 Hr (Partially Cleaned)

Figure 26. Salt Buildup After 25 Hr (Closeup View) Pilot Incinerator

TABLE XI

PILOT INCINERATOR TEST RESULTS

	May-Jul*	Aug-Sep**
Incinerator Operating Time	70 hr	29 hr
Moyno Pump Operating Time	66 hr	27 hr
Cumulative Time on Fused Silica Liner	74 hr	--
Operating Time on Firebrick Liner	-	29 hr
Salt Water Sludge Operating Time	66 hr	--
Quantity of Sludge Processed	280 gal	105 gal
Operating Time on Steel Baffle	--	29 hr

RESULTS

*Silica liner cracked and was replaced with firebrick liner.

Moyno pump operation satisfactory.

Salt accumulation observed - has not affected incinerator operation. Occasional cleaning will be required approximately every 25 operating hours.

**The firebrick liner was coated with Setskold cement. After approximately 20 hours of operation the cement started to blister and flaked off exposing the soft brick which eroded quite rapidly in the severe incinerator environment.

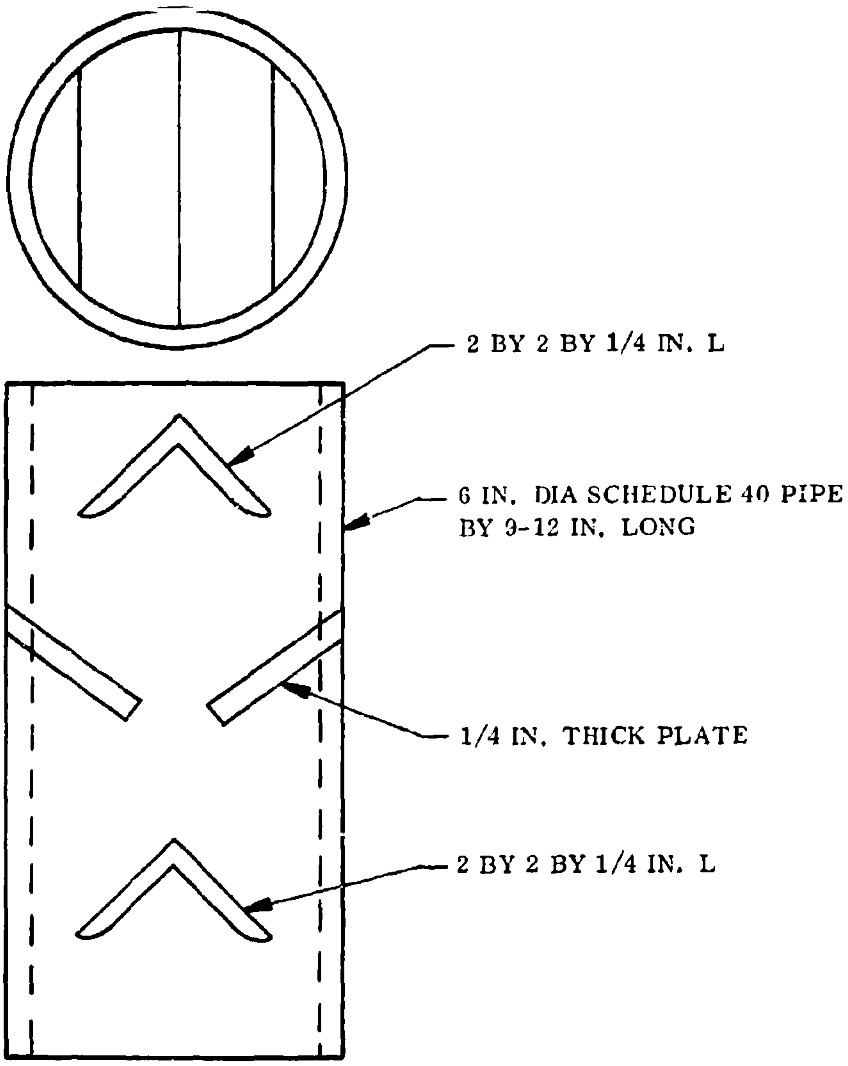


Figure 27. Typical Baffle Arrangement

3.2.4.4 Incinerator Materials Evaluation

Materials play an important part in the performance of the incinerator. The three major zones of environment within the incinerator require materials selected and evaluated to provide an overall low maintenance unit. Besides the (1) combustion chamber, (2) the sludge feed and combustion baffle, and (3) the exhaust stack, overall insulation is also required.

Materials were evaluated to withstand the 1,800° to 2,000°F combustion temperatures, the thermal shock conditions of sludge feeding, and the high temperature corrosion and spalling of the baffle and exhaust system.

The following materials have been evaluated and considered as incinerator components.

1. Mild steel
2. Titanium
3. Stainless steel
4. Fused silica
5. Insulating firebrick
6. Refractory cements

1. Mild Steel - Extensive use of mild steel in the sludge feed and baffle zone has shown the corroding and spalling associated with mild steel under the condition of high temperature, thermal shock and corrosive environment. However, the mild steel baffles have held shape and permitted various designs to be tested. Operating life of mild steel components may be long enough to permit their use based on long term replacement. Evaluation of flame sprayed ceramic coatings on mild steel has been conducted under different conditions and it is believed that this material combination holds promise for incinerator use.

2. Titanium - A 3/8 in. thick titanium sludge distribution plate appeared to oxidize quite rapidly when subjected to the sludge combustion conditions. Warpage due to thermal gradients was also experienced. No further testing is anticipated.

3. Stainless Steel - Early tests using stainless steel as a sludge distribution screen were entirely unsatisfactory. These screens (wire diameter of 1/16 in.) failed after several hours of run time due to a breakdown of individual wires. Testing of 310 stainless steel liners is called for due to the high temperature (2,200°F) corrosion resistance and spalling resistance reported in the literature. Good performance of the stainless steel liners is expected upon review of encouraging results achieved with mild steel.

4. Fused Silica - The high density (110 lb/cu ft) fused silica has been used primarily as a liner material and appears to have performed better than other materials with the exception of perhaps some of the refractory cements. In the region of the sludge distribution plate, this material has shown some cracking apparently due to the excessive temperature gradients in this region and a possible reaction of the material with molten salt to form a sodium silicate. Low density (35 lb/cu ft) fused silica has been evaluated as the primary insulation material and has shown excellent performance.

5. Insulating Firebrick - This material has performed well where there is no mechanical or thermal stresses. However, even the slight stress causes the material to crack excessively. When this material is coated with a refractory cement, it performs reasonably well.

6. Refractory Cements - The materials seem to perform very well in the incinerator as a repair material and a liner as long as the material is not built up into a thick layer. When very thick layers are made, some cracking appears.

It is recommended that the low density silica be used as the main insulating material in the incinerator. The high density is recommended for the liner material in the combustion chamber as well as the stack exhaust zone. Because of its reported resistance to spalling at temperature below 2,200°F, 310 stainless steel is recommended for the sludge feed and combustion zone liner.

3.2.5 Pretreatment Subsystem Development

Several configurations of the hydraulic macerator have been fabricated and tested. The design which worked very well is shown in Figure 28. This is a prototype constructed of plexiglass in order to be able to observe the action of the macerator.

In testing on the macerator, a flow of 10 gpm was used to simulate the influent condition. This flow was introduced through a 4 in. pipe into the center of the macerator. Copious amounts of paper towels and toilet tissue were added to the influent flow and were pulverized almost immediately. Sanitary napkins were also fed into the influent stream and were also torn up although not as fast as the paper products.

Metal objects such as nuts and bolts were dropped into the macerator. They were swirled around on the periphery of the cylindrical section; however, they were never discharged through the outlet tube. Their presence in the macerator did not hinder nor assist in the macerating of the paper products.

The first configuration tested used a small plastic tank approximately 14 in. in diameter and 18 in. high. The tank had a rounded bottom, was open at the top, and 1/2 in. diameter holes drilled in the walls starting about 8 in. from the bottom. The two jets created a good vortex and shredded the paper products without difficulty; however, the holes soon plugged and the flow was forced over the top of the tank. Several attempts were made at devices to clean the holes, some partially successful; however, the results were not promising. Cutting blades were installed along the periphery of the tank wall. The cutting action was insignificant and in fact caused more clogging than cutting.

Air jets were also tried instead of the high pressure water; however, the energy transfer was not as efficient and vortexing was not satisfactory.

Figure 28. Prototype Hydraulic Macerator

NOT REPRODUCIBLE

3.3 Prototype System Design and Development Testing

Based on the subsystem development test results presented in Section 3.2 of this report, a 200-man prototype waste treatment system was designed, fabricated, and tested to obtain total system performance data and demonstrate all subsystems to be used in the Phase II waste treatment system. Several variations of the 200-man prototype design were evaluated to assess performance of alternate approached prior to making final subsystem selections for the Phase II system. The subsequent sections describe the 200-man prototype design and design variations and present the results of the development tests conducted on the subsystems and total system.

3.3.1 Prototype System Design Description

A schematic of the 200-man prototype system which was evaluated is shown on Figure 29. This schematic shows the pretreatment, primary treatment, and secondary treatment equipment comprising the total system. Two secondary treatment loops are shown; a PEPCON ultraviolet loop and a PEPCON catalytic column loop since both were evaluated during Phase I.

A complete set of drawings defining the total system was prepared during Phase I. Figure 30 provides a drawing tree of the designs which were released during Phase I. These drawings will form the basis for the Phase II design and will be updated at the initiation of Phase II. The final system assembly drawing, 7U43872, will also be prepared and released at the beginning of Phase II. The basic system evaluated during Phase I was comprised of the following major subsystems.

1. Pretreatment Subsystem (7U43868)--The pretreatment subsystem consists of a primary holding tank to provide surge capacity, a screen assembly to intercept the incoming foreign objects and separate large solids, and a pump to transfer material from the holding tank to the centrifuge.

2. Primary Treatment Subsystem (7U43874)--The primary treatment subsystem is comprised of a centrifuge to separate incoming solids, a sludge receiver to collect the separated solids, a centrate tank to collect the centrate, and two pumps--one to transfer the sludge to the incinerator and the other to transfer the centrate to the secondary treatment system. All components are mounted on a common base.

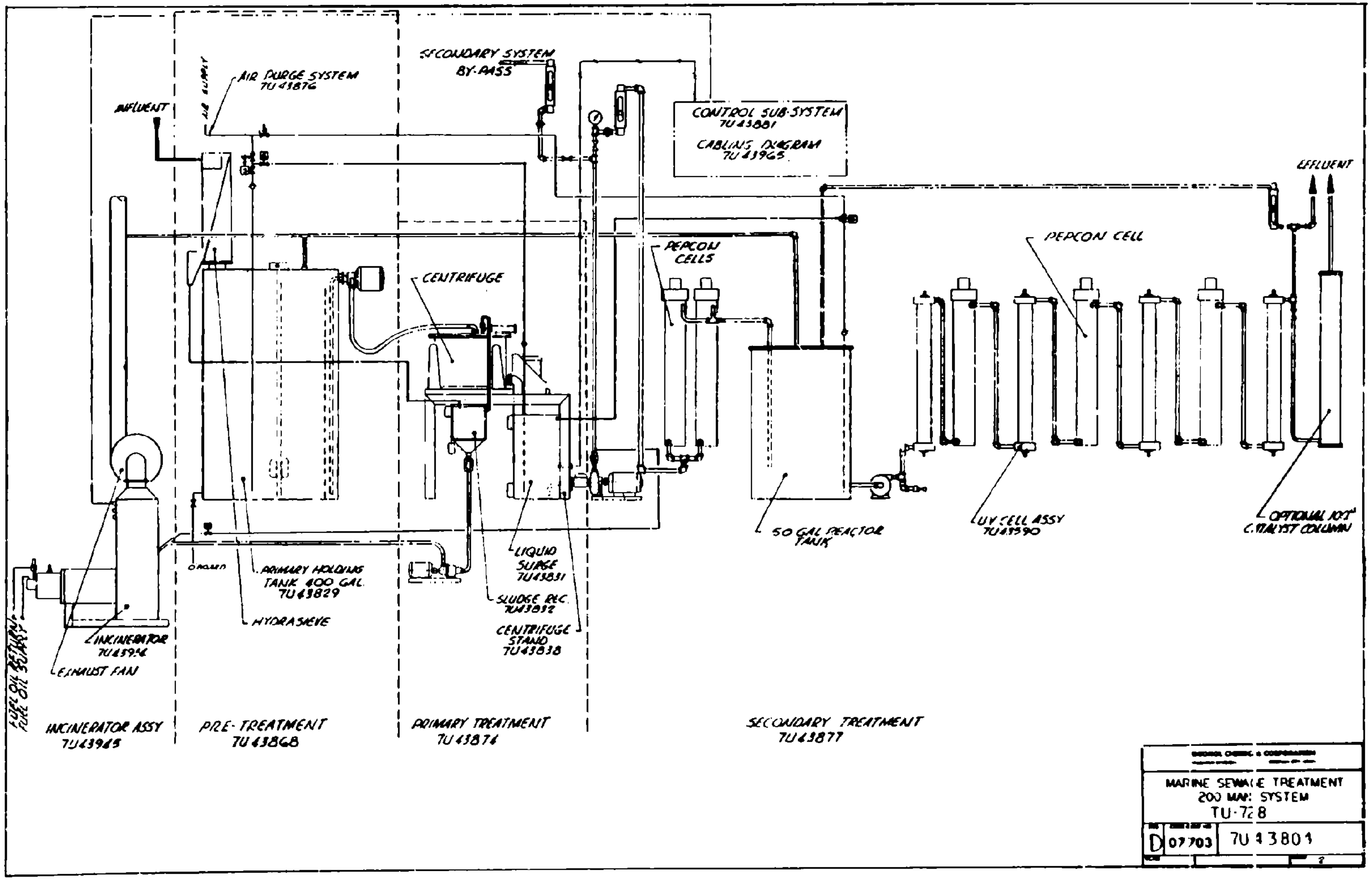


Figure 29. Schematic of Sewage Treatment System

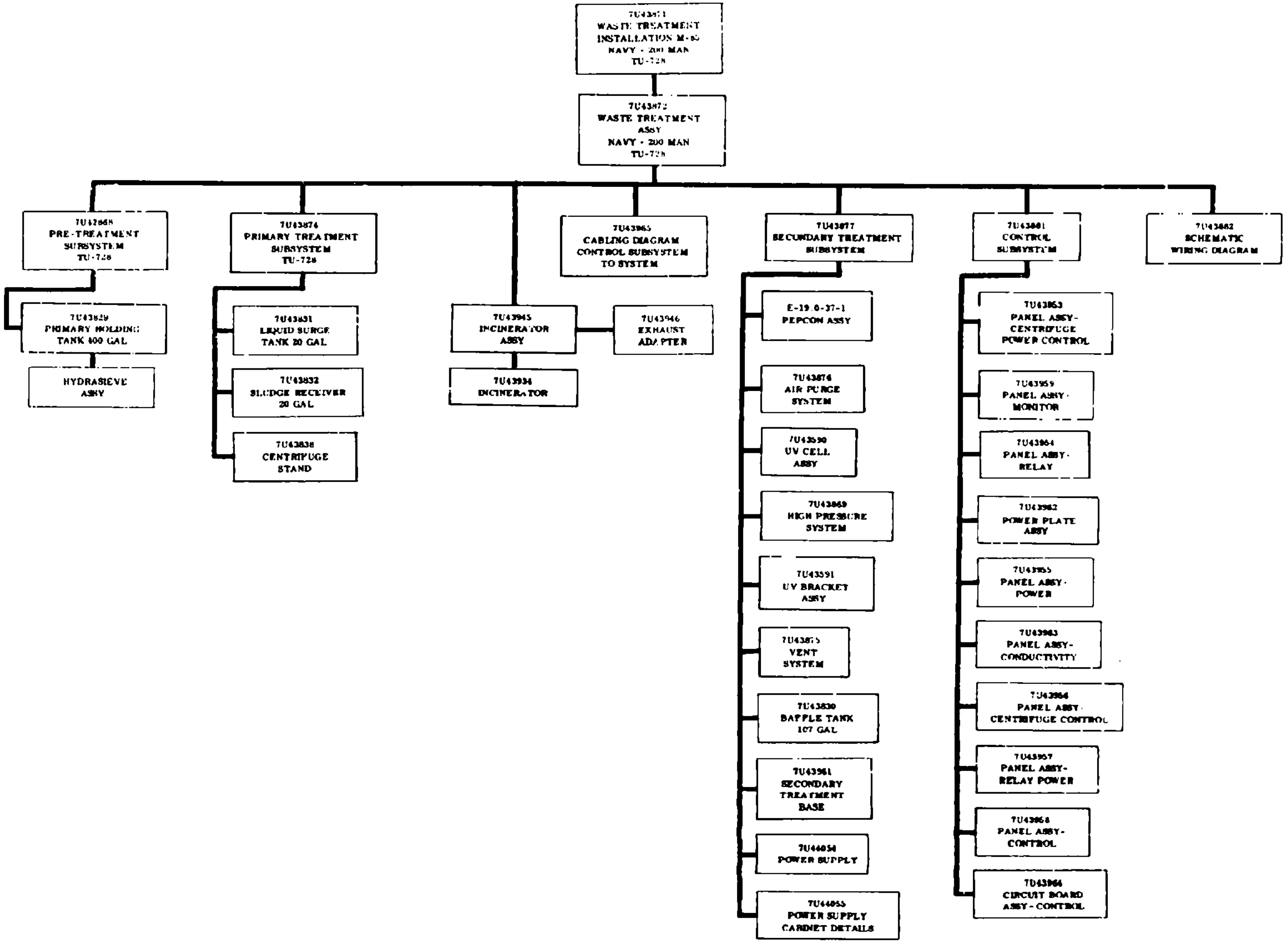


Figure 30. Drawing Tree - 200 Man Navy Waste Treatment System

3. Secondary Treatment Subsystem (7U43877)--A secondary treatment subsystem is comprised of the electrolytic and ultraviolet reactors and their electrical power supplies and a secondary holding tank to provide holding time and venting of gases after electrolytic addition of hypochlorite to the centrate from the primary treatment system.

4. Control Subsystem (7U43881)--A control subsystem integrates all system control functions and provides for automatic operation of the system.

5. Incinerator Assembly (7U43945)--The incinerator assembly consists of an incinerator and its associated components to receive sludge from the primary treatment system and incinerate the sludge on a periodic, as required, basis.

The system also includes auxiliary subsystems to provide for venting and purging at various places in the system. Detailed descriptions of all subsystems are included in subsequent sections.

3.3.1.1 Pretreatment Subsystem Design

The pretreatment system consists of a hydrasieve screen, a macerator, a 400 gal primary holding tank (Drawing 7U43829), a pump for transferring the contents of the holding tank to the centrifuge, a sludge tank to collect screenings from the hydrasieve and sludge from the centrifuge and a sludge pump to transfer sludge to the incinerator.

Influent from the sewage source enters the top of the hydrasieve. Liquids and solids of less than 0.010 in. pass through the screen and go directly to the holding tank. Solids slide down the self-cleaning inclined screen and enter the sludge tank. Screened solids are pumped from the sludge tank using a macerator pump. The solids are recirculated and continuously macerated at a rate of 4.7 gpm. A portion of the recirculated macerated sludge is bypassed through a sludge pump and fed to the incinerator at a rate of 3.0 gph.

The primary holding tank (Drawing 7U43829), located below the hydrasieve, has a capacity of 400 gal. This tank will accommodate normal expected surges of influent from the 200 man sewage collection system.

The sludge pump is a Moyno Model BA100-BGQ and is powered by a 1/3 hp electric motor through a variable drive sheave and belt system. The purpose of the variable drive is to determine the ideal rpm of the pump before selecting the final drive system. This pump, motor, sheaves and belt are the same as used previously in the waste treatment system.

The transfer pump is located on top of the primary tank to conserve space and to minimize the amount of fluid loss in the event of a packing failure. This unit (Model 777-F) is a bronze body, neoprene impeller, self-priming pump manufactured by Jabsco Pumps of International Telephone and Telegraph Corp.

The inlet of the pump piping is located near the bottom of the primary tank, within a perforated metal cylinder which extends the full length of the tank. In this way, the pump and centrifuge are afforded a redundant screening and a means of protecting the pump inlet and instrumentation tubing from possible damage due to severe liquid agitation caused by the roll of the ship.

The pump is protected against running dry by a pressure switch located in the discharge piping. The rate of discharge controlled by pump size, pulley sizes, and motor speed is based on the maximum efficient capacity of the centrifuge.

The primary holding tank has a level detection for control of the effluent level in the primary tank. Pressure switches were chosen for this operation. Level sensing using pressure switches in contact with the medium would require special diaphragms which would be prohibitively expensive. However, through the use of tubes in the center and redundant switches mounted at the top of the tank (on these tubes), it was possible to use the pressure switches for level detection.

3.3.1.2 High Pressure Subsystem Design

The purpose of the high pressure subsystem was to supply flow under pressure from the baffle tank to a hydraulic macerator. Thiokol Drawing 7U43869 depicts the high pressure subsystem as conceived during the design stage of Phase I. The final configuration did not include the hydraulic macerator, and the high pressure subsystem was eliminated from the design.

3.3.1.3 Incinerator Assembly Design

The incinerator assembly (Drawing 7U43945) consists of three major components: the incinerator, the burner, and the exhaust fan. Sludge influent is pumped into the incinerator near the center of the incinerator and is dropped on a baffle. Hot gases from the burner vaporize the water in the sludge, and the oxygen rich gases pyrolize and oxidize the sludge.

The velocity of the gases in the incinerator are high enough to fluidize any solid particles such as precipitated salt, and most of this is carried out the stack along the flue.

The exhaust system causes a negative pressure in the burner so that all leakage in the incinerator is to the inside. Air is induced near the top of the chamber so that the temperature of the gases to the exhaust fan are kept below 650° F. During Phase II the exhaust fan will be replaced by a blower/air ejector system. This system will provide the same negative pressure in the incinerator chamber and will eliminate the necessity for a fan to operate in the hot exhaust gases.

The incinerator is equipped with a door for easy access and examination and/or cleaning of internal surfaces. The incinerator is lined with a fused silica material and 3 in. of 30 lb fused silica is used as insulation. The outside of the incinerator is constructed of 1/4 in. mild steel plate.

3.3.1.4 Primary Treatment Subsystem Design

The primary treatment subsystem separates the solids remaining in suspension after hydrasieve screening. The liquid sewage is pumped from the holding tank into the centrifuge at an average rate of 3.6 gpm. The solids then are separated by centrifugal force and collect in the sludge receiver, while the liquid is gravity fed into the liquid surge tank at approximately 3.6 gpm for circulation through the secondary treatment system.

The primary treatment subsystem is as shown on Drawing 7U43874. Basic components are as follows.

1. Centrifuge.
2. Centrifuge Stand, 7U43834.
3. Vented Liquid Surge Tank.
4. Centrate Pump.

The centrifuge is a De Laval 20 by 14 in. ECM clarifier. This machine was placed into operation during Phase I.

The centrifuge stand is a steel weldment designed to support all the other components and to tie them together into the one system. Channels, 3 in. high, at the base provide a skid so a forklift truck can transport the system. The steel used is standard shapes and plate sizes.

The centrate pump is a Jabsco Model 777F powered by a 1/4 hp electric motor through a drive sheave and belt. This pump was selected because of the larger ports (1 in. suction and discharge) and is the same pump and motor as is on the pretreatment holding tank.

The piping connecting the components is primarily PVDC high temperature, schedule 80 pipe. All connections, where possible, are socket welded per standard Navy design. It was decided to use the PVDC piping as this material was the cheapest material that would resist the hypochlorite solution and the 160° F temperature.

3.3.1.5 Vent Subsystem Design

The vent subsystem is shown schematically on Drawing 7U43804 (Figure 29).

The vent system utilizes high rate liquid recirculation through the PEPCON cells and catalyst columns to transport gases to open vent tanks. The PEPCON cell vent tank exhausts hydrogen rich gas and the catalyst vent tank exhausts oxygen rich gas. Both tanks will have a tendency to expel ozone, oxygen, water and hypochlorite. The PEPCON and ultraviolet vent tanks are attached to a suction side of the incinerator blower assembly as shown schematically in Figure 21. It is apparent that blower corrosion will have to be contended with. It is planned to evaluate the use of oxidizer resistant aluminum alloys and coatings in the blower to minimize the corrosion problem. The temperature will be held below 300°F which enables consideration of a wide variety of coatings including polyurethanes, epoxies, and halocarbons.

At present, the effluent is being recirculated to the secondary holding tank which is not pressurized. Pumping through the secondary system at a higher rate tends to eliminate some of the problems of gas formation in the PEPCON and UV cells. Since the secondary holding tank is unpressurized, this allows sufficient ullage for the release of the entrained gas to be vented.

3.3.1.6 Secondary Treatment Subsystem Design

As previously noted, two secondary treatment systems were evaluated during Phase I. Both systems are shown schematically on Figure 29. The PEPCON/ultraviolet system is defined by Drawing 7U43877. This drawing shows a series piping arrangement between alternate PEPCON/ultraviolet cells. The final system arrangement was connected as shown on the Figure 29 schematic. The PEPCON/catalytic system was connected as shown on Figure 29. The basic difference between the ultraviolet and catalytic systems is the substitution of a catalytic column for an ultraviolet cell. The major components comprising the secondary treatment system(s) are as follows.

1. Secondary holding tank.
2. PEPCON Assembly, Pacific Engineering Drawing (E 19. 0-37-1).
3. UV Cell Assembly (7U43590), or Catalytic Column.
4. PEPCON Power Supply, Pacific Engineering Drawing (E 19. 5-16).
5. UV Power Supply (7U43879).

Secondary Holding Tank

The secondary holding tank employed in the Phase I test configuration was a simple 50 gal vented polyurethane tank. The tank was installed schematically as shown on Figure 29 depending on which secondary treatment system was operational.

PEPCON Assembly

The PEPCON assembly was designed by Pacific Engineering and Production Company of Nevada and consists primarily of five PEPCON cells each with a 500 sq in. anode, copper bus bars which act as conductors to the cells and also as supports for the PEPCON and UV cells, and the associated plumbing required for connecting the system. The pipe between cells is 3/4 in. schedule 80 PVDC cemented to socket type PVDC fittings.

The current density for each PEPCON cell is 1.0 amp/sq in.; hence, the total current for the eight cells is 4,000 amps. To carry this current, two copper bus bars, each 5 in. wide and 1.0 in. thick, are required. The two tinned copper bus bars extend horizontally from the power supply with the anode and cathode 65-1/2 and 36 in. from the base respectively.

The structural support for both the PEPCON and UV cells is the cathode bus bar. Details of the UV assembly is discussed in 3.2.2 . The structural support for the PEPCON cell also acts as the electrical connection to the cathode of the cell.

Since the bus bars are essentially cantilevered from the power supply, two structures are used to support the bars; one near the end of the bus bars and the second near the power supply. The support structure is made of 1/4 by 3 by 3 in. fiberglass angle, bolted together. A detailed drawing of the structure is given in Pacific Engineering Drawing E 19.0-37-1. The fiberglass angle is strong structurally and also provides good electrical insulation.

The entire PEPCON assembly, including the support structure, is mounted on a skid shown in Drawing 7U43961. The primary purpose of the skid is to make it possible to move the entire assembly as a unit with a forklift or similar device. The assembly can be relocated during the testing phase with a minimum effort.

The line size was selected on the basis of fluid velocity and pressure loss in the lines. Using 3/4 in. schedule 80 pipe, the OD is 1.05 in., the ID is 0.742 in., and the internal area is 0.433 sq in. At a flow of 3 gpm, the velocity is 2.25 fps, while a flow of 6 gpm will give a velocity of 4.5 fps. This is assuming the pipe is filled with water. Gas generated within the PEPCON cell will increase the volumetric flow rate resulting in higher fluid velocities.

The following table compares line velocity and pressure loss for 1/2 and 3/4 in. pipe. Since the PEPCON cells as now constructed are limited to approximately 25 psig pressure, the 3/4 in. line was chosen in order to reduce the pressure loss throughout the entire system. This pressure loss is difficult to calculate since it is a function of the plumbing arrangement, number of elbows, tees, etc; however, a total drop of less than 10 psi is expected.

Pipe Size (in.)	Flow (gpm)	Velocity (fps)	ΔP (psi/ft)
1/2	3.0	4.1	0.082
	6.0	8.2	0.3
3/4	3.0	2.23	0.018
	6.0	4.45	0.06

A drain line is attached to the bottom of each PEPCON cell. This line is also used for the air purge system. The 1/2 in. PVDC drain pipes are connected to a 3/4 in. PVDC pipe which acts as a manifold for the air purge system. Checkvalves are located in the manifold line between PEPCON cells to prevent flow from bypassing the cells during normal operation.

Fabrication and actual plumbing of the PEPCON assembly was accomplished at Thiokol by Pacific Engineering. Flanged connections are used instead of threaded connections where possible.

UV Cell Assembly

The UV cell assembly is shown in Drawing 7U43590. This assembly consists primarily of a UV lamp (General Electric UA-37), quartz tube, and an aluminum outer shell and end caps.

The quartz tube is 48 in. long and has an ID of 40 mm, with a 1.8 mm wall thickness. The purpose of the quartz tube is to permit the UV radiation to penetrate the waste material being processed, yet does not allow the waste to come in contact with the lamp. The lamp operates most efficiently in the temperature range of 500° to 700° C. Although convection cooling is required, water in contact with the lamp would cool the lamp below its normal operating temperature.

The outer shell is made of 4 in. 6061-T6 aluminum tubing with 1/8 in. wall thickness. A diffuser ring with 10 equally spaced holes is welded inside each end of the outer shell. The quartz tube passes through the center of the diffuser ring. The purpose of the ring is to distribute the flow equally around the quartz tube and to prevent any short circuit flow paths. The outer shell is welded to the aluminum end caps eliminating the need for a seal.

The end caps are machined from 6061-T6 aluminum. The inlet and outlet ports are 3/4 in. NPT. An O-ring groove was machined in the inside diameter of the end cap. This O-ring provided the seal between the end cap and the quartz tube. It was found, however, that the tolerance on the OD of the quartz tube was so great that the O-ring could not make an effective seal. The end caps were reworked, eliminating the groove and cutting inside pipe threads into the end caps so that a jamnut could be threaded around the OD of the quartz tube. The jamnut pressed against the O-ring forming a seal. Again the wide tolerance of the quartz tube OD and the thermal expansion of the tube allowed leakage past the O-ring. Increasing the O-ring pressure by tightening the jamnut resulted in cracking the quartz tube.

The jamnut and O-ring were removed and the entire cavity filled with RTV which bonded to the quartz tube and the end cap. There is sufficient resiliency in the RTV to allow thermal growth in the quartz tube. This method of sealing is more positive than using the O-ring configuration. Several hours of use have been obtained with the RTV seal without any indication of leakage or deterioration.

The lamp support is constructed of aluminum with a fused silica insert as an insulator between the lamp end cap and the lamp holder. The support is attached to the end cap with three spacers approximately 1.5 in. long to allow space for adequate ventilation around the lamp.

A square screen box is bolted to the end caps and covers the electrical connections as a safety precaution to prevent accidental contact with the high voltage.

The cell assembly is mounted to the cathode bus bar by a bracket shown in Drawing 7U43591. The bracket is electrically insulated from the bus bar by two insulators supplied by Pacific Engineering. The insulators are Red Seal fiberglass strain insulators tapped and threaded with 3/8 by 7/16 in. holes. The bolts attaching the insulators to the bus bar and to the bracket are 3/8 in. diameter silicone bronze bolts. After assembly of the PEPCON and UV systems, it was decided that a common ground be provided to minimize any electrical shock hazard; therefore, a grounding cable has been installed between the UV cell bracket and the cathode bus bar.

PEPCON Power Supply

The power supply required to drive the PEPCON cells is shown by Pacific Engineering Drawing E-19.5-16. The power supply will deliver 4,000 amp at 9 vdc. The unit is a constant current device with the desired operating current manually set on a current meter on the control panel. The voltage will vary depending on the salt concentration in the solution.

The power supply is mounted in a cabinet 34-1/2 in. by 34-1/2 in. by 65 in. high. A hood on the top extends an additional 5-1/4 in. A fan mounted near the top of the cabinet pulls air through a filter for cooling electrical components. The hood effectively makes the unit drip-proof. A 6 in. opening in both the front and back allows the unit to be moved by a forklift.

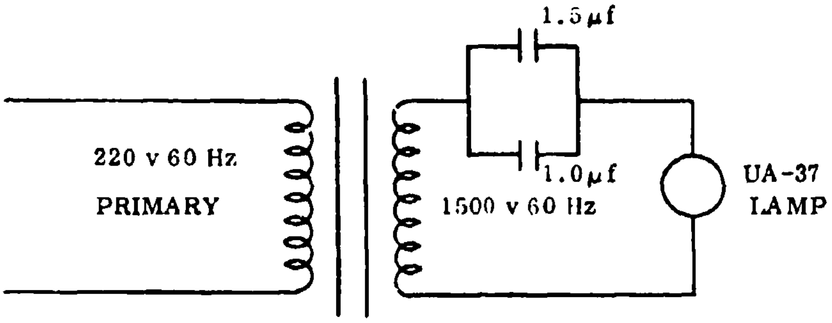
During any time that treatment is not required or desired and the PEPCON cells are filled with water, a small trickle charge must be applied. The power supply upon signal from the control system will reduce the current to the cell, maintaining only a small difference of potential between the anode and cathode. This is required to prevent any reverse current flow which would damage the anode.

The input to the power supply is 440 v, 60 Hz, three phase. A control unit in the power supply does not allow instantaneous full power being applied to the cells. Power goes up on a ramp which may be adjusted from 3 to 15 sec. This is done to relieve the power transients on the entire facility when the treatment cycle begins.

UV Power Supply

Each UV lamp is driven by an individual power source. Each power source delivers 1,500 v, 60 Hz, at 2.0 amp and consists of a transformer and capacitor. The UV power supply assembly is shown in Drawing 7U43879.

The transformer used during the early part of Phase I of the program was a Hanovia Model 49114, with a 3,500 w output. The transformer has two 1.5 μf capacitors connected in parallel; however, one of the capacitors was replaced with a 1.0 μf capacitor to reduce the power output to 3,000 w which is the power rating of the UA-37 lamps. The wiring arrangement for each lamp is shown in the sketch below.



HANOVIA MODEL 49114

The four transformers and capacitors were mounted in a drip-proof enclosure. A microswitch is mounted inside the enclosure so that if the enclosure cover is removed, the power is automatically removed from the transformers. Four MS type electrical connectors are mounted on the box to provide a convenient method of removing power to individual lamps.

The ballast presently used for each lamp is a General Electric Model 9T68Y3161. They are completely enclosed and the transformers are potted in a compound which will transmit the heat generated to the metal container. All wiring is brought out to terminals in a wiring compartment. The wiring is similar to that shown above except a single 2.66 μf capacitor replaces the two capacitors wired in parallel. The input power is 440 v, 60 Hz, single phase.

Catalytic Column

The catalytic column was constructed of 8 in. diameter aluminum pipe 72 in. long. Each column was loaded with 100 lb of WNC-1 catalyst. Diffuser plates on the top and bottom of the column retained the catalyst. Flow through the columns which were mounted in a vertical position was from the bottom to the top.

3.3.1.7 Control Subsystem Design

The overall design of the control subsystem is based on requirements imposed by Contract N00024-71-C-5332. MIL-E-917 Electrical Power Equipment Basic Requirement is being utilized for general guidelines. Cabling is being accomplished using MIL-C-915 and MIL-W16878 cabling. Wiring is being accomplished using MIL-W-16878 wire.

All units that are exposed to human touch intentional or otherwise will be grounded to a common plane which will be capable of being tied to a facilities ground or common plane.

Interlocks are provided so that personnel and equipment will not be exposed to unnecessary dangerous environments such as high voltage, heat, etc.

1. Primary Holding Tank--The primary holding tank will have level detection for control of the level of influent in the primary tank. In selecting the detection method level detection by conductivity was ruled out because solids deposited on probe could maintain a false indication. Level detection by temperature was ruled out for the same reason. Level detection using floats was also rejected because of the problem of the float getting weighted down with solids. Level detection using load cells would require conditioning electronics and would be prohibitive because of costs as would level sensing using pressure transducers. Level sensing using pressure switches in contact with the medium requires special diaphragms which make method expensive. By using tubes in the center and redundant switches mounted at the top of tank on these tubes it was decided to use the pressure switch for level detection. Also by placing tubes in center of tank it would null out the effect of pitch and roll. The air column which is the pressure media would serve as a buffer between the effluent and the diaphragm of the pressure switch.

   The discharge level starts the centrifuge. The upper level shuts the system off and gives an audible, visual, and electrical alarm.

Once the centrifuge is up to speed, the primary holding tank output pump is turned on. When the primary holding tank is empty a pressure switch on the output pump drops out shutting off the centrifuge and output pump.

Since the system output may be somewhat less than the primary holding tank output pump, the primary holding tank output pump is controlled, in part, by the centrate tank level. If the centrate tank upper level is reached this pump is shut off until the centrate tank level is sufficiently lowered.

2. Centrifuge--The centrifuge is provided with a start signal, stop signal, and a skim control. The basic controls were provided by the manufacturer, DeLaval, and have been integrated into the Thiokol control system.

   Skimming will be accomplished on either time or when the primary tank is empty.

3. Incinerator--The incinerator receives a start signal from the centrifuge after each skim cycle. Once it is up to the proper burn temperature the sludge pump starts pumping.

   Incinerator interlocks for burner, exhaust fan and excessive temperatures are provided. When updating, another interlock for the incinerator door will be provided.

4. Air Purge System--Solenoid valves will be operated every hour for three pulses of 6 sec on and 30 sec off. This system will also have manual [illegible] capability.

5. Centrate Tank--Levels in the centrate tank control the pumping of centrate through the secondary treatment system and the pumping of influent into the centrifuge.

   Level detection is accomplished by highly sensitive pressure switches.

6. System Power Distribution--The required electrical input to the system is 440 three-phase ac voltage at approximately 100 amp and ground reference. When power is applied the exhaust fan, air compressor,

208 three-phase ac voltage and PEPCON power supply (trickle charge) are turned on. The rest of the system is turned on by the start-stop switch.

The UV and PEPCON power supply (full power) are turned on only when liquid is being pumped through the system.

3.3.2 Subsystem Development Testing

3.3.2.1 Pretreatment Subsystems

The objective of the pretreatment subsystem is to equalize the hydraulic flow and to remove suspended solids potentially capable of obstructing pumps, pipe lines, and other restrictions in subsequent subsystems. The pretreatment system selected and evaluated in the pilot plant consisted of a six inch wide inclined screen (Bauer Hydrasieve) for suspended solids removal and a three hundred gallon holding tank for hydraulic flow equalization. The process liquid is delivered from the pretreatment subsystem by a self-priming centrifugal pump. The subsystem is depicted in Figure 31 and 32.

The performance of the inclined screen, tested with 0.010 inch openings is illustrated in Figure 33 in terms of percent solids removal. As shown, the higher the influent suspended solids concentration, the greater the percentage solids removal. The inclined screen is observed to accomplish considerably more than merely removing coarse, obstructive material from the system but functions as an efficient primary separator. This effect should be more predominant in actual shipboard operation where the influent sewage is not macerated to as high a degree as in the pilot plant.

Sizing of the pretreatment subsystem for the 200-man system is complicated by large variations in hydraulic flow and by dynamic pitch and roll conditions present on shipboard. The average rate of flow for a 200-man crew is 26.2 gal/day/man or 5.240 gallons per day. This is equivalent to an average flow of 3.6 gpm. Surges in flow of 300 percent of average and pitch and roll conditions of 5 and 30 degrees respectively are anticipated.

The 300 gallon holding tank and 3.6 gpm discharge pump would provide a maximum surge capacity as follows:

$$\text{Surge} = \text{Tank Vol} + \text{Outflow}$$

$$\text{Surge (Gal)} = 300 + 3.6\ t$$

Figure 31. Bauer Hydrasieve Self-Cleaning Screen (Front View)

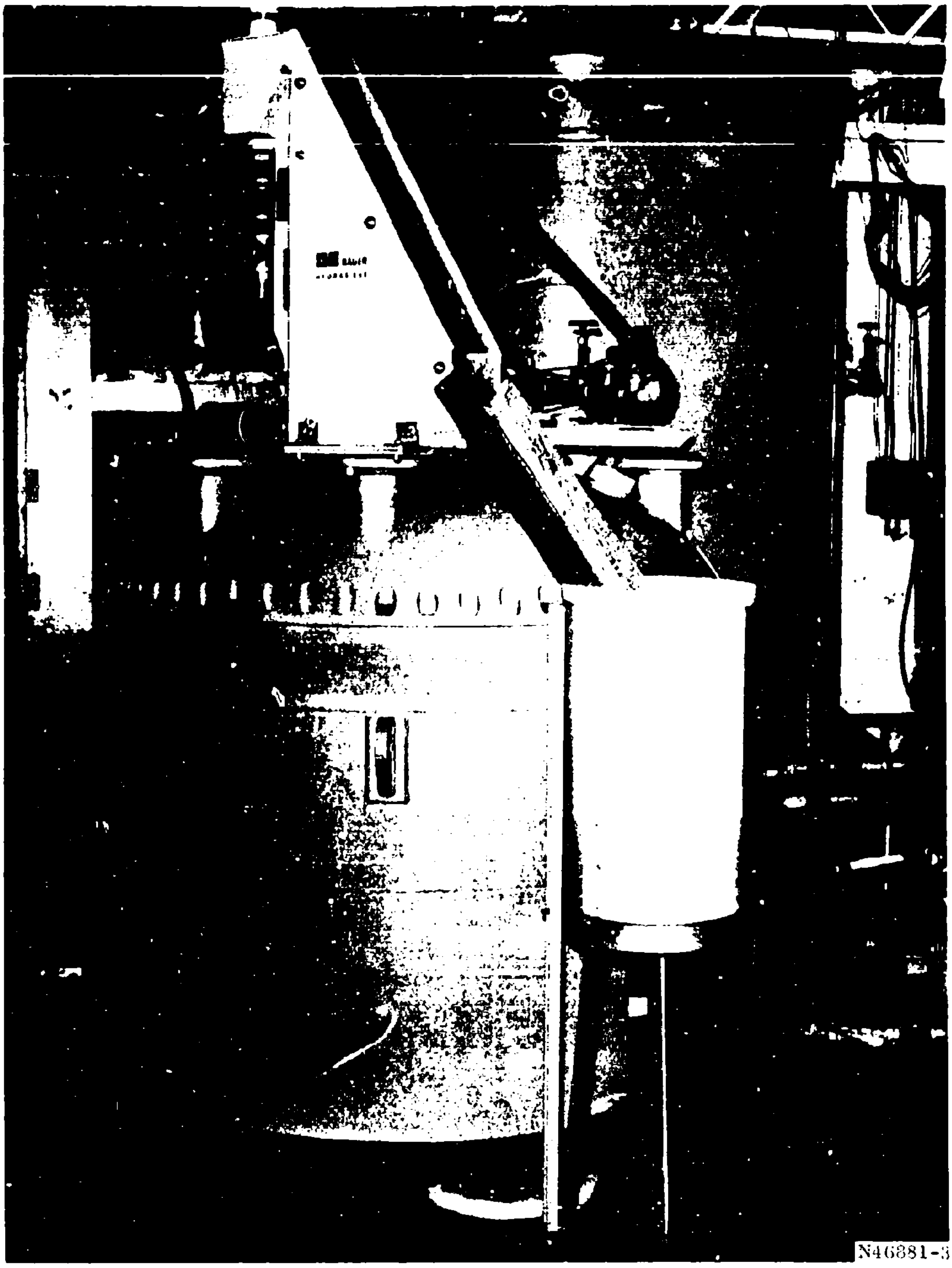


Figure 32. Bauer Hydrasieve Self-Cleaning Screen (Overall View)

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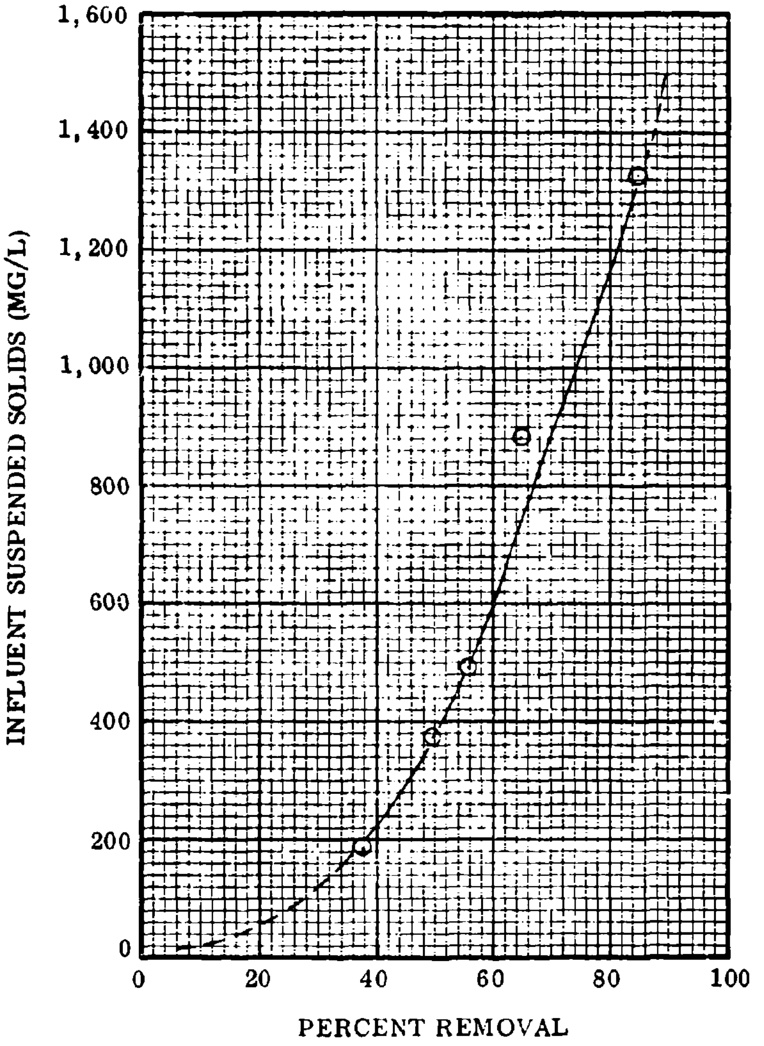

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Figure 33. Hydrasieve Test Results (0.010 Inch Screen)

where t is the surge duration in minutes. This would be equivalent to a 300 percent surge for a duration of forty minutes. The holding tank is relatively uneffected by dynamic pitch and roll conditions providing delay timers are incorporated in level sensors controls.

Operation of the hydrasieve is significantly effected by dynamic pitch and roll conditions. Coordination with the manufacturer and limited pilot plant testing indicate, however, that proper orientation of the hydrasieve and the addition of baffles will minimize operational problems. Tilting of the hydrasieve in the direction perpendicular to the screen, as shown in Figure 34, does not appreciably effect hydrasieve performance up to an angle of 5 to 10 degrees. Tilting of the screen in a direction parallel to the screen has significant effect causing the process liquid to channel down the side of the screen. Thiokol has demonstrated that the addition of a baffle to the side of the screen apparently resolves the problem by deflecting liquids back on the screen. Once the liquid is on the screen, flow is directional somewhat independent of the screen orientation as shown in Figure 34. Orientation of the screen relative to pitch and roll conditions, the addition of baffles and an increased screen width as shown should provide continuous operation under shipboard conditions.

The addition of a double weir design to the hydrasieve as shown in Figure 34 would direct flows in the 5 to 10 gpm range to the center section of the screen. Hydraulic surges in excess of this range would be distributed over the entire weir area. According to manufacturer's data, flows of up to 100 gpm could be handled with 18 inches of screen width with the 0.010 inch openings. Modifications of the screen to accept pitch and roll conditions therefore also provides more than ample hydraulic capacity.

The hydrasieve is completely self-cleaning during operation. However, if the hydraulic loading is intermittent with long periods of no flow the screen may become partially blinded thru the buildup of salt, grease, or other residue as the screen dries. Installation of wash nozzles would, therefore, be required for shipboard installation to facilitate periodic cleaning with steam or hot water.

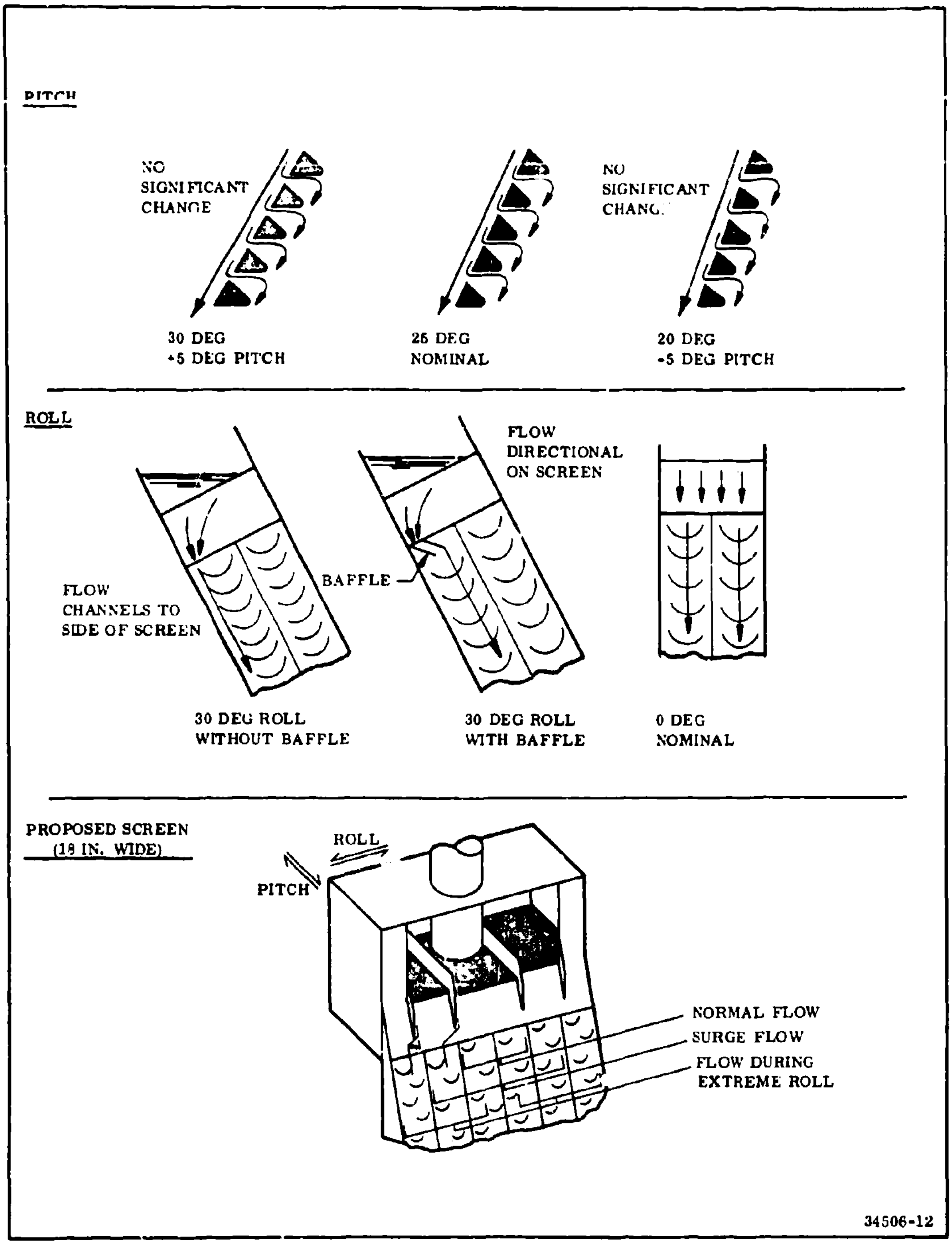

Figure 34. Hydrasieve Testing Summary, Pitch and Roll

3.3.2.2 Primary Subsystem Testing

The first objective of the primary treatment subsystem is to remove, without the use of chemical additives, the majority of suspended solids in raw sewage. The removal process must be at a high rate with minimal residence time in the system. Solids removal tests early in the program indicated that the most effective means of separation, using commercially available equipment, was by centrifugation. The type centrifuge selected for use was a basket machine. The centrifuge purchased for the Navy program was a 20 in. diameter DeLaval ECM basket clarifier. This machine was installed in the pilot plant and suspended solids removal tests conducted. A comparison of the solids removal efficiency of the Navy centrifuge and the 14 in. diameter unit evaluated in the test program is presented in Figure 35 as a function of flow rate. At the average flow rate of the primary system, 3.6 gpm, a suspended solids removal efficiency in excess of 80 percent was observed with the Navy machine. This removal capability can be further improved through the addition of conventional flocculents, however, 80 percent removal is considered adequate for overall system performance.

The second objective of the primary treatment system is to store the removed solids for subsequent incineration. From the standpoint of a centrifuge, this involves a periodic discharge of the solids or sludge from the centrifuge into a surge container. Two methods of sludge removal are available on commercial basket centrifuges, depending on the nature of the sludge and the size of the centrifuge. For fluid sludges, a tube is inserted into centrifuge, opposing the direction of bowl rotation, skimming out the contents. For nonfluid sludges, a mechanical plow or knife is used to dislodge the sludge, discharginin g it through an opening in the bottom of the bowl. Due to the size and nature of the plow mechanism, it is only available on large machines; ie, 30 in. diameter and larger. The sludge formed from untreated sewage is not sufficiently fluid to be completely removable by skimming. The size of the centriguge selected for the Navy program prohibits use of a plow or knife mechanism. Therefore, an alternate method of sludge removal was developed. In this method, the rotation of the bowl is reduced to half speed and the skimmer tube inserted to remove liquid and flowable sludge. The residual, heavy sludge is then fluidized by means of a water jet and removed through the skimmer tube. The nature of the liquids and sludge discharged from the centrifuge by this method was evaluated in terms of solids content. Twelve hundred gallons of sewage were processed through the centrifuge over a 4 hr period. The contents of the basket were skimmed and collected in 2 gal increments. The solids content of the skimmed material is shown in Figure 36 as a function of cumulative gallons removed.

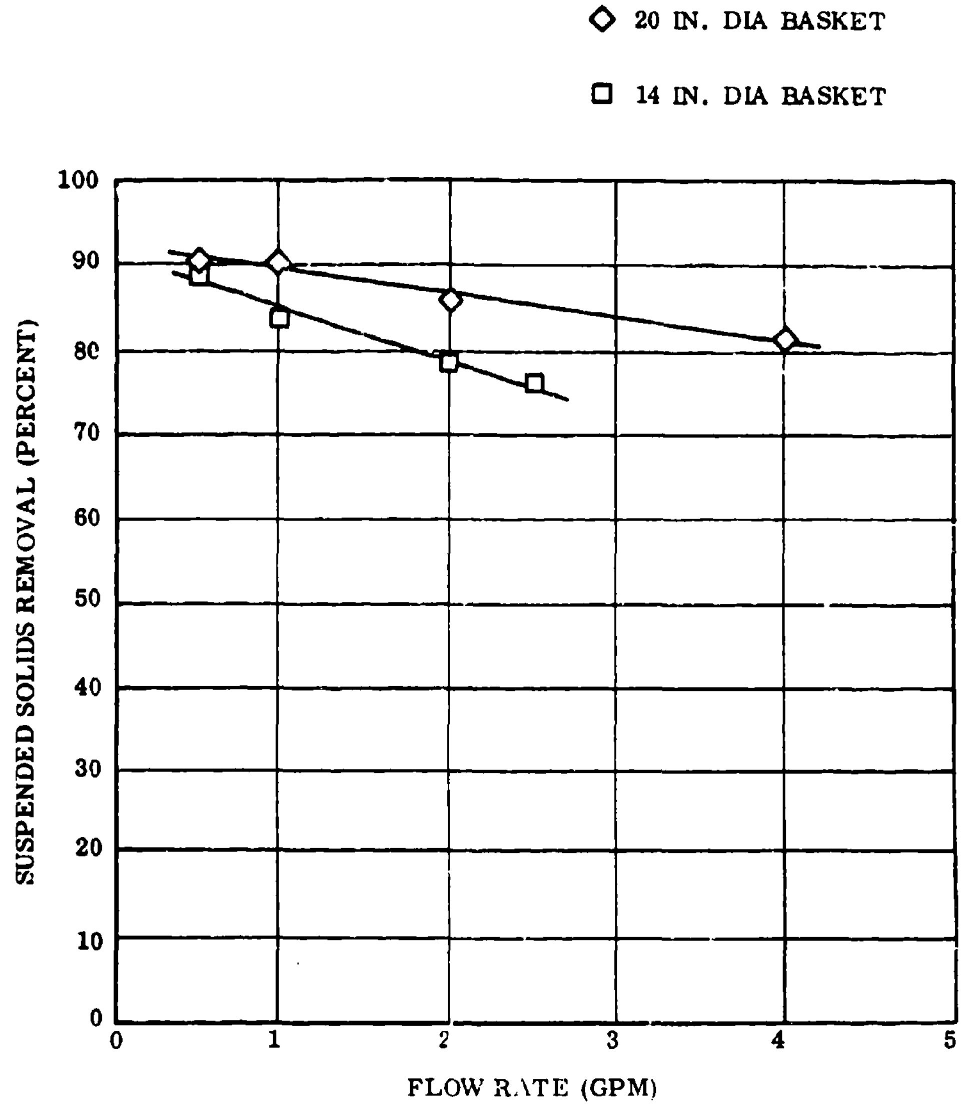

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Figure 35. Suspended Solids Removal

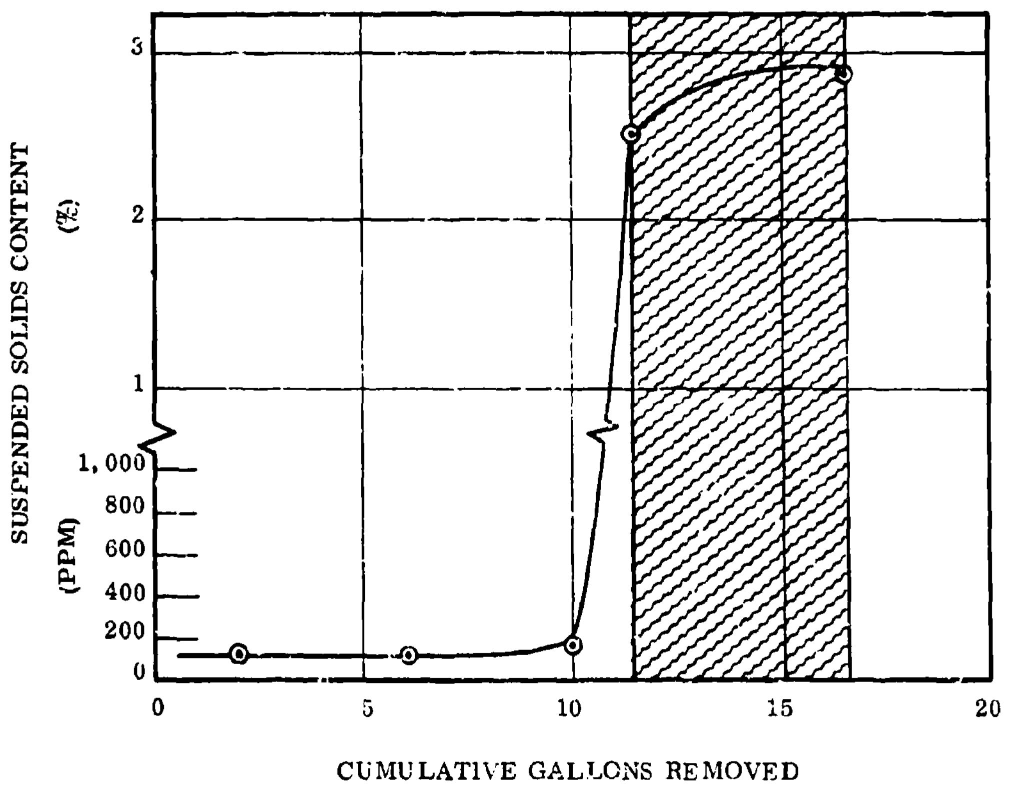

Figure 36 . Solids Content of Liquid Skimmed from 20 In. Basket (11-1/2 Gal Bowl) Centrifuge

These data indicate that the first 8 to 10 gal of liquid removed during the skimming cycle is very low in suspended solids and only the remaining 1-1/2 to 3-1/2 gal, plus wash water, contain a high degree of solids. In order to reduce the load on the incinerator, a diverter valve was added to the centrifuge to allow discharge of a portion of the low solids liquid into the centrate tank. The initial 1 to 2 gal of liquid is currently programed into the sludge tank and serves to flush the skimmer tube of residual solids from the previous cycle. The next 6 to 8 gal is programed into the centrate tank. The remaining liquid plus wash water containing a high solids content is programed back to the sludge tank.

Several problems have been experienced with the centrifuge relative to sludge removal. A large amount of paper and fibrous product in the influent sewage compact in the centrifuge bowl into a matting which exhibits considerable strength and resists fluidization by the water jet. When the material does break up, it is generally in sufficiently large sections which obstruct the intake of the skimmer tube. This type material must therefore be prescreened from the influent to facilitate the use of the skimmer tube/water jet approach to sludge removal. Two types of screens appear feasible for use. A Sweco vibrating screen, evaluated early in the program, was very satisfactory. An inclined, self-cleaning screen currently being evaluated also has proven satisfactory to date, Section 3.3.2.1.

To optimum skim cycle, water jet location, volume or wash water required, etc, has not been totally identified to date. This has been due in part to late installation of the two-speed motor on the centrifuge and by problems associated with paper matting in the sludge. Thiokol proposes to complete this phase of study under Phase II of the program.

The addition of an efficient screen to the pretreatment system not only facilitates sludge removal from the centrifuge but also substantially reduces the suspended solids concentration entering the centrifuge. Under these reduced load conditions, the 20 inch basket centrifuge may have excess capacity for the system. Preliminary sizing tests on prescreened influent were conducted with a 15 inch and 20 inch diameter basket unit for comparison. These data are tabulated below:

	Suspended Solids (mg/l)			
Flow (gpm)	Influent	Prescreen	15 in. Basket	20 in. Basket
2	284	130	68	78
3	284	130	92	72
4	284	130	100	68

Although the removal efficiencies are low the absolute values of suspended solids in the centrate from both centrifuges are in an acceptable range for system performance. In order to be realistic, this comparison must be made at higher influent suspended solids concentrations. This final centrifuge sizing test will be concluded in Phase II of the program using available 15 and 20 inch diameter centrifuges.

3.3.2.3 Incinerator Prototype Testing

The prototype incinerator has been tested for over 60 hr. The basic design shown in Drawings 7U43945 and 7U43934 was used except for the addition of a steel baffle above the combustion zone and air inlets at the top. A schematic of the test configuration, Figure 37, details the position of the temperature measurements, air inlets, and baffles. Photographs of the prototype incinerator, Figures 38 thru 40, show the component configurations.

The incinerator performed well and the chamber was kept reasonably clean by the high velocity gases sweeping the precipitated salt and ash from the chamber area. The only area that retained a salt buildup was the L-shaped adapter from the incinerator chamber to the exhaust fan. This buildup was alleviated by controlling the air inlet at the incinerator top. Originally, cooling air was to have entered at the flanged inlet near the top of the incinerator but this caused a localized buildup of salt and a spalling of the incinerator liner. When the cooling air inlet was changed to the top location and closer to the fan, both of these problems were essentially eliminated.

During these tests, it was proved that the temperature in the incinerator could be regulated reasonably well by maintaining the proper air-to-fuel ratio, thereby eliminating the problem of overheating which caused severe deterioration of the liner materials in the developmental incinerator.

The negative pressure created by the exhaust fan mounted above the incinerator was amajor factor in the testing program. Air inlets on the 1.5 gph fuel oil burner were almost closed to obtain the best combustion air-to-fuel ratio. Temperatures in the incinerator were held to 1,800°F in the combustion zone, to 1,200°F above the sludge inlet, and below 400°F at the exhaust fan.

A total of 10 sustained runs was conducted for the incinerator testing. The last and longest run was 8 hr. Conditions of the test were:

Burner	1.5 gph fuel oil nozzle
Sludge	3.5 gph sludge from 3% salt influent
Temperatures	1,800°F Combustion 1,200°F Stack 350°F Fan
Upper air inlet	7 sq in.

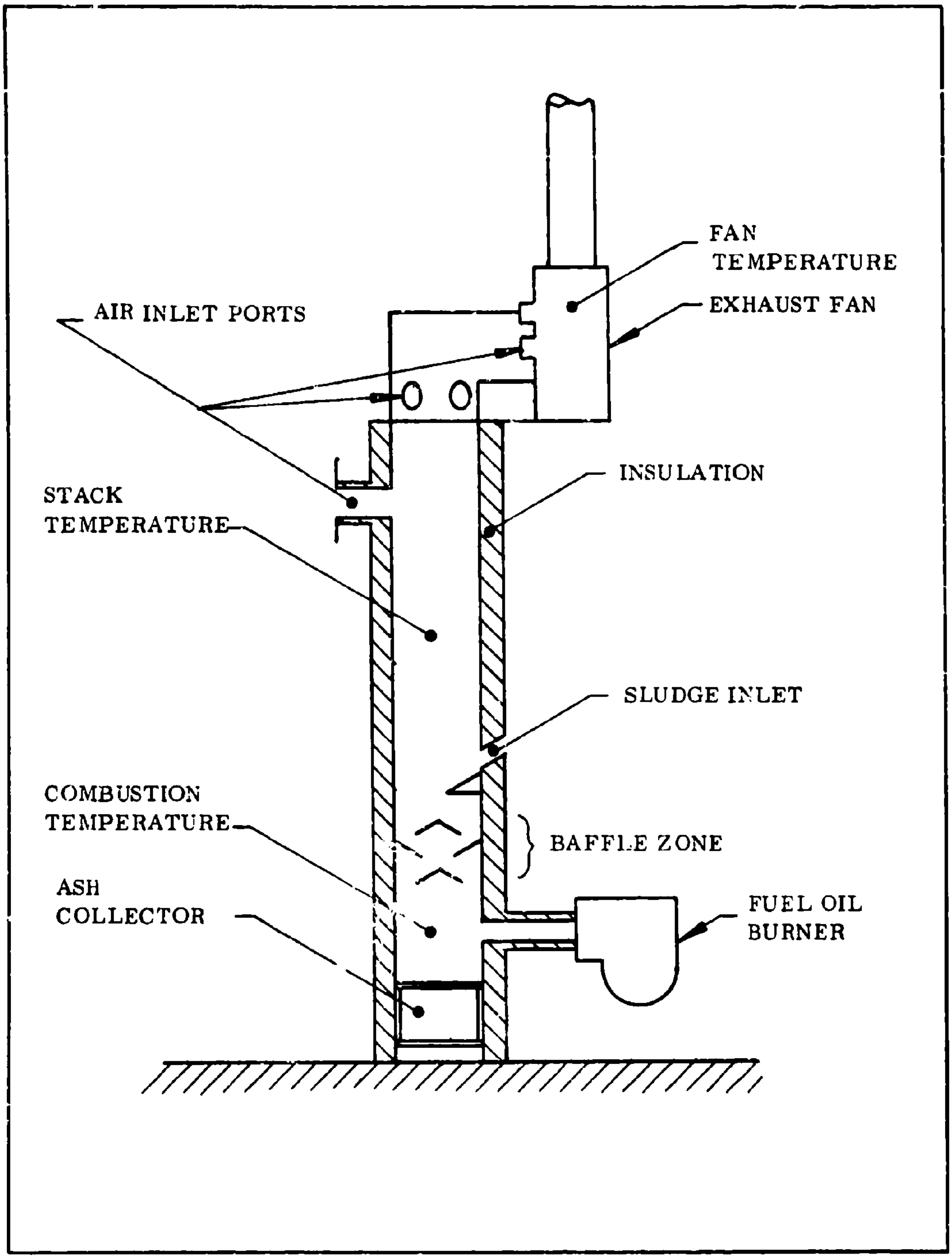

Figure 37. Incinerator Test Configuration

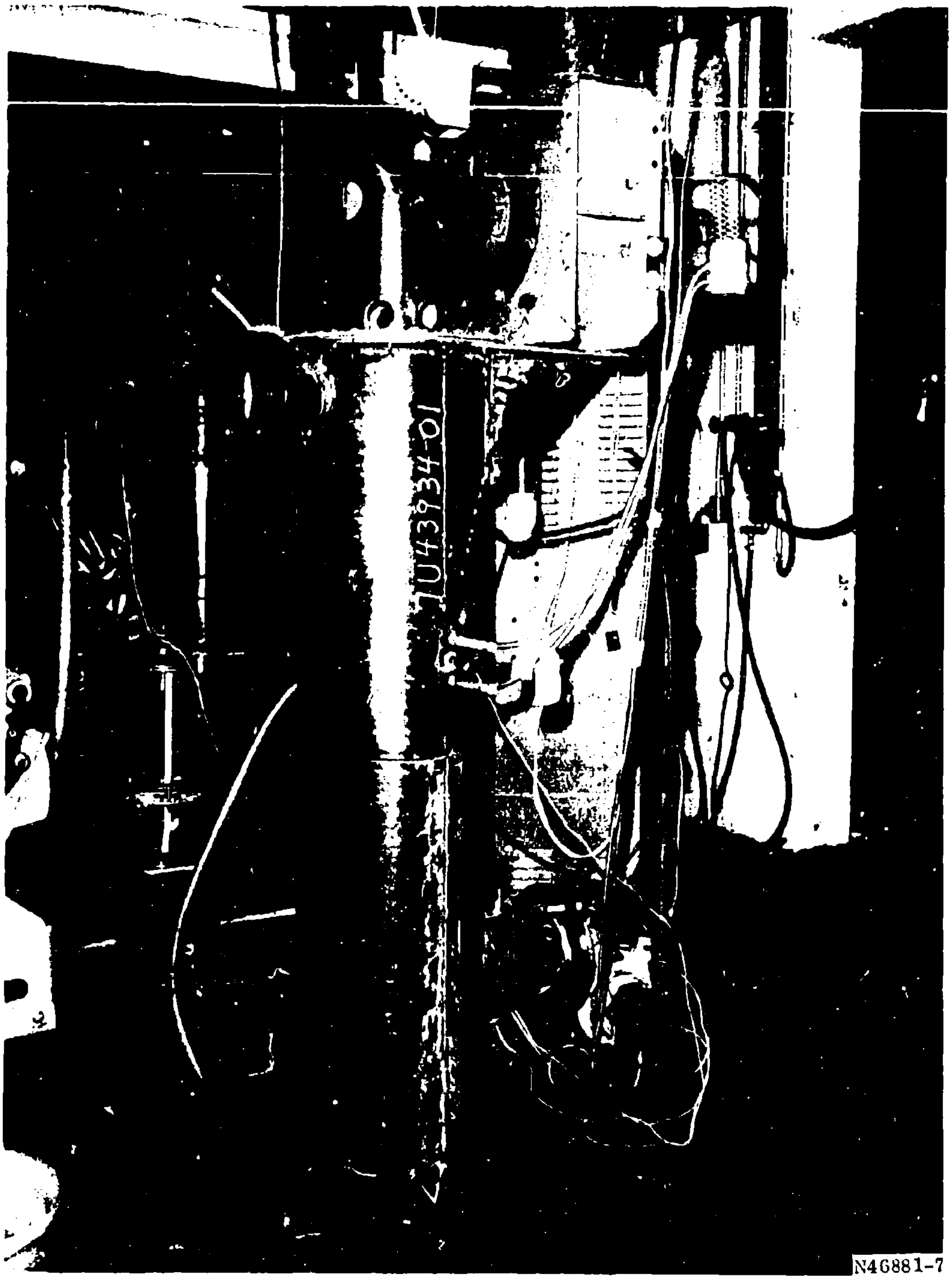

Figure 38. Photograph of Prototype Incinerator

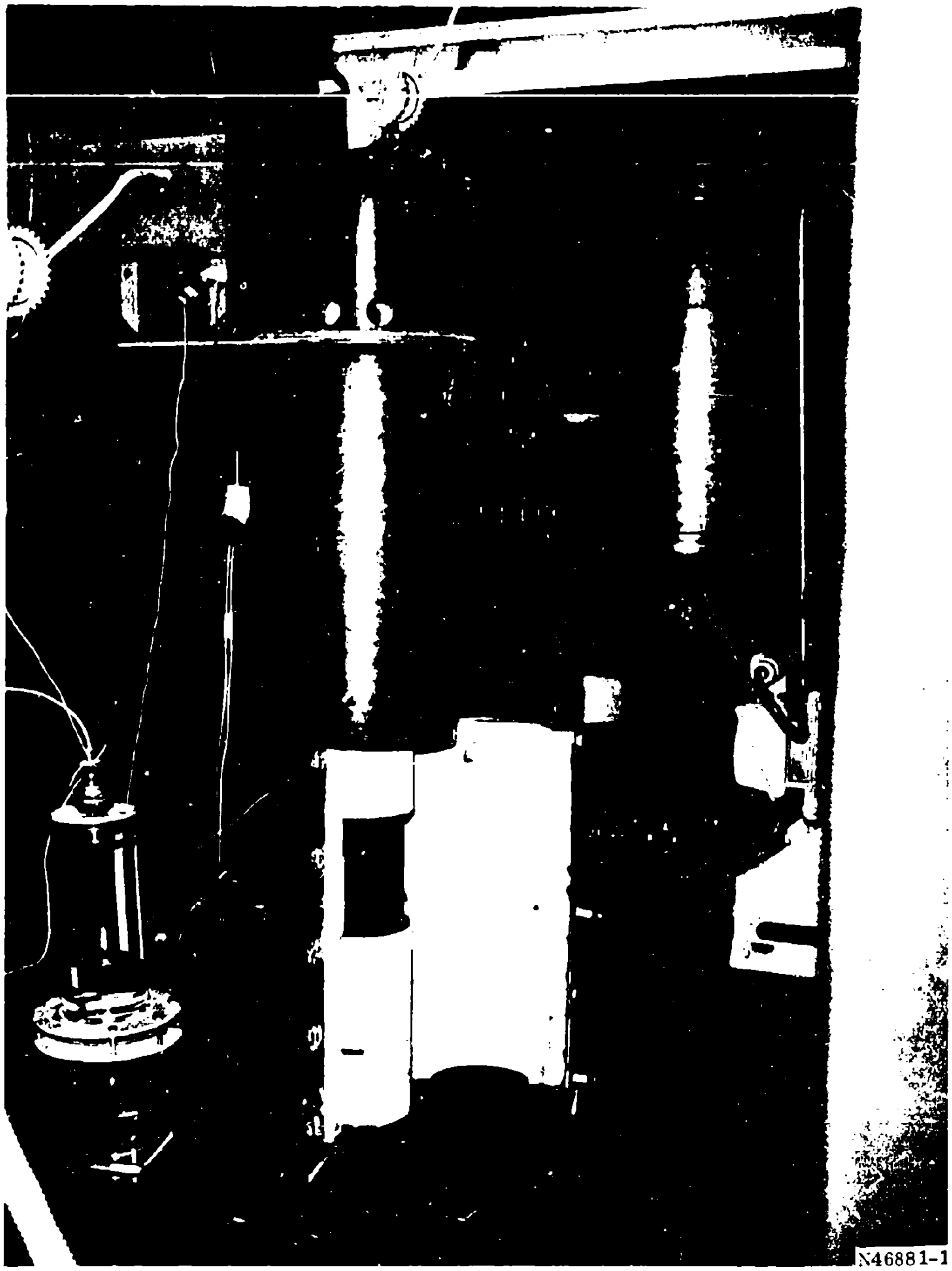

Figure 39. Photograph of Prototype Incinerator

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Figure 40. Photograph of Prototype Incinerator

A wide variety of sludge composition was tested. Sludge feed rates into the incinerator also were varied. All of the influent to the system was raw sewage salted to a 3 percent solution. The sludge from the centrifuge contained one third fresh water from the wash cycle. Paper content of the sludge varied depending on the pretreatment and the batch-to-batch nature of the raw sewage. Some stoppage in the feed line was experienced with thick sludges; however, this problem was elminated by smoothing out the line connections and reducing the line diameter to produce higher flow velocities. A feed rate between 3 and 4 gph provided the best equilibrium conditions in the incinerator. Low feed rates would be inefficient and high feed rates would cause low stack temperatures and buildup in the stack and baffle areas.

Incinerator insulation kept the outside wall temperature below 150° F. Temperatures on the upper stack reached 400° F at times and varied with the cooling air intake position. Liner components were subjected to temperature changes in the baffle and sludge inlet areas. The mild steel baffle remained intact but experienced oxidation and spalling. The high density fused silica liner in the sludge inlet area cracked and spalled throughout the early testing and had to be replaced twice. As incinerator conditions were stabilized and longer runs obtained, this liner section had less cracking. Thiokol plans to replace this section with a better material, such as 310 stainless steel, for future testing.

The prototype incinerator testing demonstrated that system sludge decomposition can be accomplished by this method. Control of the startup needs further evaluation to integrate the incinerator into the treatment system, since air intake positions and temperature buildup are critical. During operation, the incinerator maintains an equilibrium balance within acceptable ranges of feed rates, sludge composition, and equipment temperatures. Further testing will establish maintenance factors such as ash removal frequency, insulation repair and replacement, baffle cleaning or replacement, and other equipment life spans.

3.3.2.4 Total Solids Transfer and Incineration

A prototype of an advanced total solids transfer system has been tested on concentrated sludge. The system is a recirculating sludge maceration system combined with a small sludge pump to transport collected solids to the prototype incinerator. The test configuration is shown schematically in Figure 41. A photograph of the prototype system, Figure 42, shows component configuration and location.

Maceration of the solids is provided by a Robbins & Myers Model EWM-200 macerator pump. Maceration is accomplished by four fixed and four rotating tool steel cutters. The high cutter velocity, 132 ft/sec, combined with a unique arrangement of 1/8 inch flow passages control the size of the particles. A typical flexible stator Moyno pump provides a flow rate of 4.7 gpm. Both the macerator section and the pump section are mounted on a 1 horsepower 230 VAC motor.

To perform the demonstration test, 1,100 gallons of raw sewage was subjected to Hydrasieve separation. The solids were collected and placed in the sludge surge tank. Fine solids were removed using a centrifuge cycle and added to the sludge surge tank. The resulting sludge was further concentrated by adding approximately 75 paper towels, filter tipped cigarette butts representative of 2 packages, and toilet tissues.

Overall performance of the system was satisfactory, however, the feed to the incinerator was erratic and some stoppages in the feed line was noted. In all cases the stoppages were cleared by momentarily increasing the feed rate. The stoppages were caused by the low inlet velocity of the incinerator feed pump allowing the particulate matter to precipitate and accumulate.

Several methods of correcting this condition have been considered including a modification of the Pitot tube principle, locating the inlet of the incinerator feed pump in an area of smaller particles, an initial maceration cycle prior to incinerator start, air injection, induced water hammer scrubbing, ultrasonic agitation, etc.

The systems considered the most promising are shown schematically in Figure 43, 44, and 45.

Of the three methods shown, the modified Pitot tube principle is recommended for phase II because:

(1) sludge is obtained in the area of the highest velocity within the bypass tube thus insuring a consistent mixture

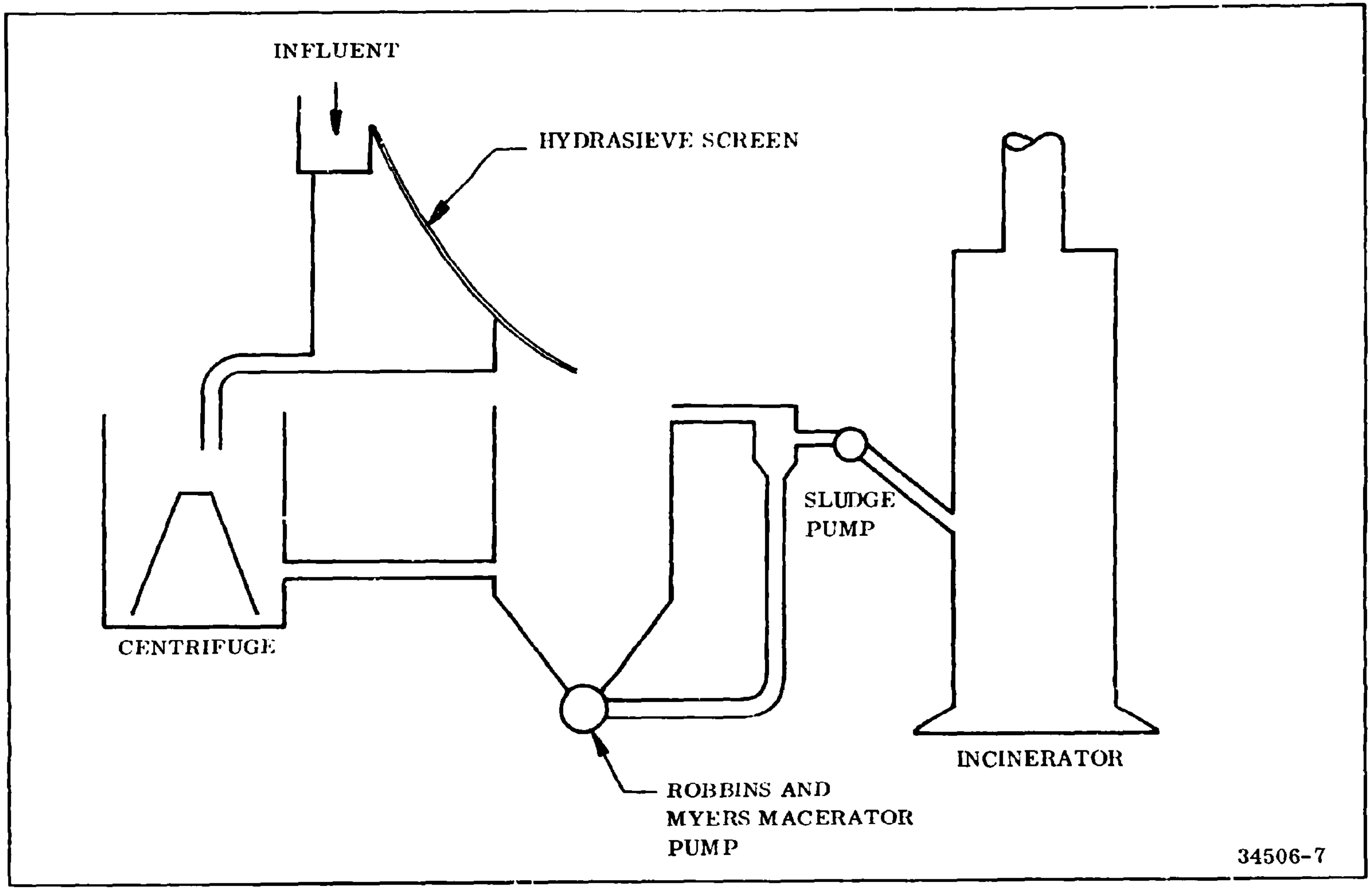

Figure 41. Total Solids Transfer and Incineration

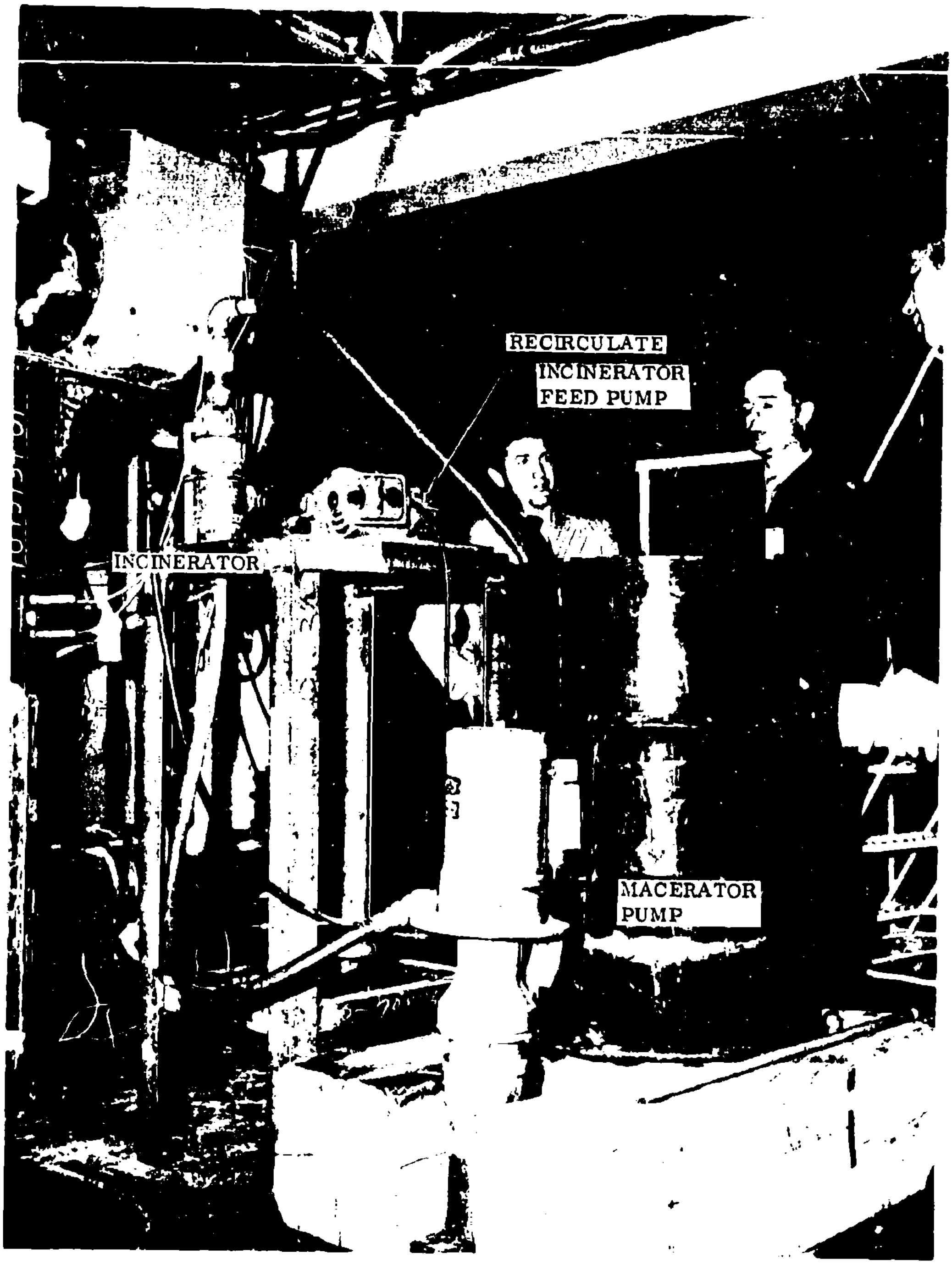

Figure 42. Prototype System

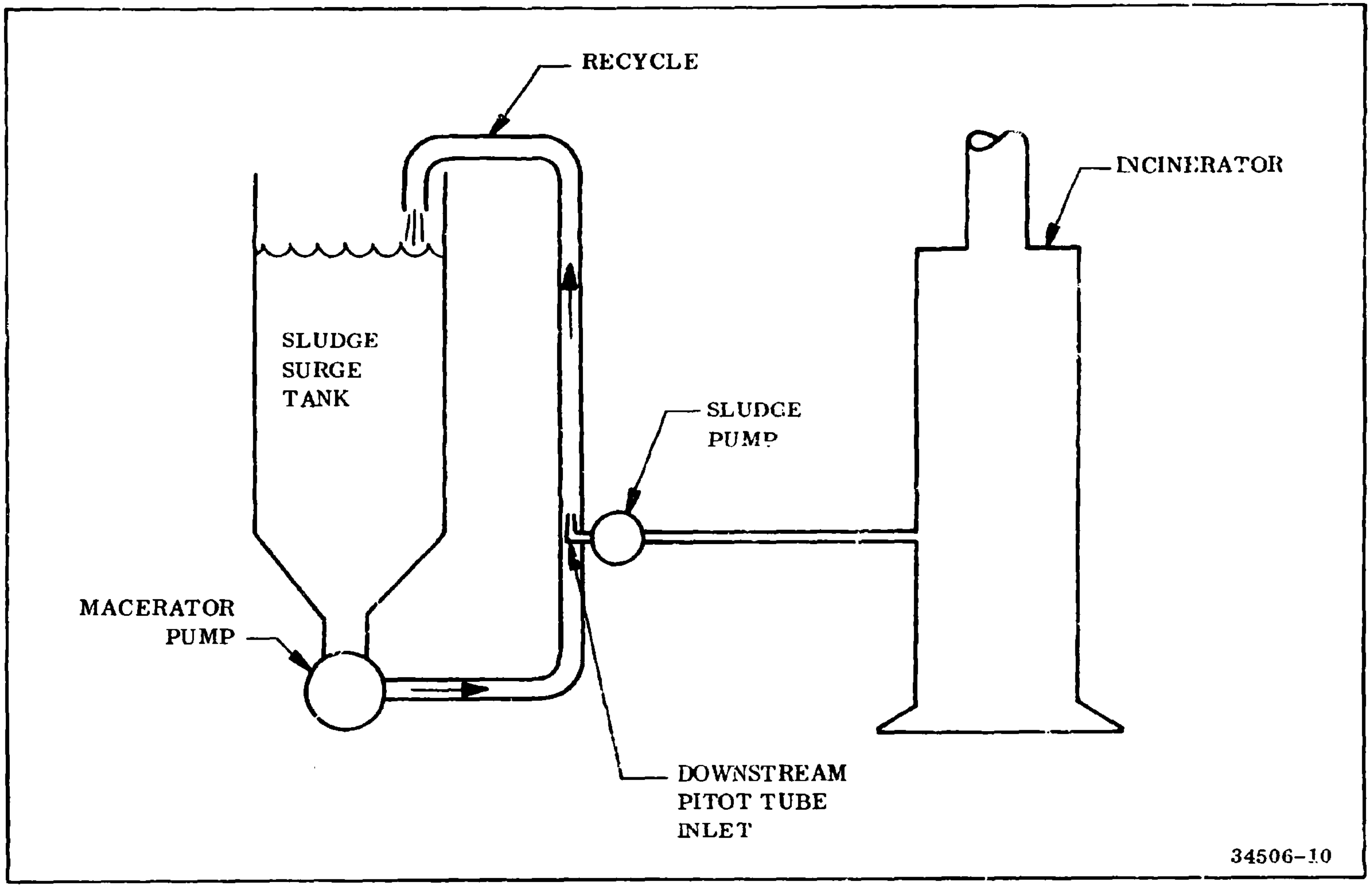

Figure 43. Modified Pitot Tube Principle

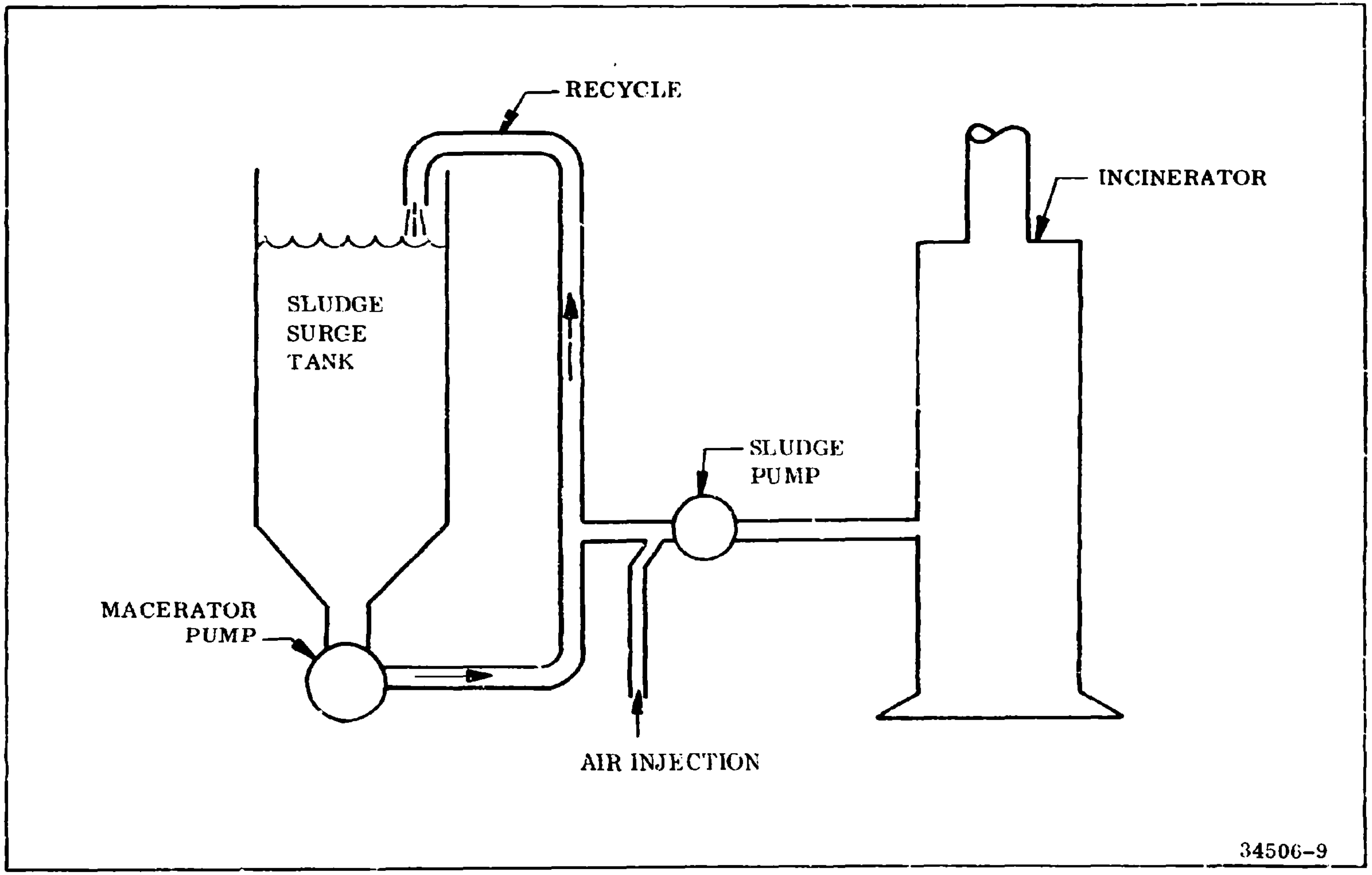

Figure 44. Air Injection

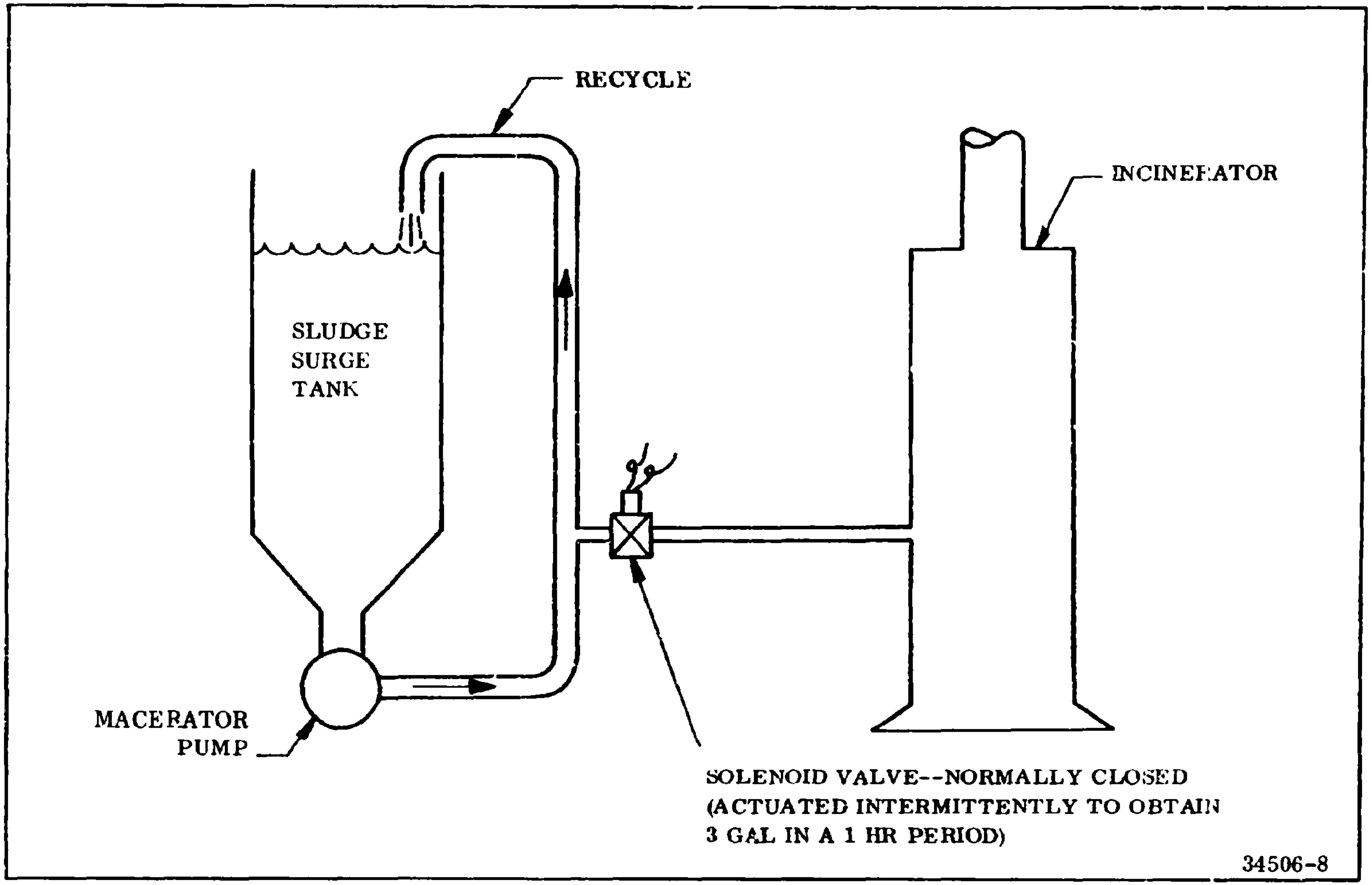

Figure 45. Intermittent Feed

(2) larger particles will tend to bypass the feed line, due to velocity, and be macerated to smaller size

(3) addition of active components such as ultrasonic transducers, etc., are not required

(4) the sludge pump inlet line can be made relatively small which will increase flow velocity, thus minimizing silting.

The prototype total solids feed and incinerator testing demonstrated that system sludge can be fed and decomposed by this method. Further testing will demonstrate the reliability of the Pitot tube feed. The prototype system tests also demonstrated the inherent capability of the incinerator to burn high solids feed.

3.3.2.5 Secondary Treatment Subsystem Testing

The objective of the secondary treatment system is to generate and catalyze sufficient sodium hypochlorite to oxidize the dissolved and suspended solids remaining after primary treatment. Tests were conducted to determine typical BOD and COD values remaining after primary treatment and the sodium hypochlorite dosage required for treatment. Results are summarized below.

Sewage Batch	Test	Suspended Solids (mg/l)		BOD (mg/l)		COD (mg/l)	
		Influent	Centrate	Influent	Centrate	Influent	Centrate
M85-040	A	385	39	400	300	1,478	840
M85-041	A	451	143	660	430	1,516	779
	B	451	80	660	400	1,516	893
M85-042	B	410	146	530	300	1,409	846

These tests very closely approach typical influent values specified in the Navy RFP for BOD and low for suspended solids. The centrate values are therefore considered representative of typical effluent from the primary treatment system for BOD. The low suspended solids indicate a higher concentration of dissolved solids and thus a more severe test condition. These centrates were treated by incremental sodium hypochlorite addition and reaction with periodic sampling to determine the hypochlorite requirement for complete treatment. Results of these tests, presented in Figure 46, indicate that a sodium hypochlorite dosage of approximately 5,000 ppm is required to achieve complete treatment with resulting BOD values of less than 50 mg/l.

The 500 sq in. electrolytic cell manufactured by Pacific Engineering has been selected to generate the required sodium hypochlorite electrolytically from the sodium chloride present in sea water. Calibration testing of the cells received for the Navy program was completed. The results of these tests and previous data generated in the pilot plant are presented in Figure 47 as a function of current concentration (current/flow rate). These data indicate that at ambient temperature and with 3 percent salt water a current concentration of approximately 1,200 amp-min/gal would be required to generate the 5,000 ppm NaOCl needed in the secondary treatment system. Since the hypochlorite generation rate is slightly nonlinear relative to current concentration, an incremental or stage-wise generation would reduce this required current concentration to approximately 1,000 amp-min/gal. This current concentration would increase with increased temperature and/or reduced salt concentration. Incremental sodium hypochlorate addition in stages was therefore selected for the Navy secondary treatment system.

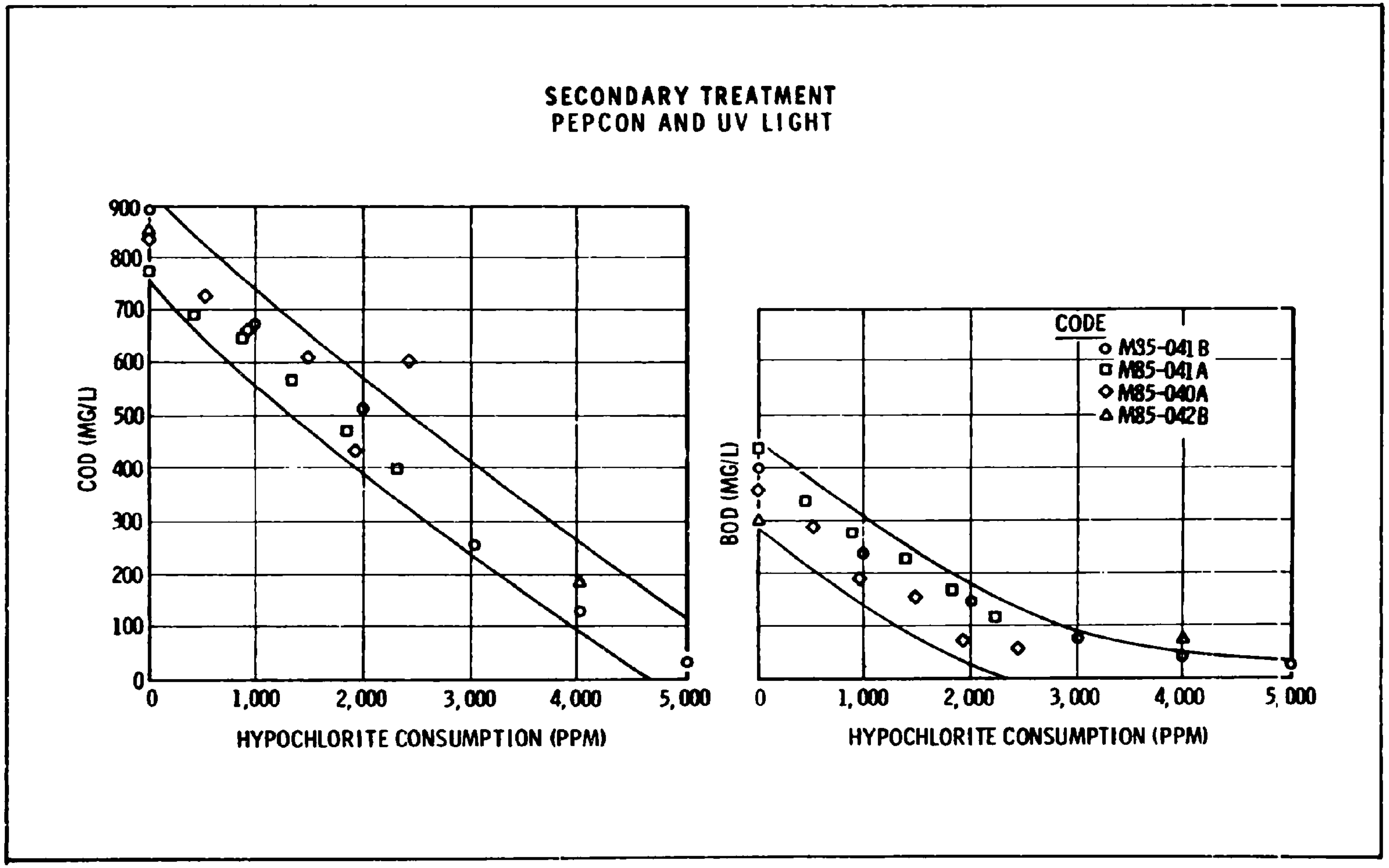

Figure 46. Determination of Sodium Hypochlorite Dosage

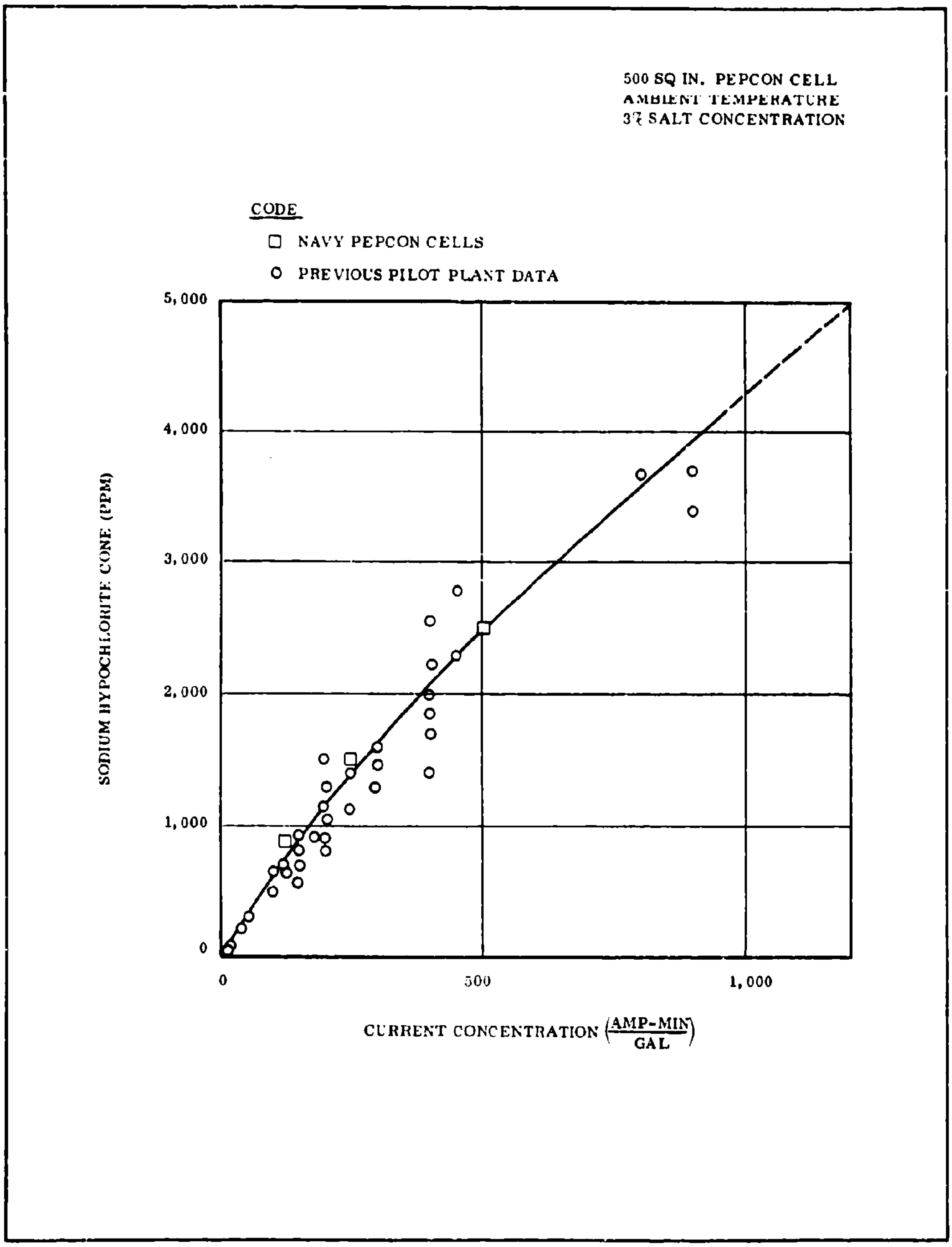

Figure 47. Sodium Hypochlorite Generation Rate

However, to facilitate operation in low salt content water as well as normal sea water, a four-stage system with the first stage operating at a current concentration of approximately 400 amp-min/gal and the remaining three stages at 200 amp-min/gal was selected for initial Navy system testing. The higher current concentration in the initial stage is to compensate for the high initial chlorine demand (dark reaction) of the centrate.

In order to catalyze the decomposition of sodium hypochlorite and simultaneous oxidation of organic compounds present in sewage, a photochemical reactor is being used. This reactor consists of a UV light source located in a concentric tubular reactor with the process liquid surrounding the light source. The light and process liquid are separated by a quartz tube. Calibration data obtained in the pilot plant photochemical reactor cells are presented in Figure 48 as a function of reactor volume/flow rate. This figure is used to graphically calculate the number of photochemical cells required under a given set of flow conditions in the system. The average flow rate required in the Navy 200 man system is 3.6 gpm with the flow divided in the secondary treatment system at 1.8 gpm. Since approximately 1,000 ppm of sodium hypochlorite are generated or residual in each stage of the secondary treatment system, it can be seen from Figure 48 that a flow rate or 1.8 gpm (reactor volume/flow rate = 1), two photochemical reactors would be required per stage to substantially decompose the residual hypochlorite. One reactor per stage is presently in the system followed by one 100 lb catalyst column to remove residual hypochlorite from the effluent with some resulting BOD and COD reduction.

Other process requirements that need to be considered are dissipation of heat generated by the photochemical cells, dissipation of gases generated in the electrolytic cells, inhibition of the corrosive aspects of sea water combined with sodium hypochlorite, and protection of personnel from UV radiation leakage and high voltages present in the system. Heat dissipation may be readily accomplished by inline heat exchangers or jacketed reactors and partially accomplished by recirculating of liquids at higher flow rates. Dissipation or gases generated in the PEPCON cells was initially to be accomplished by the use of float type gas vent valves. PVD and PVDC piping, aluminum photochemical cells, and cathodically protected copper electrolytic cells were implemented for corrosion control. Shielding and grounding connections were employed for personnel protection from electrical and radiation hazards.

Initial assembly and startup of the secondary treatment system was accompanied by several problems. The first problem encountered

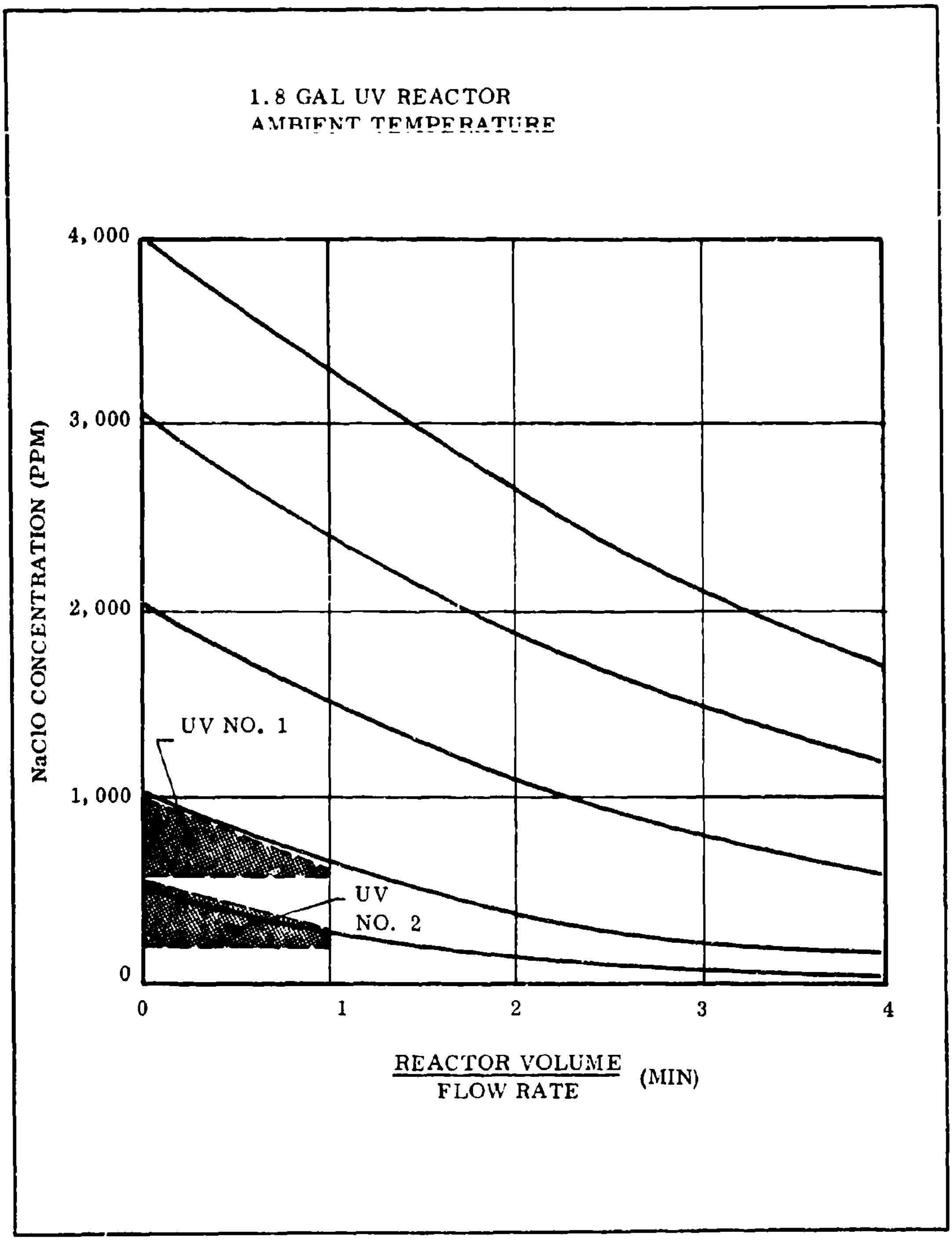

Figure 48 . Photodecomposition of Sodium Hypochlorite

was with the end seals in the photochemical cell. The planned O-ring bore seal was ineffective due to poor tolerance control with respect to the OD of the quartz tube. A second type seal was evaluated wherein the O-ring was compressed with a jamnut. Again, difficulties were encountered due to tolerance control on the quartz tube. Several tubes were fractured from overtightening of the jamnut. Finally, a high temperature silicone rubber was used to bond the tube ends in position. This seal technique has proven satisfactory to date.

During initial trial runs, excessive gassing and sporadic flows were evident. It was observed that the planned down-flow condition in the photochemical cells was not satisfactory and resulted in large gas pocket formation and overheating. The system was changed to produce up flow in the cells as was used in the pilot plant equipment. It was also observed that the gas vent values were not functioning and that the liquid flow was heavily aerated. The vent valve malfunction was attributed to deposits in the valve obstructing the outlet orifice and to the fine entrainment of gas bubbles in the liquid stream. Liquid was observed at times exiting the gas vent system. The vent system was finally disassembled and removed. The pressurized dark reactor also was removed and replaced with an ambient pressure vented tank to provide deaeration. During subsequent testing, the flow rate in the secondary treatment system was increased and an internal recycle loop to the dark reactor added for additional deaeration purposes. This change also resulted in a reduced operating temperature due to heat dissipation in the dark reactor.

It was noted during system operation that the centering cap at the top of the PEPCON cells was partially unseated from internal pressures in the cell. Some leakage also was experienced. The present PEPCON design appears to be marginal for a pressurized system and will require modification during Phase II if a pressurized system is employed.

During initial testing of the secondary treatment system, periodic loss in performance of individual photochemical cells was observed. This was determined to be the result of deposits coating the quartz tube restricting UV penetration. The coating was removed with dilute hydrochloric acid. This coating is believed to be a result of initial foaming, gas entrapment, and localized heating during startup and shutdown modes. Several steps have been taken to minimize foaming and aeration of the liquid stream (mentioned above). In addition, the system is placed on closed loop recycle during startup and shutdown modes providing a controlled cooldown. This mode of operation more closely approaches that employed in the pilot plant. Quartz tube coating problems were not encountered in the pilot plant.

After initial startup problems were resolved, a series of secondary treatment tests were conducted wherein flow rate and current concentration were varied in accordance with the test matrix below.

Flow Rate (gpm)		100	200
	2.5	X	X
	2.0	X	X
	1.5	X	X

Current Concentration

$\left(\frac{\text{Amp-Min}}{\text{Gal}}\right)$

The results of these tests are presented in Table XII and provide a means of final selection of optimum operating conditions. A buildup of residual hypochlorite is noted in each test run conducted at a 200 amp-min/gal current concentration and to a lesser extent at 100 amp-min/gal indicating a limitation in photochemical capacity. A review of BOD and COD reduction indicate that maximum reduction is obtained at the lower flow rate and higher current concentration although reasonable treatment also is obtained with higher flows. A catalyst column was added subsequently to remove residual hypochlorite present in the effluent.

Additional testing of the secondary system is covered under 3.3.3.

Photographs of the ball valve vent system originally planned to vent gases from the secondary treatment system are shown in Figure 49.

TABLE XII

200 MAN WASTE TREATMENT SYSTEM EVALUATION
NAVY PROGRAM

Sewage Batch	Test	Flow (gpm)	Cur. Conc. Amp-Min / Gal	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-102	A	1.5	100	Influent		7.35	--	1217	1014	535
				Centrate		7.15	--	615	445	126
				PEPCON 1	78	7.2	195			
				U. V. 1	90	6.4	Nil			
				PEPCON 2	91	7.25	400			
				U.V. 2	103	6.25	Nil			
				PEPCON 3	114	7.0	412			
				U.V. 3	118	6.0	15			
				PEPCON 4	119	6.8	550			
				U.V. 4	125	6.25	225	105	140	44
	B	1.5	200	Influent		7.35	--	1217	1014	535
				Centrate		7.15	--	615	445	126
				PEPCON 1	85	7.8	1000			
				U.V. 1	98	7.2	475			
				PEPCON 2	102	7.85	1550			
				U.V. 2	115	7.5	875			
				PEPCON 3	119	7.75	1800			
				U. V. 3	132	7.4	1000			
				PEPCON 4	135	7.65	1850			
				U. V. 4	143	7.5	1325	47	177	41

TABLE XII (Cont)

200 MAN WASTE TREATMENT SYSTEM EVALUATION
NAVY PROGRAM

Sewage Batch	Test	Flow (gpm)	Cur. Conc. Amp-Min Gal	Sample Station		Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
	E	2.0	100	Influent			7.35	--	1217	1014	535
				Centrate			7.15	--	615	445	126
				PEPCON	1	84	7.6	400			
				U.V.	1	93	6.65	120			
				PEPCON	2	95	7.55	650			
				U.V.	2	105	6.9	260			
				PEPCON	3	106	7.4	675			
				U.V.	3	115	6.8	300			
				PEPCON	4	118	7.2	650			
				U.V.	4	124	6.9	500	191	155	38
	F	2.0	200	Influent			7.35	--	1217	1014	535
				Centrate			7.15	--	615	445	126
				PEPCON	1	89	7.9	1150			
				U.V.	1	99	7.65	750			
				PEPCON	2	104	7.95	1750			
				U.V.	2	113	7.7	1275			
				PEPCON	3	118	7.9	2000			
				U.V.	3	128	7.65	1500			
				PEPCON	4	133	7.85	2100			
				U.V.	4	140	7.6	1750	130	179	49

TABLE XII (Cont)

200 MAN WASTE TREATMENT SYSTEM EVALUATION
NAVY PROGRAM

Sewage Batch	Test	Flow (gpm)	Cur. Conc. Amp-Min / Gal	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
	C	2.5	100	Influent		7.35	--	1217	1014	535
				Centrate		7.15	--	615	445	126
				PEPCON 1	82	7.5	350			
				U.V. 1	89	7.2	90			
				PEPCON 2	91	7.5	750			
				U.V. 2	100	7.2	400			
				PEPCON 3	101	7.5	850			
				U.V. 3	109	7.2	575			
				PEPCON 4	111	7.5	975			
				U.V. 4	116	7.2	775	188	217	40
	D	2.5	200	Influent		7.35	--	1217	1014	535
				Centrate		7.15	--	615	445	126
				PEPCON 1	90	7.9	1200			
				U.V. 1	98	7.6	900			
				PEPCON 2	105	7.9	1750			
				U.V. 2	113	7.75	1500			
				PEPCON 3	117	8.0	2300			
				U.V. 3	124	7.8	1825			
				PEPCON 4	131	7.85	2500			
				U.V. 4	135	7.7	2200	103	179	44

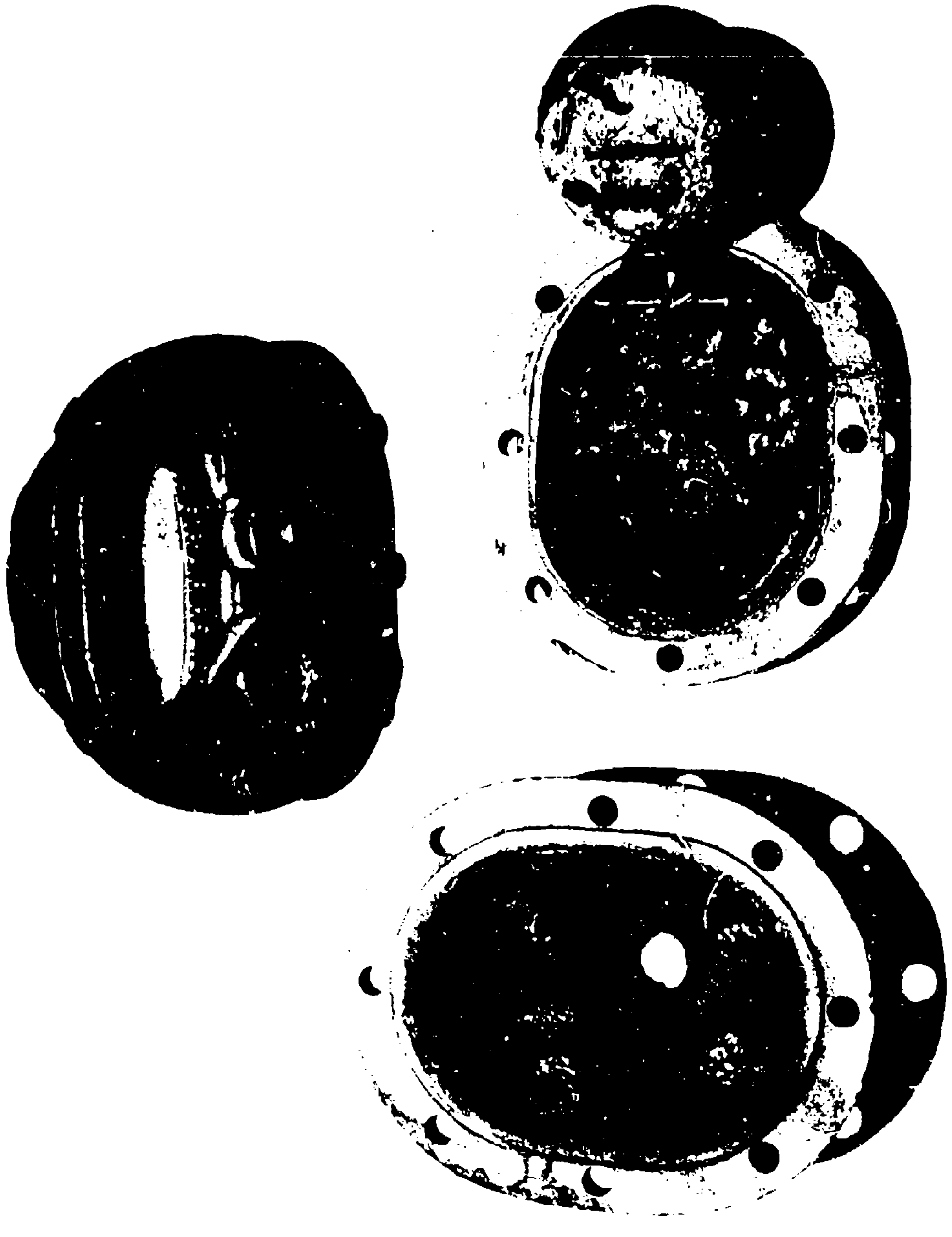

Figure 49. Corrosion Buildup on Original Vent System Ball Valve

3.3.2.6 Secondary Treatment Subsystem Testing with Chemical Catalyst

Dissolved biochemical oxygen demand is removed by the Thiokol Advanced Waste Treatment System based on the oxidative power of hypochlorite. This reaction can be catalyzed by ultraviolet light or metal oxide solid catalysts. Both of these have been extensively studied by Thiokol. A patent has been applied for under TCC 715-J4 using the Thiokol developed catalyst reaction. The chemistry involved in this reaction is presented as follows:

$$2NaClO \xrightarrow[Catalyst]{} 2NaCl + 2O^{\cdot}$$

The atomic oxygen produced by the decomposition of hypochlorite reacts readily with organic compounds in which it comes in contact to oxidize them to carbon dioxide and water. It also reacts with ammonia to oxidize the ammonia in nitrogen and various nitrogen oxides. Typical equations for oxidations of dissolved organics and nitrogen compounds follow:

$$C_n H_m O_x + O^{\cdot} \longrightarrow CO_2 + H_2O$$

$$NH_2CONH_2 + 3O^{\cdot} \longrightarrow N_2 + 2H_2O + CO_2$$

In addition, some oxidation is achieved from the hypochlorite directly per the following

$$C_n H_m O_x + NaClO \xrightarrow{Catalyst} CO_2 + NaCl + H_2O$$

$$NH_2 CONH_2 + 3 NaClO \xrightarrow{Catalyst} N_2 + 3 NaCl + CO_2 \; 2 H_2O$$

Atomic oxygen also combines with itself, producing molecular gaseous oxygen which can be seen bubbling from the system and again can enhance the oxidation of dissolved solids. If the decomposition rate of hypochlorite is depressed in the form

$$\frac{d(OCl^-)}{dt} = -k \; (O^{\cdot}) \; (Cl^-)^2$$

then the value of k for the catalyst is 75. In the absence of the catalyst with hypochlorite alone, k was equal to 0.01. It can be seen that by using the catalyst it is possible to get the same amount of reaction in an hour that would take days without the catalyst. In addition, the temperature coefficient of the catalyst reactivity is over 2 per 10°C rise, or the k value more than doubles per 10°C temperature increase. The Thiokol catalyst is insoluble in water and can be pelletized or impregnated on different sizes of substrates to provide an activated filter bed for removing solids. Solid substrates act as promoters to the catalyst and will increase its activity.

Preliminary investigations substantiate the establishment of catalyst requirement development goals as listed below:

Temperature - Should be active within 50° to 100°F

Operational Life - Six months or more without replacement

Efficiency - A maximum of COD-BOD reduction for a given time interval and catalyst weight or volume

Reduction after 30 minute reaction cycle in catalytic reaction

COD - 700 to 150 mg/l

BOD - 300 to 50 mg/l

Suspended Solids - Less than 100 mg/l

Laboratory scale tests comparing the initial nickel-cobalt Thiokol catalyst with UV light are presented in Table XIIA. Biochemical oxygen demand was reduced from 460 mg/l to 52 with catalyst and 1 127 with UV light after 45 minutes exposure.

TABLE XIIA

CATALYST AND UV EVALUATION
(Sewage Batch M-85-053)

	Suspended Solids, COD and BOD				
	Nickel - Cobalt (TCC)			Spectrosil - UV	
Time	Suspended Solids	COD	BOD	COD	BOD
Feed	493	1,004	460	888	290
30 min PEPCON	335	655	300	545	210
30 min + 10 Catalyst or UV	100	421	160	352	200
30 min + 20 Catalyst or UV	75	318	--	316	185
30 min + 30 Catalyst or UV	155	266	57	301	145
30 min + 45 Catalyst or UV	95	143	52	167	127

Subsequent laboratory data confirmed these data and helped establish the sequence of hypochlorination addition as summarized in Table XIIB.

These data indicate BOD reductions to near zero after 30 minutes of exposure of sodium hypochlorite. The BOD reductions were obtained with the sodium hypochlorite added before or after solids removal.

Several different substrates for the catalyst material have been evaluated. These substrates vary from porous aluminum oxide to various magnesium aluminum silicates having a great variety in the number of active reactions weights within the substrates. Data presented in Figure 49a compare the activity index of the catalysts prepared using different substrates and the same basic cobalt catalyst treatment process. The tests were conducted at temperatures of 72° and 130°F. A colored organic dye (ferroin) was used and the time recorded to obtain a major reduction in the concentration of the dye as measured by colorimetric techniques. Approximately one percent hypochlorite was used for comparison purposes and assigned an activity index of one. Substrates evaluated had comparative activity indexes varying up to 5.8 for CC5 at 70°F, 11 for WNC-1 at 130°F, and 19 for CC5 at 130°F. A more detailed review of the characteristics of the substrates is presented in Table XIIC.

The aging characteristics of the catalyst are of obvious interest to the successful development on the catalytic system. Thiokol has conducted an aging program on the catalyst over the last six months. The catalyst utilized was WNC-1 and a summary of the data is presented in Figure 49b. The tests were conducted feeding different batches of raw sewage filtrate to a catalyst reactor filled with WNC-1 catalyst. The original chemical oxygen demand reduction efficiency of the catalyst was assigned as 1.0. It will be observed from the data that this value varied from 1.0 to 3.0 and has stabilized around 2.0. The higher values reflect a decrease in activity to a level of one-half of the original activity at the present time. Values where the activity index dropped to three were obtained when abnormally high concentration sewage with BOD and suspended solids with over 1,000 mg/l was run through the system. Based upon present tests, it is concluded that the catalyst retains its activity with repeated usage over a six month time period. Thiokol's design goal is to provide a catalyst which can be continuously used for one year without replacement. Tests have been conducted on inplace reactivation of the catalyst. Catalyst activity has been successfully increased by simple exposure to hypochlorite solution.

TABLE XIIB

CATALYST REACTOR DATA
HYPOCHLORATE ADDITION STUDY

	Suspended Solids		COD		BOD	
	A	B	A	B	A	B
Tests A and B	With NaClO Pretreatment					
Feed	355	422	745	994	*	*
30 min pretreatment	306	280	232	470	*	330
After filtration	87	8	130	365	*	255
30 min catalytic column	71	*	126	*	*	35
60 min catalytic column	*	0	*	217	*	0
Percent reduction	89	100	85	78	*	100

Test C	Suspended Solids	COD	BOD
	With NaClO Pretreatment (1/2, 1/2)		
Feed	462	1,001	*
30 min pretreatment	420	595	350
After filtration	8	232	115
30 min catalytic column	0	221	0
Percent reduction	100	78.0	100

Test D	Suspended Solids	COD	BOD
	With NaClO Multiple Addition (1/4, 1/2, 1/4)		
Feed	458	952	405
30 min pretreatment	238	748	295
After filtration	0	404	50
30 min catalytic column	0	289	0
60 min catalytic column	0	220	0
Percent reduction	100	76.9	100

Test E	Suspended Solids	COD	BOD
	No Pretreatment, NaClO Added to Filtrate		
Feed	518	1,047	525
After filtration	138	554	405
30 min catalytic column	0	548	0
90 min catalytic column	0	181	0
Percent reduction	100	83	100

---

*No data

TABLE XIIC

SUMMARY OF CATALYST SUBSTRATE TYPES

1. HARSHAW ALUMINA - WNC-1

Has good high temperature properties and activity.(1) Excellent efficiency.(2) Hard pellet, good operating life. High cost and density. Poor ambient temperature properties.

2. UNION CARBIDE MOLECULAR SIEVES - WNC-2, WNC-3

Good high and low temperature properties. Average efficiency and good activity. Low cost and density. More friable than others.

3. GRACE SILICA GEL

Has excellent hardness and medium density. Good high temperature efficiency and activity. Average low temperature activity. More study required.

4. UNION CARBIDE PREPARED CATALYST

Five samples sent to date. Sample 4 is similar to WNC-3 except for poor efficiency. Sample 5 preliminary data indicates excellent high and low temperature activity and average efficiency. Some density and friability as No. 2 above. Testing not completed.

5. NORTON ALUMINA

In general activity below those above per unit of volume. Testing not complete.

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(1) The ability to accelerate the decomposition of hypochlorite.

(2) An indication of the amount of organic material decomposed per unit of hypochlorite.

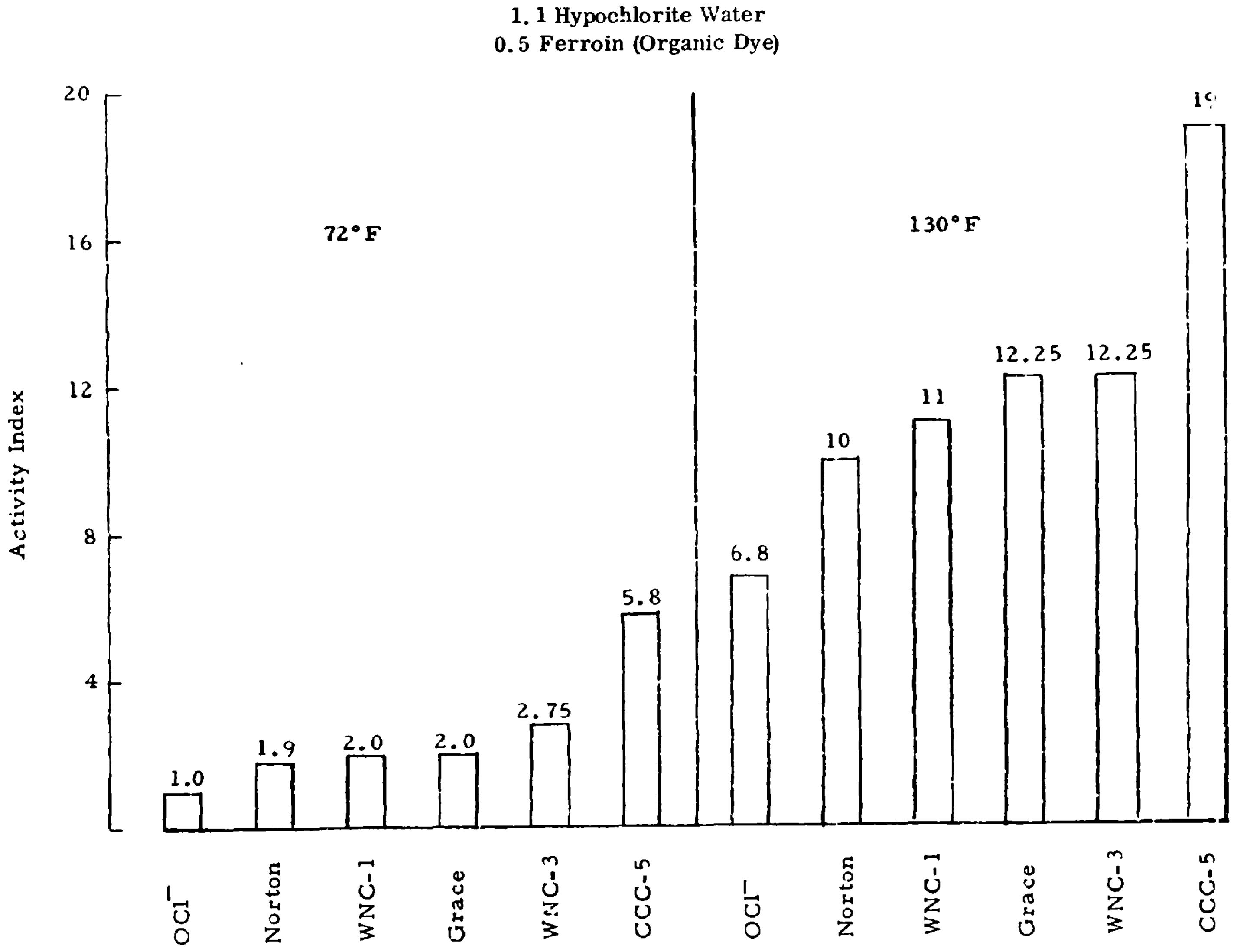


Figure 49a. Catalyst Activity

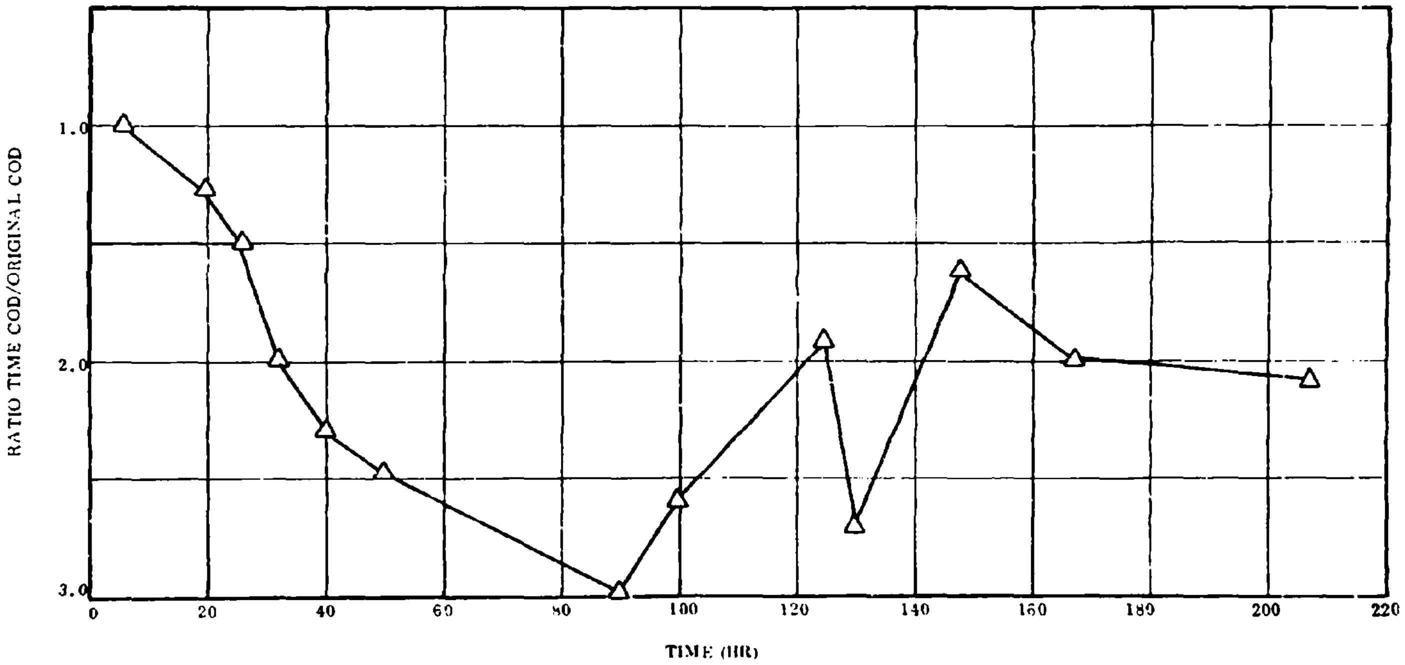
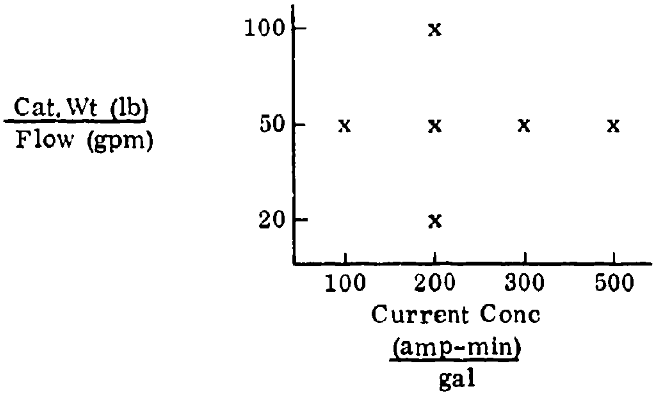


Figure 49b. Catalyst Activity vs Time, WNC-1 Catalyst

After obtaining the highly encouraging laboratory data reviewed above, a 50 lb catalyst column was fabricated and tested in conjunction with a PEPCON electrolytic cell and several different batches of sewage centrate.

Calibration data obtained in the pilot plant are presented in Figures 50, 51, and 52 relating the disappearance of sodium hypochlorite as a function of catalyst weight/flow rate at several temperatures. The activity of the catalyst is observed to exhibit a strong temperature dependency. A temperature of 130° F was selected as an operating temperature for initial testing.

A series of tests were conducted using clarified sewage to evaluate the efficiency of hypochlorite utilization in BOD reduction in the catalyst system under different flow and concentration conditions. A 500 sq. in. PEPCON cell and a 50 lb catalyst column were arranged in a batch recycle system for these tests. The ratio of catalyst weight/flow rate and current concentration were varied as follows.



The results of these tests are presented in Table XIII. A graphical analysis of these data, presented in Figure 53, indicate the catalyst to be inefficient at high current concentrations and high hypochlorite concentrations. Although hypochlorite is rapidly converted under these conditions it is evidently consumed in competing reaction such as molecular oxygen formation rather than BOD reductions. Hypochlorite concentrations of less than 1,000 ppm per stage appear to be satisfactory. The catalyst to flow rate ratio of 50 to 100 per stage also appear favorable for optimum system operation.

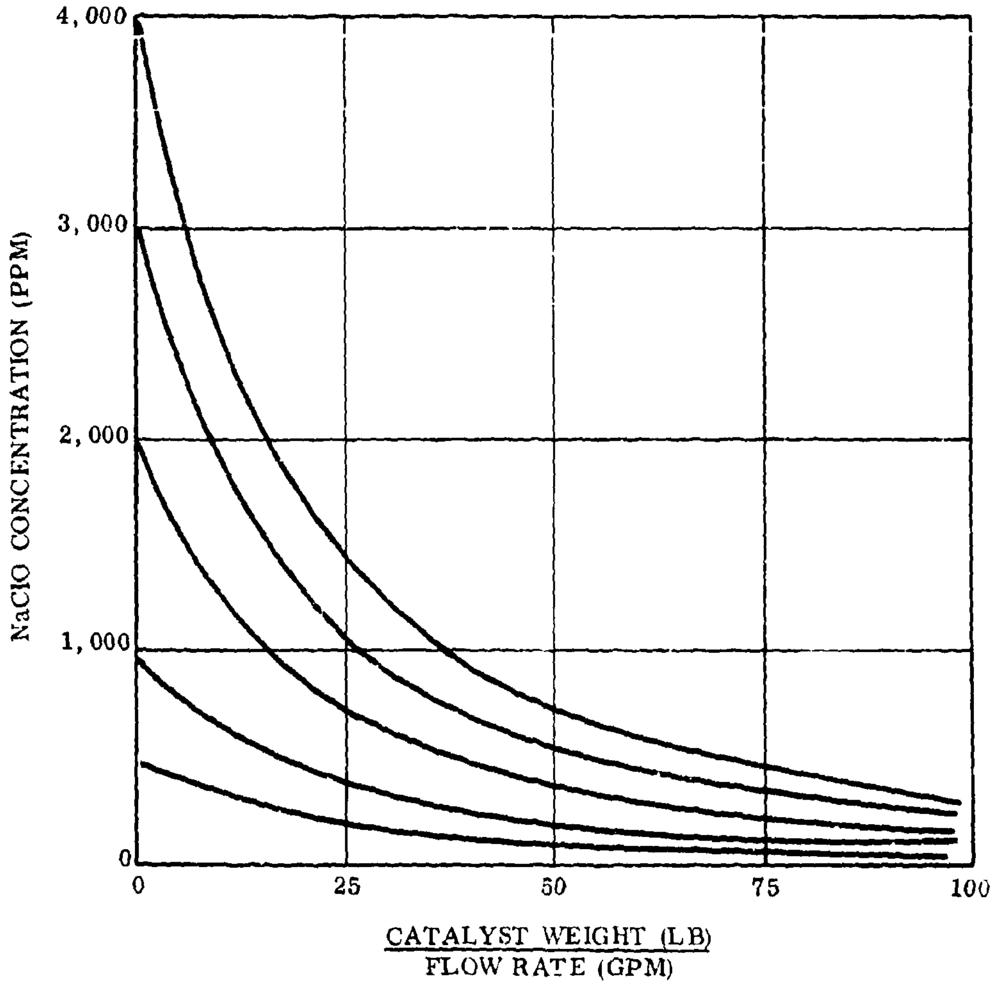


Figure 50. NaClO Concentration Profile at 135° F (WNC-1 Catalyst Column)

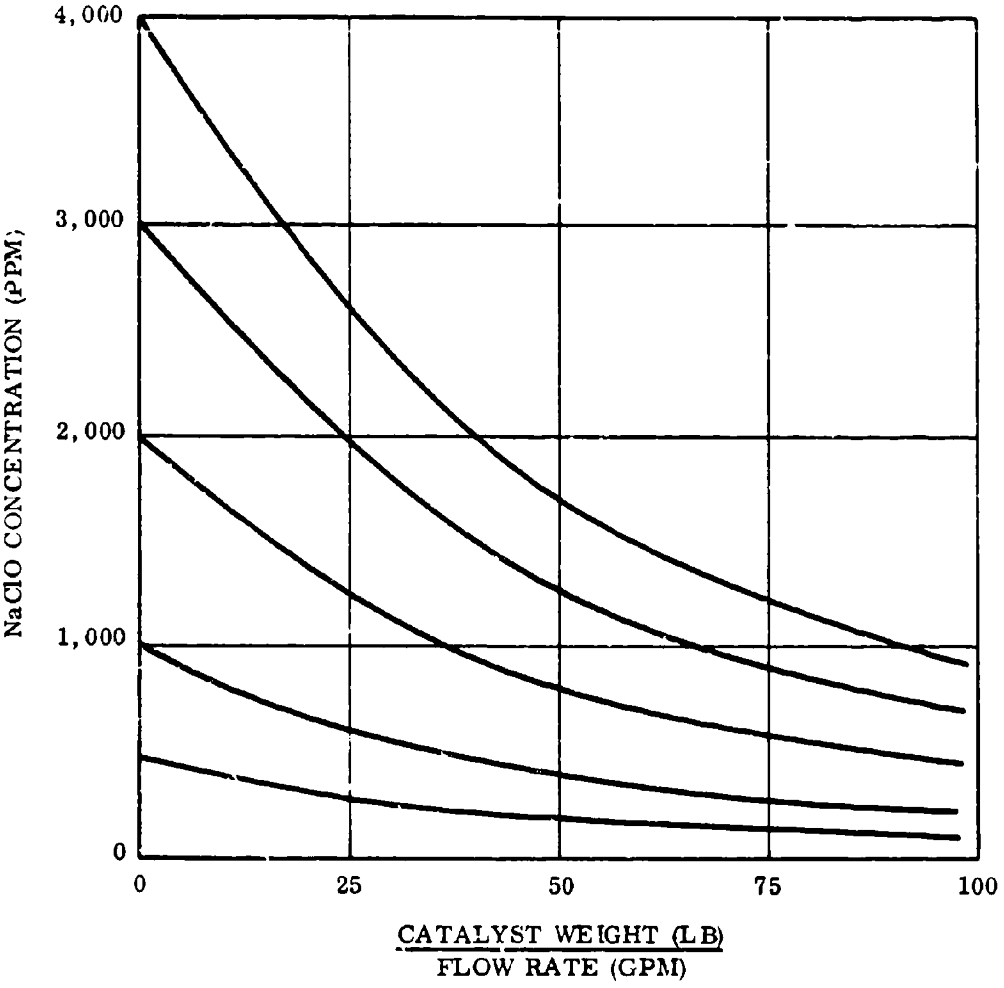


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Figure 51. NaClO Concentration Profile at 90° F (WNC-1 Catalyst Column)

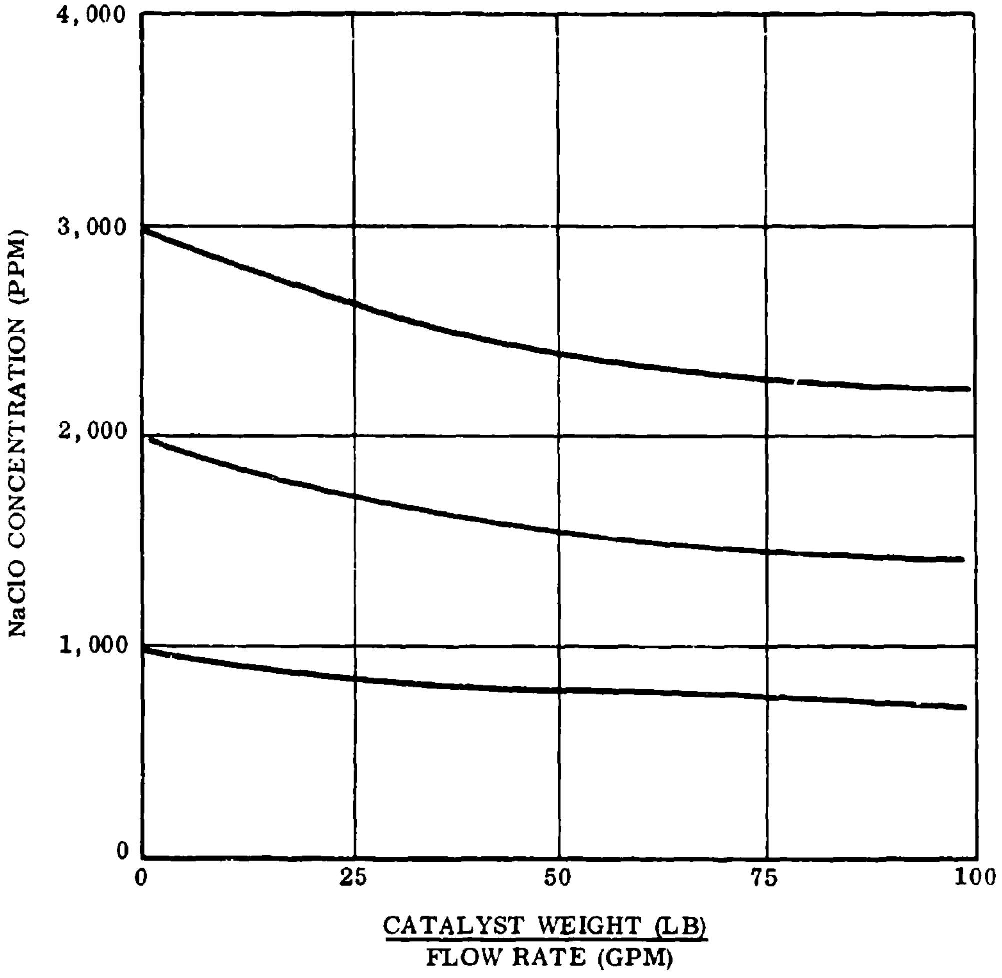

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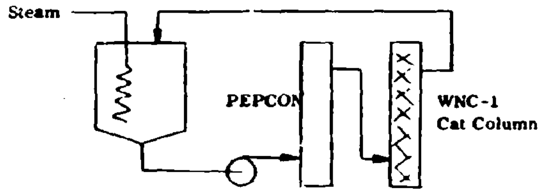
Figure 52. NaClO Concentration Profile at 60° F (WNC-1 Catalyst)

TABLE XIII

CATALYTIC WASTE TREATMENT EVALUATION



Sewage Batch	Test	Flow (gpm)	Current Conc. (amp-min/Gal)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-098	C	1	100	Influent	--	7.7	--	888	237	313
				Centrate	--	7.55	--	684	181	86
				Pepcon 1	131	7.35	155			
				Cat Col 1	130	7.05	130			
				Pepcon 2	126	7.75	235			
				Cat Col 2	122	7.1	165			
				Pepcon 3	132	7.55	510			
				Cat Col 3	128	7.2	255			
				Pepcon 4	127	7.4	600			
				Cat Col 4	133	7.05	280	233	76	46
	E	1	300	Influent	--	7.7	--	888	237	313
				Centrate	--	7.55	--	684	181	86
				Pepcon 1	152	7.8	950			
				Cat Col 1	128	7.1	480			
				Pepcon 2	140	7.9	1400			
				Cat Col 2	134	7.3	780			
				Pepcon 3	135	7.8	1750			
				Cat Col 3	130	7.4	950			
				Pepcon 4	127	7.9	2125			
				Cat Col 4	127	7.5	975	137	54	56

TABLE XIII (Cont)

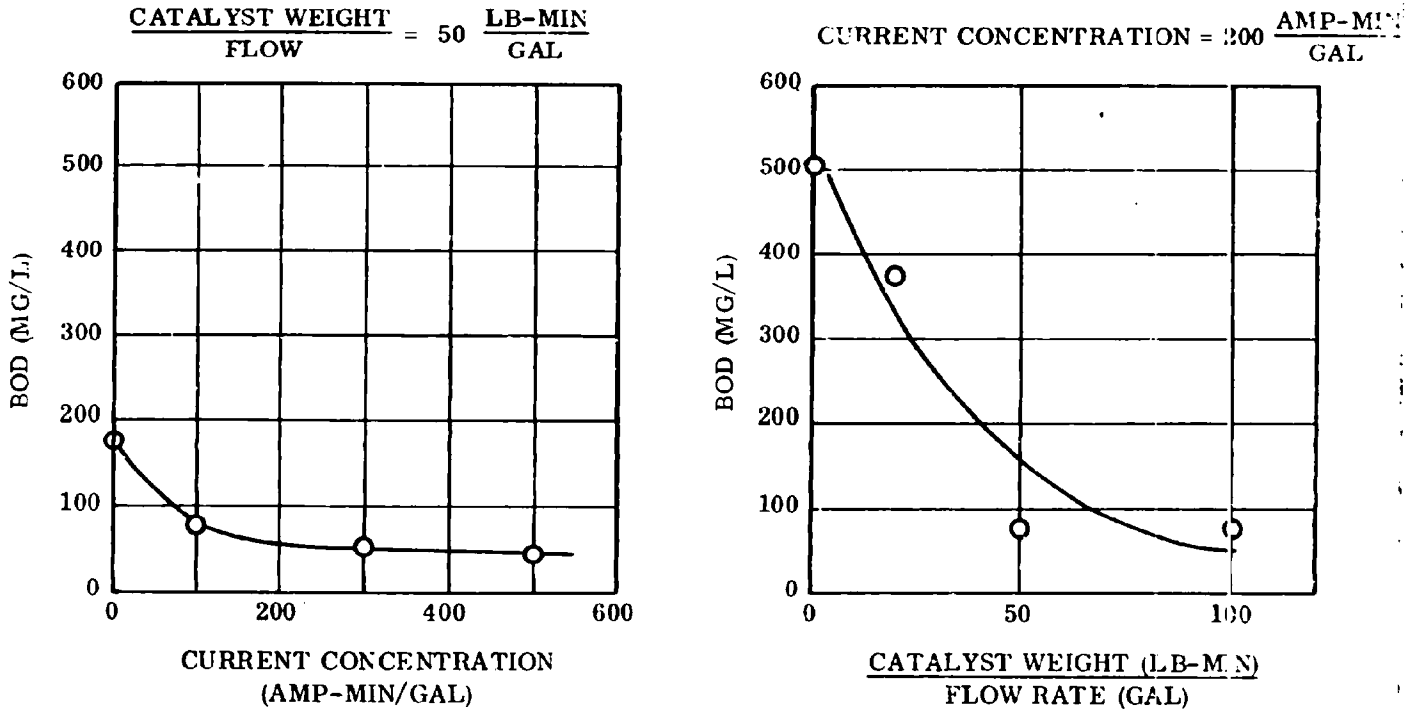
CATALYTIC WASTE TREATMENT EVALUATION

Sewage Batch	Test	Flow (gpm)	Current Conc. (amp-min / gal)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M-85-098	G	1	500	Influent	--	7.7	--	888	237	313
				Centrate	--	7.55	--	684	181	86
				Pepcon 1	157	7.9	1675			
				Cat Col 1	137	7.6	675			
				Pepcon 2	148	8.1	2225			
				Cat Col 2	140	7.5	945			
				Pepcon 3	143	8.1	2475			
				Cat Col 3	140	7.5	1200			
				Pepcon 4	142	8.1	3100			
				Cat Col 4	139	7.55	1445	62	47	53
M85-100	A	2 1/2	200	Influent	--	7.1	--	811	840	400
				Centrate	--	7.4	--	569	500	107
				Pepcon 1	140	7.1	260			
				Cat Col 1	140	6.7	75			
				Pepcon 2	134	7.65	750			
				Cat Col 2	138	7.25	450			
				Pepcon 3	135	7.7	1250			
				Cat Col 3	136	7.4	775			
				Pepcon 4	137	7.8	1550			
				Cat Col 4	135	7.5	925	182	375	56

TABLE XIII (Cont)

CATALYTIC WASTE TREATMENT EVALUATION

Sewage	Test	Flow (gpm)	Current Conc. (amp-min / Gal)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M-85-100	B	1	200	Influent	--	7.1		811	840	400
				Centrate	--	7.4		569	500	107
				Pepcon 1	126	7.15	372			
				Cat Col 1	128	6.75	75			
				Pepcon 2	142	7.5	750			
				Cat Col 2	136	6.9	190			
				Pepcon 3	132	7.65	950			
				Cat Col 3	132	7.15	315			
				Pepcon 4	124	7.65	1180			
				Cat Col 4	128	7.25	625	135	70	25
	C	1/2	200	Influent -	--	7.1	--	811	840	400
				Centrate	--	7.4	--	569	500	107
				Pepcon 1	137	6.8	208			
				Cat Col 1	119	6.75	Nil			
				Pepcon 2	163	7.0	325			
				Cat Col 2	149	6.7	Nil			
				Pepcon 3	116		625			
				Cat Col 3	132	6.8	125			
				Pepcon 4	127	7.5	750			
				Cat Col 4	120	7.0	265	72	81	43



$\frac{\text{CATALYST WEIGHT}}{\text{FLOW}} = 50\ \frac{\text{LB-MIN}}{\text{GAL}}$

CURRENT CONCENTRATION = 200 $\frac{\text{AMP-MIN}}{\text{GAL}}$

Figure 53. Catalyst Secondary Treatment Evaluation, Four Stage PEPCON/WNC-1 Catalyst Column, Temp = 135° F

3.3.2.7 Control Subsystem Testing

Prototype Evaluation

Prototype evaluation was accomplished during installation and checkout. The following descriptions are results from that evaluation.

Primary Treatment System

The present pressure switches, used for level detection on the primary tank, are inadequate due to their large differential pressure and repeat accuracy.

Centrifuge

It was found that the centrifuge motor draws 40 amp for greater than 12 sec during startup, when the basket is loaded. This excessive current overheats the motor and if continued starts are made under this condition, the motor could be seriously damaged. Since the handbrake is to remain on the centrifuge, care should be taken to insure it is not in the locked position when attempting to operate.

Sludge Tank

The sludge pump output does not provide adequate pressure to actuate the sludge pump pressure switch thus terminating the flow of sludge to the incinerator. With the different method of introducing sludge into the sludge tank, the present handling of sludge is inadequate.

Incinerator

The location of the present thermoswitches on the incinerator are wrong. The sensing probes of the switches extend only to the edge of the insulation and are more sentitive to the insulation temperature rather than the atmosphere in which the sludge is being incinerated. Ideally, the sensing instrument should be at or near the burner. The temperature at this location is in the vicinity of 1,900° F. The present thermoswitches are only capable of 1,500° F.

At present, care must be taken to turn off the incinerator burner and make sure it cannot be turned on prior to opening the incinerator door since the burner is a personnel hazard if it should light with the door open.

3.3.3 Integrated System Performance with Ultraviolet Lamps

The complete 200 man Navy waste treatment system has been operated for 86 hr. The incinerator operated for approximately 50 of these hours. The centrifuge, part of the primary treatment subsystem, accumulated an additional 153 hr earlier in the program for a total of 239 hr. Problems encountered in system startup and operation were discussed under the applicable subsystem section. A brief summary of the problems and the corrective measured taken is given below.

System Problem Summary

Subsystem		Problem		Corrective Action
1. Primary	(a)	Matted paper resisting fluidization and obstructing skimmer tube during skim mode	(a)	Prescreening influent
	(b)	Level detectors drift	(b)	Reset and calibrate
2. Secondary	(a)	Leakage of liquid seal in UV cell	(a)	Replaced O-ring with RTV seal
	(b)	Excessive aeration of process liquid	(b)	Gas vent valves and pressurized dark reactor removed. Vented tank with recycle loop added
	(c)	Coating over quartz tube in UV cell	(c)	System placed on recycle during startup and shutdown for temperature control
	(d)	Excessive temperature	(d)	Liquid recycle and replacement of UV lamps with catalyst
	(e)	Anode movement in PEPCON cell from internal pressure	(e)	Available larger ports will lower backpressure
3. Incinerator	(a)	Burner will not light	(a)	Air flow thru burner reduced for lighting
	(b)	Residue buildup in blower adapter	(b)	Redesign using plenum chamber and eductor
	(c)	Temperature control	(c)	Proper air inlet control
	(d)	Silica liner failure	(d)	Changed air inlet position. Replaced part

Data accumulated during initial system operation are presented in Tables XII thru XVIII. The tables are segregated to reflect changes in process flow evolved during startup.

Table XIV reflects the initial process flow configuration. In this configuration, the secondary flow is divided after the dark reactor with one-half being processed in the PEPCON/UV series and the remaining one-half discharging to a drain field. The discharge stream would pass through a second PEPCON/UV series in the completed system. Analysis of these data indicate a very low sodium hypochlorite concentration exiting from the dark reactor resulting in poor utilization of UV Cell No. 1. A continued increase in hypochlorite concentration in the system indicates a lack of photochemical conversion or insufficient number of UV cells. The primary feed pump was delivering 9 gpm of sewage to the centrifuge on an intermittent basis (dictated by level sensors in the centrate tank) resulting in lower than normal solids removal, and high COD's and BOD's. Primary tank feed pump output was subsequently adjusted to the design value of 5 gpm and satisfactory suspended solids removal was obtained. The centrifuge is designed to operate continuously regardless of feed rate and the data obtained at the 5 gpm feed rate both with continuous feed and intermittent feed showed no difference in operating characteristics.

The secondary flow was divided prior to the first two PEPCON cells and dark reactors in the tests shown in Table XV. This resulted in a higher hypochlorite concentration entering UV Cell No. 1 and better utilization of UV Cell No. 1. A continued buildup of residual hypochlorite is still observed indicating insufficient number of UV cells for the flow rate and power levels used in the test run. The primary feed pump still operated on an intermittent, high flow rate basis. Adequate treatment was not achieved.

A 100 lb catalyst column was added to the secondary treatment system (tests shown in Table XVI) to remove residual hypochlorite from the effluent. A gate valve was added to the primary pump as an interim measure to control the flow rate to the centrifuge.

Periodic problems were experienced during the skim mode on the centrifuge with paper matting obstructing the intake of the skimmer tube. An inclined screen with 0.060 in. openings was added to the system in the tests shown in Table XVII to remove paper and other materials potentially capable of plugging the skimmer tube. The flow rate was also reduced to correspond to the average rate of flow anticipated for a 200 man system; ie, 3.6 gpm. High residual hypochlorite concentrations present still indicate the lack of sufficient

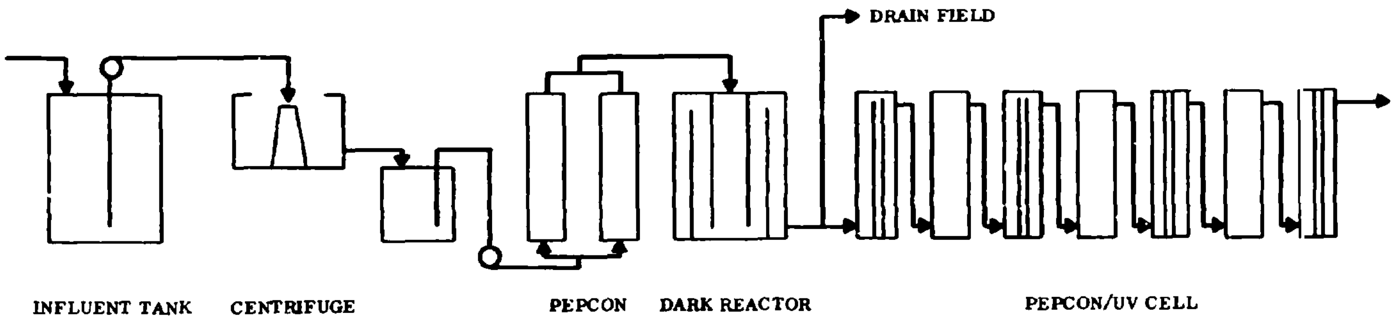
UV cells in the system. Improved treatment was obtained, however, due to the lower flow rate.

In order to reduce the degree of aeration of the process fluid believed to contribute to the quartz tube coating problem, a recycle loop was added to the secondary system as indicated in Table XVIII. The gas vent valves, which proved nonfunctional, and the pressurized dark reactor were removed and replaced with an ambient pressure tank. The flow rate through the secondary system was increased to 7.2 gpm with 1.8 gpm flowing through the system and 5.4 gpm recycle. Flow is initiated (full recycle) prior to system startup and after system shutdown to prevent localized heating in the UV cells. A reduced operating temperature was observed with the recycle system due to heat dissipation in the recycle tank. The high residual hypochlorite concentration in the recycle effluent again indicates the limited photochemical capacity of the system for the flow rate and power levels tested. Analytical data obtained indicate acceptable performance in suspended solids removal and marginal performance in BOD reduction. The presence of a white, colloidal precipitate in the effluent prompted addition of a second centrifuge to the system. Removal of this precipitate resulted in a slight reduction in COD.

In conclusion it is apparent from the data presented in Table XVIII that the proposed Navy system with 8 UV lamps will not meet the BOD requirement of 50 mg/l without the addition of more UV cells. It is estimated from data presented in Figure 11, Section 3.2.2.3, that the UV lamps will have to be doubled to meet the BOD specification. The technical feasibility of all other subsystems have been demonstrated. It is, therefore, concluded that all Navy requirements can be met with a 200 man system containing 16 UV cells in place of the 8 cells originally proposed.

TABLE XIV

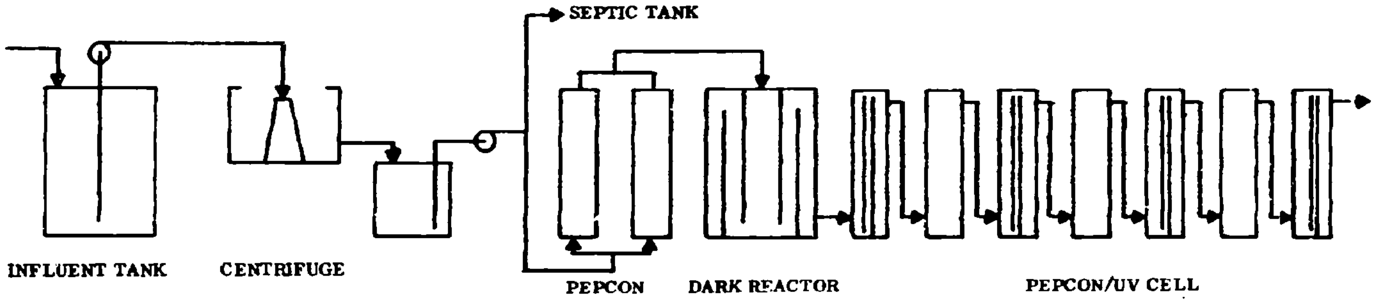
200 MAN WASTE TREATMENT SYSTEM EVALUATION
(Flow A)



Sewage Batch	Test	Primary Flow (gpm)	Secondary Flow (gpm)	PEPCON Current (amp)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-113	A	9	2-1/2	500	Influent	68	7.4		1,399	290	520
					Centrate	68	7.7		772	305	255
					Effluent	125	7.8		210	165	105
	B	9	2-1/2	400	Effluent	118	7.65	1,500	245	170	95
	C	9	2-1/2	300	Effluent	116	7.4		330	192	86
M85-114	A	9	2-1/2	350	Influent	67	7.1		1,128	295	535
					Centrate	69	7.8		876	228	150
					PEPCON 1, 2	74	7.75	200			
					Dark Reactor	75	7.0	100			
					UV No. 1	80	6.75	50			
					PEPCON 3	83	7.85	850			
					UV No. 2	93	7.55	500			
					PEPCON 4	96	7.9	1,200			
					UV No. 3	105	7.6	825			
					PEPCON 5	109	7.75	1,400			
					UV No. 4	117	7.5	1,050	398	97	103

TABLE XV

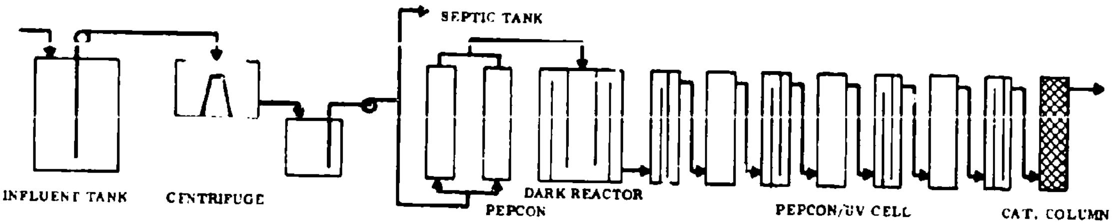
200 MAN WASTE TREATMENT SYSTEM EVALUATION
(Flow B)



Sewage Batch	Test	Primary Flow (gpm)	Secondary Flow (gpm)	PEPCON Current (amp)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-115	A	9	2-1/2	350	Influent	67			768	288	560
					Centrate	69	7.9		622	338	346
					PEPCON 1,2	77	8.1	725			
					Dark reactor	77	7.7	588			
					UV No. 1	80	7.65	520			
					PEPCON 3	82	8.0	1,275			
					UV No. 2	92	7.8	925			
					PEPCON 4	96	8.0	1,500			
					UV No. 3	115	7.75	1,075			
					PEPCON 5	108	7.85	1,700			
					UV No. 4	115	7.6	1,225	443	238	110

TABLE XVI

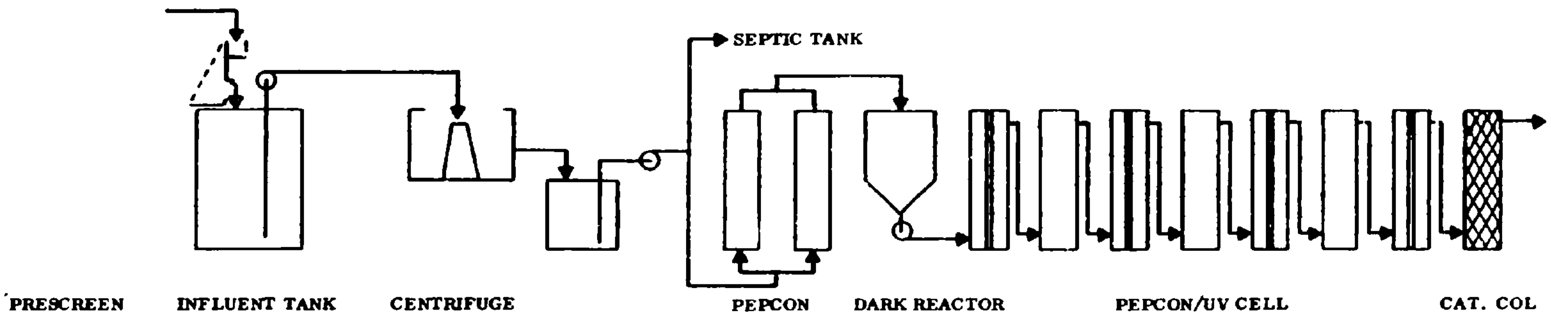
200 MAN WASTE TREATMENT SYSTEM EVALUATION
(Flow C)



Sewage Batch	Test	Primary Flow (gpm)	Secondary Flow (gpm)	PEPCON Current (amp)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-119	A	5	2-1/2	500	Influent	63	7.35	--	842	228	270
					Centrate	66	7.50	--	540	288	135
					PEPCON 1, 2	81	7.95	1,538			
					Dark reactor	80	7.85	1,386			
					UV No. 1	85	7.80	1,225			
					PEPCON 3	93	8.05	2,550			
					UV No. 2	103	7.90	1,925			
					PEPCON 4	110	8.05	2,850			
					UV No. 3	120	7.90	2,075			
					PEPCON 5	131	8.05	3,150			
					UV No. 4	143	7.85	2,600	235	193	142
					Cat. Col	142	6.80	14	80	114	104
M85-119	A	5	2-1/2	500	Influent			--	674	560	262
					Centrate			--	358	300	136
					PEPCON 1,2			700			
					Dark reactor			738			
					UV No. 1			600			
					PEPCON 3			1,600			
					UV No. 2			1,150			
					PEPCON 4			1,950			
					UV No. 3			1,460			
					PEPCON 5			2,300			
					UV No. 4			2,050	60	230	125
					Cat. Col			540	18	160	122
M85-119	B	3	1-1/2	300	Influent			--	497	420	162
					Centrate			--	295	270	92
					PEPCON 1, 2			1,250			
					Dark reactor			1,025			
					UV No. 1			900			
					PEPCON 3			1,900			
					UV No. 2			1,250			
					PEPCON 4			2,100			
					UV No. 3			1,350			
					PEPCON 5			2,100			
					UV No. 4			1,950	Nil	Nil	70
					Cat. Col			133	Nil	62	88

TABLE XVII

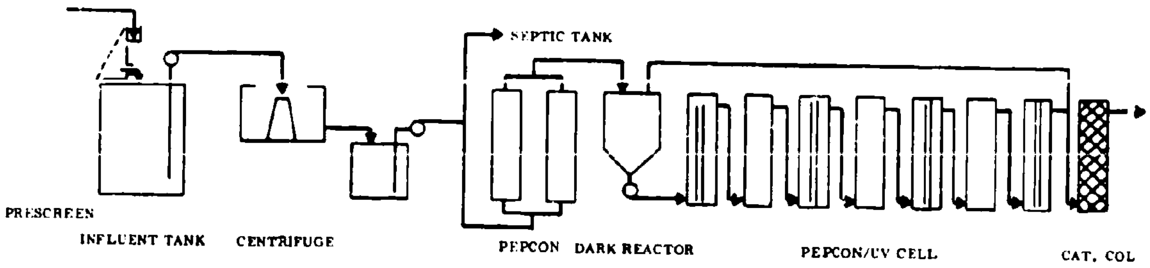
200 MAN WASTE TREATMENT SYSTEM EVALUATION
(Flow D)



Sewage Batch	Test	Primary Flow (gpm)	Secondary Flow (gmp)	PEPCON Current (amp)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-121	A	3.6	1.8	350	Influent	62		--			
					Prescreen	62		--	916	458	520
					Centrate	62		--	463	312	124
					PEPCON 1,2	73		900			
					Dark reactor	74		738			
					UV No. 1	80		575			
					PEPCON 3	86		1,650			
					UV No. 2	98		1,225			
					PEPCON 4	104		2,100			
					UV No. 3	122		1,450			
					PEPCON 5	142		2,450			
					UV No. 4	157		2,150	nil	92	58
					Cat. Col	123		170	nil	112	71

TABLE XVIII

200 MAN WASTE TREATMENT SYSTEM EVALUATION
(Flow F)



Sewage Batch	Test	Primary Flow (gpm)	Secondary Flow (gpm)	PEPCON Current (amp)	Sample Station	Temp (°F)	pH	NaClO (ppm)	COD (mg/l)	BOD (mg/l)	SS (mg/l)
M85-123	A	3.6	1.8	300	Influent	66	7.10	--	2,462	344	1,452
					Screen	66	7.10	--	1,474	222	694
					Centrate	69	7.55	--	739	179	384
					PEPCON 1, 2	74	7.60	590			
					Dark reactor	108	7.60	1,075			
					UV No. 1	109	7.60	1,075			
					PEPCON 3	110	7.75	1,325			
					UV No. 2	113	7.75	1,150			
					PEPCON 4	113	7.85	1,400			
					UV No. 3	116	7.80	1,250			
					PEPCON 5	116	7.85	1,450			
					UV No. 4	119	7.80	1,325	154	182	75
					Cat. Col	114	7.20	430	220	108	88
					Cat. Col*				100	32	36
M85-124	A	3.6	1.8	300	Influent	65		--	6,812	2,016	5,694
					Screen	64		--	5,387	190	546
					Centrate	67		--	1,575	176	126
					PEPCON 1, 2	73		700			
					Dark reactor**	109		1,100			
					UV No. 1	112		1,100			
					PEPCON 3	113		1,500			
					UV No. 2	115		1,350			
					PEPCON 4	115		1,500			
					UV No. 3	119		1,400			
					PEPCON 5	119		1,700			
					UV No. 4	123		1,500		83	68
					Cat. Col	117		420		68	45
M85-125	A	3.6	1.8	300	Influent						
					Screen				814	163	278
					Centrate				568	188	116
					UV No. 4***				315	108	78
					Cat. Col				242	103	75
M85-125	B	3.6	1.8	300	Influent						
					Screen				662	168	305
					Centrate				372	151	52
					UV No. 4				112	110	55
					Cat. Col				68	89	52
M85-126	A	3.6	1.8	300	Influent				1,468	456	559
					Screen						
					Centrate				686	206	140
					UV No. 4				258	196	53
					Cat. Col				124	Nil	45

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*Catalyst column effluent passed through second centrifuge.

**Dark reactor effluent passed through second centrifuge.

***Recycle loop passed through second centrifuge.

3.3.4 Integrated Systems Performance with Thiokol Catalyst Reactor

Due to the problems associated with the addition of extra UV cells to the Navy system, Thiokol conducted a parallel program to evaluate the performance of a newly developed catalyst system as a candidate replacement for the UV cells in the integrated system design. The catalyst reactor subsystem performance was discussed in Section 3.3.2.5. The purpose of testing review in this section of the report was to verify performance of the catalyst integrated with other full scale Navy subsystems.

A catalytic secondary system was constructed capable of processing 1.8 gpm of clarified sewage. Five 500 sq in. PEPCON cells were arranged in series with four 100 lb catalyst columns. A heat exchanger was added for temperature control. A current concentration of approximately 200 amp-min/gal* and a catalyst weight/flow rate ratio of 60 to 70 lb-min/gal were used per stage. Several test runs were conducted with this system for evaluation. The results of these tests are outlined in Table XIX. No problems were encountered during the tests. Suspended solids and BOD reductions obtained were generally within the desired effluent standards.

The prototype Navy waste treatment system containing catalyst columns to replace the UV cells produced an effluent with an average suspended solids of 39 mg/l and BOD of 52.5 mg/l for six runs. This compared to an average suspended solids of 57.5 mg/l and BOD of 142 mg/l for four PEPCON/UV runs.

It is recommended that the catalyst treatment system be selected for the Phase II Navy system due to better performance with a smaller number of cells at greatly reduced electrical power. The design recommended in Figure 58 also incorporates a final catalyst polishing column. This will reduce effluent hypochlorite concentration from around 200 mg/l to less than 50 mg/l. The catalyst column will also reduce effluent BOD by 5 to 10 mg per liter.

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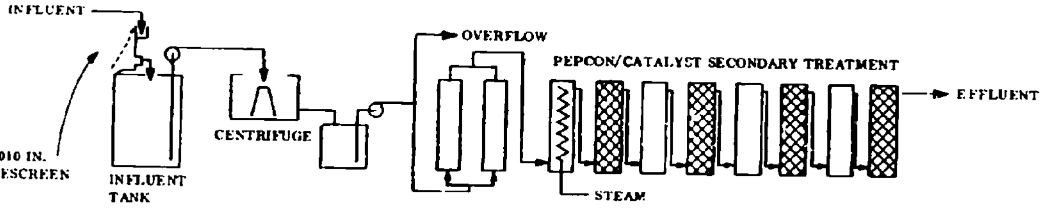
*A current concentration of 400 amp-min/gal was used in stage one to compensate for the high initial chlorine demand as in the PEPCON/UV system.

TABLE XIX

CATALYTIC WASTE TREATMENT SYSTEM EVALUATION AT 130°F



Sewage Batch	Test	Primary Flow (gpm)	Secondary Flow (gpm)	PEPCON Current (amp)	Suspended Solids (mg/l)				COD (mg/l)				BOD (mg/l)			
					Influent	Prescreen	Centrifuge	Effluent	Influent	Prescreen	Centrifuge	Effluent	Influent	Prescreen	Centrifuge	Effluent
M85-129	B	3.0	1.5	1,500	886	307	88	38	1,252	742	648	86	344	232	29[illegible]	57
M85-130	A	3.6	1.8	1,500	1,330	192	59	24	1,344	762	662	48	278	206	24[illegible]	47
M85-131	A	3.6	1.8	1,500	184	114	82	41	676	534	471	74	150	150	17[illegible]	42
M85-131	B	3.6	1.8	1,500	184	138	92	62	676	580	509	148	150	174	13[illegible]	56
M85-133	B	3.6	1.8	1,500	378	194	87	47	978	—	—	148	178	--	16[illegible]	44
M85-134	A	2.0	1.0	1,000	485	214	62	24	1,467	—	603	52	490	--	27[illegible]	69

3.3.5 Phase II Design Performance Verification

The Phase I feasibility and demonstration tests with the UV photochemical and chemical catalyst systems were conducted in a stagewise, series configuration. While this type system is adequate for system performance analysis, it is not necessarily the optimum configuration for shipboard installation. Several problems are inherent with a series system.

1. Maintenance work required on an individual component would require total system shutdown.
2. The comparatively low flow rates involved in the series system facilitate residue buildup on the PEPCON cathode and in the catalyst columns and UV cells.
3. Degassing of the process liquid would be required in each stage.
4. The high temperature operation of the PEPCON cells result in reduced operation efficiency.

The disadvantages of a series process may be resolved by a revision in process flow incorporating a high rate recycle secondary treatment system as shown in Figure 54. The PEPCON electrolytic cells, chemical catalyst columns or UV photochemical cells are arranged in parallel flow.

This system balances the rate of sodium hypochlorite generation in the PEPCON cells with the rate of decomposition in the catalyst columns or UV cells such that a low equilibrium concentration is achieved in the two recycle tanks. A small catalyst column or UV cell on the effluent line removes residual hypochlorite from the discharge. The average consumption of hypochlorite per gallon of process liquid discharged is sufficient for adequate BOD removal. Heat is added to the catalyst system or removed in the UV system by an inline heat exchanger. The electrolytic cells operate at a reduced temperature the case of the catalyst system by exchanging heat between catalyst influent and effluent streams. The advantages of this type system over a series arrangement are listed below.

1. Individual components, by valving, may be removed for servicing without system shutdown. Stand by units are also easily placed on stream in a parallel flow arrangement.

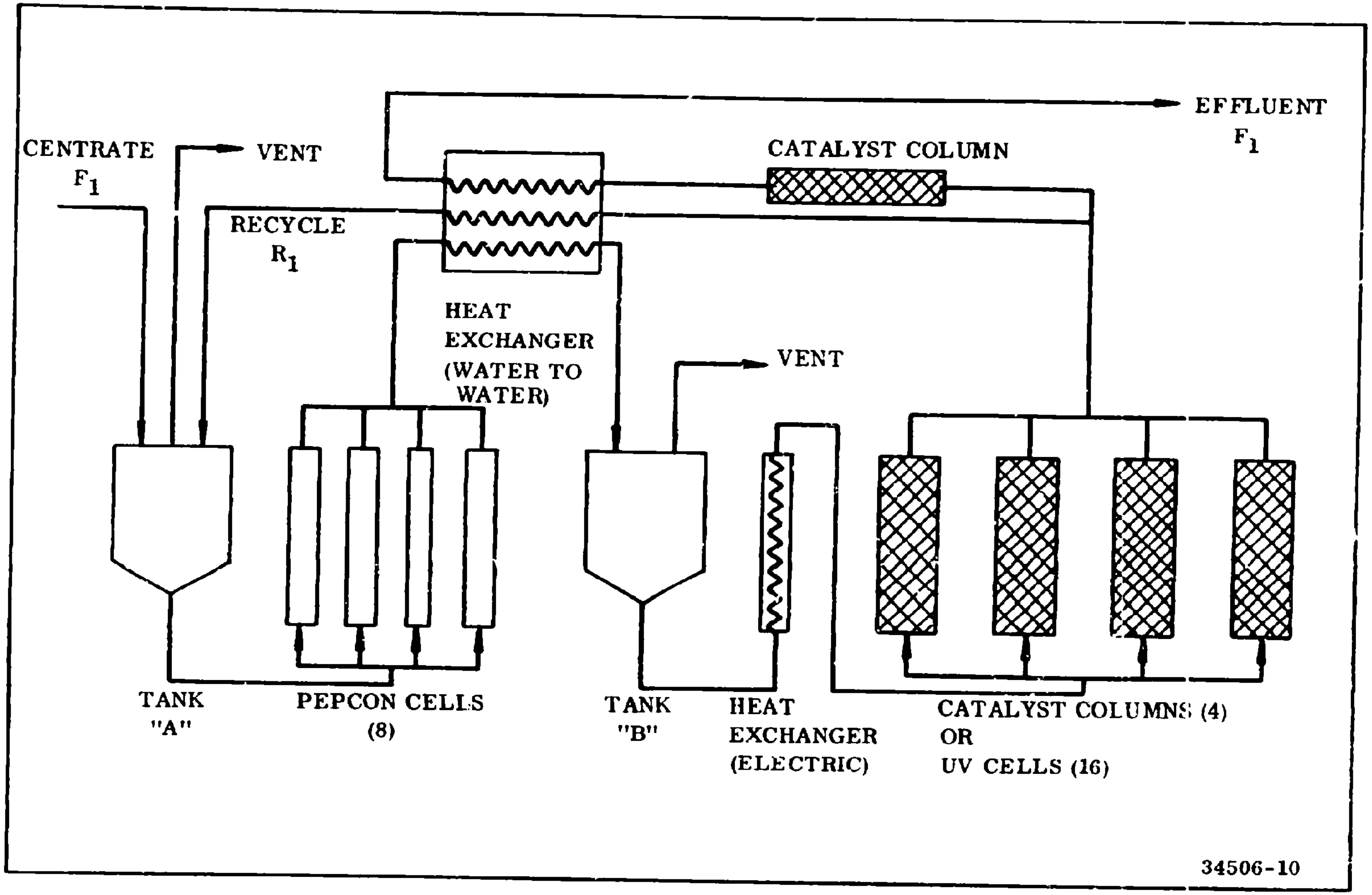


Figure 54. Recommended Phase II Process Flow Secondary Treatment

2. Higher velocities in the recycle system retard deposit buildup on the PEPCON cathode and in the partially fluidized catalytic bed.

3. Thermal isolation of the PEPCON cells provide more efficient operation at a reduced temperature.

4. The process liquid is degassed at two locations, hydrogen from tank "B" and oxygen and oxidation products from tank "A."

Several test runs were conducted with the recycle type secondary treatment system using both the catalyst and the UV photochemical cells. The test results from these runs are presented in Table XX. Effluent suspended solids and BOD values are generally in line with effluent requirements.

Additional problems are inherent with use of the UV photochemical cells, however, regardless of the process flow.

1. High power requirements.

2. High voltages.

3. Ultraviolet radiation leakage.

4. Potential breakage of components, quartz tube, lamp, etc.

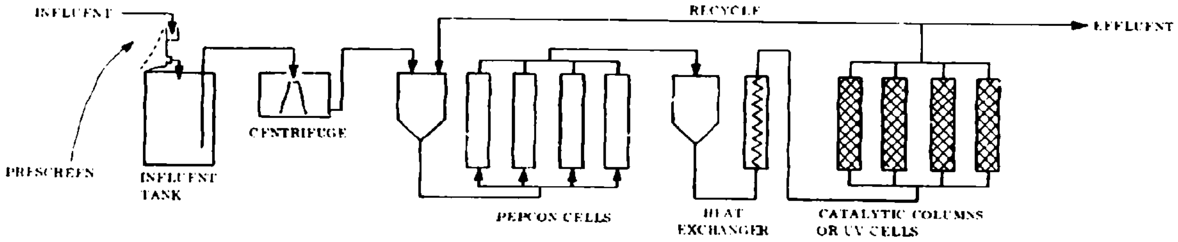
5. Potential coating of quartz tube with contaminants.

The use of a chemical catalyst system eliminates those problems associated with the UV photochemical system and accomplishes the same basic function. The chemical catalyst system is, therefore, much better suited for shipboard application.

The process flow recommended for Phase II evaluation involves a high rate recycle secondary treatment system with PEPCON electrolytic cells and chemical catalyst columns arranged in parallel flow as shown in Figure 54. The following process parameters have been defined for system performance based on test results to date.

TABLE XX

CATALYST AND UV TEST RESULTS



Sewage Batch	Test	Temp (°F)	Flow Thru Rate (gpm)	Recycle Flow (gpm)	PEPCON Current (amp)	Suspended Solids (mg/l)				COD (mg/l)			BOD (mg/l)			NaClO (ppm)	
						Influent	Prescreen	Centrifuge	Effluent	Influent	Prescreen	Centrifuge	Influent	Centrifuge	Effluent	PEPCON	Catalytic Column/UV
Chemical Catalyst System																	
MS5-110	A	130	1.5	20	1,500	400	215	155	63	1,120	890	690	288	218	65	625	390
MS5-111	A	130	1.0	20	1,000	222	138	104	63	681	576	461	169	199	52	540	280
MS5-113	A	100	1.0	20	1,000	415	259	100	25	840	560	425	304	514	59	888	610
UV Photochemical System																	
MS5-115	A	[illegible]	1.0	20	1,000	390	322	99	73	1,374	1,249	1,650	294	204	47	1,300	1,100

Parameter	Definition	Value
Current Concentration	$\frac{\text{PEPCON Current}}{\text{Flow thru Rate}}$	1,000 $\frac{\text{Amp-Min}}{\text{Gal}}$
Catalyst Requirement	$\frac{\text{Catalyst Weight}}{\text{Flow thru Rate}}$	225 to 300 $\frac{\text{Lb-Min}}{\text{Gal}}$
Catalyst Operating Temperature	--	125° to 135°F
Recycle Ratio	$\frac{\text{Recycle Flow}}{\text{Flow thru Rate}}$	10 to 20

For a 3.6 gpm average flow rate, the secondary system would consist of eight 500 sq in. PEPCON cells operating at a current density of 0.9 amps/sq in. (3,600 amps) and four 200 lb catalyst columns (800 lb total). An additional small catalyst column will be added to the effluent stream for residual hypochlorite stripping prior to discharge.

3.4 Reliability and Maintainability

During Phase I of the Navy Waste Treatment Program, the Reliability and Maintainability (R & M) effort described in the R & M Program Plan was accomplished as follows.

1. A 13 page designer's checklist was prepared and distributed to design personnel within the first few days of the program to assure that R & M goals and concepts were incorporated in the conceptual phase of the design effort. Copies were submitted to the Navy.

2. R & M engineers attended a conceptual design review meeting held 7 Jun 1971 to follow up the initial checklist effort and make recommendations as deemed necessary to assure that R & M demonstration requirements would ultimately be met. Copies of the minutes of this meeting were submitted to the Navy.

3. R & M engineers participated in a preliminary design review meeting held at Thiokol 11-13 Jul 1971 and again made recommendations for incorporation of R & M concepts and designs to assure that the R & M goals published in the proposal would be met. Copies of the minutes of this meeting including comments by R & M engineers were submitted to the Navy.

4. A preliminary R & M Program Plan was prepared and submitted to the Navy on 25 Aug 1971 in accordance with Sequence No. A001H of the contract data requirements list.

5. R & M engineers observed the development effort by periodically visiting the waste treatment facility to ascertain problem areas and to follow up the R & M effort previously performed. Based on information obtained, a preliminary failure modes and effects analysis was completed for the initial baseline system. This analysis will be updated and become the starting point for the maintenance engineering analysis to be initiated during Phase II. Copies will be transmitted to the Navy in accordance with the approved contract data requirements list during Phase II.

6. Meetings were held with Thiokol subcontractors Gibbs and Cox, DeLaval, and Pacific Engineering and Production Co of Nevada to determine what R & M recommendations they considered important to the system. These suggestions will

be used as applicable to the overall R & M objectives for the system.

7. Reliability goals were established and included in the R & M program plan. There is not enough test data available to date to assess the demonstrated R & M for comparison to the established goals. However, problem areas have been isolated and recommendations made for continued development effort during Phase II. The findings of the R & M engineers generally agree with recommendations and comments made throughout this report.

Many of the R & M features planned for the final system were not incorporated into the Phase I baseline system since they are planned for Phase II and III. Nevertheless, all salient R & M features deemed essential for the system are being evaluated and will be available for incorporation into the final system.

3.5 Analytical Methods Waste Water Analysis

The standard test methods used for sewage and waste water analysis were found to be inaccurate in testing effluents from the waste treatment system. The three major differences from normal sewage were (1) sea water or brackish water salt content, (2) high concentrations (200-2,000 ppm) of sodium hypochlorite and (3) chlorate ion concentrations up to 1,000 ppm from hypochlorite rearrangement.

The effects of these conditions on each of the standard tests, suspended solids, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) are discussed below.

3.5.1 Suspended Solids

The suspended solids proceedure described in the Standards Methods for Water Analysis, 12th Edition, page 424, is not suitable for analyzing solids in sea water. No provision is made to wash the salt out of the mat. A study disclosed that to successfully process suspended solids the proceedure would have to be changed. Table XXI indicates the difference found when the salt is washed out of the mat.

TABLE XXI

WATER WASHING OF SUSPENDED SOLIDS MAT

Sample	Method (no water wash) mg/l	Water Washing (2,100 ml H_2O) mg/l
M-85-071E8	420	190
M-85-071F9	440	220
M-85-071G10	390	215
M-85-071K14	325	150
M-85-071M19	590	185
M-85-071P28	355	145

3.5.1.1 Suspended Solids Determination Procedure

A Thiokol Development Analytical Procedure 0090 was written and established as the standard for suspended solids determination. The procedure incorporates the glass filter mat specified in the 13th Edition of Standard Methods No. 224C, page 537. The mat used is a gelman Type A.

DEVELOPMENT ANALYTICAL PROCEDURE 0090

Determination of Suspended Solids in Sewage Samples

1.0 TEST DESCRIPTION

A sample is filtered with a glass fiber filter disc. This is washed with water. The disc is then dried and weighed. The suspended solids are then calculated.

2.0 APPARATUS

2.1 Glass fiber filter discs 4.7 cm, without organic binder, Gelman Type A, or equivalent.

2.2 Filter holder, membrane filter funnel, millipore or equivalent

2.3 Suction flask, 500 ml

2.4 Drying oven, 103-105°C

2.5 Dessicator

2.6 Analytical balance, 200 g capacity, capable of weighing to 0.1 mg.

3.0 PROCEDURE

3.1 Preparation of glass filter disc: Place the disc on the membrane filter apparatus. While vacuum is applied, wash the disc with three successive 20 ml volumes of distilled water. Remove all traces of water by continuing to apply vacuum after water has passed through. Remove filter from membrane filter apparatus, and dry in oven at 103-105°C for two hours. (Put filter in Al dish, planchet on other suitable container to dry.) Remove to dessicator cool and weigh. Repeat heating to constant weight. When constant weight is obtained store in petri dish until needed.

3.2 Place the tared disc in the filtering apparatus, assemble and begin suction. Shake the sample vigorously and rapidly transfer 100 ml to funnel by means of a 100 ml volumetric cylinder. If suspended matter is low, a larger volume may be filtered. (If solids are so high filter is plugged a smaller volume may be used).

3.3 Wash the sample with distilled water using a minimum of 100 ml.

3.4 Carefully remove the filter from the membrane filter funnel assembly. Place in drying oven and dry at 103-105°C to constant weight.

4.0 CALCULATIONS

4.1 Calculate the suspended solids as follows:

$$\text{Suspended Solids mg/l} = \frac{(A - B) \times 1000}{\text{ml of sample filtered}}$$

A = Wt. of filter and residue

B = Wt. of filter

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3.5.2 Chemical Oxygen Demand

Sodium chloride was found to have a definite effect on the COD analysis. The Standard Methods Procedure(1) calls for an addition of mercuric sulfate to the sample to tie up the chloride as slightly soluble mercuric chloride. This works well with low chloride samples but not when chloride is in the range of 1 to 3 percent.

Three sewage samples were prepared. One sample was as received, one had 1 percent NaCl added and the other had 3 percent NaCl added. The COD on these samples were determined three different ways.

1. Regular method.
2. Ag_2SO_4 was added to precipitate the chloride as silver chloride and then COD determined as usual.
3. Same as Method No. 2 except the silver chloride was filtered out.

The results of this study are shown in Table XXII. It can be seen that both attempts to remove chloride by percipitation failed. The table also shows that the COD results are higher when the chloride content is above 1 percent. The chloride ion causes high COD results by the following reaction.

$$6Cl^{-} + C_{r_2}O_7^{=} + 14H^{+} \longrightarrow 3Cl_2 + 2C_{r}^{+++} + 7H_2O$$

TABLE XXII

DETERMINATION OF COD
(mg/l)

	1 Centrate	2 Centrate 1% NaCl	3 Centrate 3% NaCl
Standard Procedure	140	158	244
Cl precipitated with Ag then COD run	170	275	214
Cl precipitated with AG then filtered COD run	--	Nil*	Nil*

---

(1) "Standard Methods for Examination of Water and Waste Water," 12th Edition, Amer. Pub. Health Assn., New York, 1965, p 510.

*Filtering may have removed organic.

Cripps and Jenkins(2) and Burns and Marshall(3) have written reports where a correction factor is applied to the final calculation. These methods are applicable up to 3.5 percent NaCl concentrations. Both methods are processed the same but the chloride correction is different. After experimenting it was determined that the method described by Burns and Marshall was the best for our use.

In this method solutions of distilled water containing known amounts of NaCl are prepared and the COD is determined on each of these solutions. A curve then is prepared on logarithmic paper of COD vs percent NaCl in solutions. From this curve a correction is obtained for use in calculation of the COD in the sample. A Development Analytical Procedure 0084 has been written to define the procedure for laboratory use.

Three samples of sewage were obtained, NaCl was added to each of these samples and the COD determined by this DAP. The results are recorded in Table XXIII. It can be noted that the COD results are approximately the same up to 3.5 percent NaCl. The slight difference is no more than the precision of the method.

Sample M-85-018A (which contained 1 percent NaCl) was tested by the new method as written in the DAP and the old method as written in the Standard Procedure. A special effort was made to add a 10:1 ratio of mercuric sulfate to sodium chloride present. The results are recorded in Table XXIV. The results are approximately the same by either method. The new method takes about one hour longer. It is recommended that for samples of 1 percent NaCl and below the present method be used. The new procedure should be used for all samples when NaCl is greater than 1 percent.

The high concentrations of NaClO used in the waste treatment to oxidize the organic materials also produce sodium chlorate through the following reactions.

$$3\,NaClO \longrightarrow NaClO_3 + 2\,NaCl$$

The presence of the chlorate in the sample causes a significant depression of the COD values. The data presented in Table XXV and Figures 55 and 56 show that the correction is not linear and is dependent upon both the $NaClO_3$ and the COD concentration.

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(2) Cripps, J. M. and Jenkins, D., "A COD Method Suitable for Analysis of Highly Saline Waters," Journal of WPCF 10, 1240, October 1964.

(3) Burns, E. R. and Marshall, C., "Correction for Chloride Interference in COD Test," Journal of WPCF 12, 1716, December 1965.

A statistical study of the data resulted in the following equation.

$$\text{A COD} = \frac{M_{\text{COD}} + 1.084\sqrt{\text{NaClO}_3} + 7.125}{1.0675 - 0.01202\sqrt{\text{NaClO}_3}}$$

This equation corrects for the nonlinearity of the $NaClO_3$ effect and the interaction of the $NaClO_3$ concentration with the COD concentration. It was based on 47 degrees of freedom and correlates at a $R^2 = 0.9970$ level with a Sy, x, x_2 = 17.1 mg/l actual COD.

3.5.2.1 COD Determination Procedure

The development analytical procedure used to determine the amount of COD in highly saline water is included as follows.

DEVELOPMENT ANALYTICAL PROCEDURE 0084 - REV. A

Determination of COD in Highly Saline Waters

1.0 TEST DESCRIPTION

A sample of sewage is put into a flask. A measured amount of standard potassium dichromate is added with sulfuric acid. This solution is boiled to oxidize the organics. The excess potassium dichromate is back titrated with standard ferrous ammonium sulfate solution. The COD is calculated from amount of potassium dichromate used in the reaction. A correction is made for sodium chloride in the sample.

2.0 APPARATUS

2.1 500 ml Erlenmeyer flask with ground-glass neck, or equivalent.

2.2 Friedrichs condenser at least 6 inches long. A Grahm condenser at least 300 mm long may be used.

2.3 Hot plate

3.0 REAGENTS

3.1 Standard potassium dichromate solution, 0.25 N
Dry primary standard grade $K_2Cr_2O_7$ at 105°C for 2 hours and dissolve 12.259 g in distilled water and dilute to 1 liter.

3.2 Sulfuric Acid reagent concentrated H_2SO_4 containing 30 g silver sulfate (Ag_2SO_4) per 9 lb. bottle (1 to 2 days required for dissolution).

3.3 Ferrous ammonium sulfate solution dissolve 98 g $Fe(NH_4)_2\ (SO_4)_2 \cdot 6H_2O$ in distilled water, add 20 ml concentrated H_2SO_4, cool and dilute to 1 liter. This solution will be about 0.25 N but must be standardized against $K_2Cr_2O_7$ daily. Standardization: Dilute 25.0 ml standard dichromate solution to about 250 ml. Add 20 ml concentration H_2SO_4 and allow to cool. Titrate with the ferrous ammonium sulfate using 2 or 3 drops of ferroin indicator.

3.4 Ferroin indicator solution dissolve 1.485 g 1, 10 phenanthroline monohydrate and 0.695 g $FeSO_4 \cdot 7H_2O$ in distilled water and dilute to 100 ml. Equivalent Fisher, Ferroin Cat. P-69.

3.5 Mercuric Sulfate, reagent grade

3.6 Isopropanol

4.0 PREPARATION OF COD DUE TO CHLORIDE CURVE

4.1 Prepare solutions of distilled water and sodium chloride to contain the following:

0.01, 0.05, 0.1, 0.5, 1, 2, and 3% NaCl.

4.2 Place 4 to 6 glass beads in a 500 ml Erlenmeyers flask and add 50 ml of one of the above NaCl solutions to each one.

4.3 Slowly add solid $HgSO_4$ to each sample in the ratio of 10 mg to each mg of Cl^- present in the aliquot. (Note it is important that there be at least a 10:1 ratio of $HgSO_4$ to Cl^-).

4.4 Cool the flask in a bath consisting of dry ice and isopropanol. Then add 75 ml of H_2SO_4 reagent. This addition should be made slowly so the sample does not warm up.

4.5 Add 25.0 ml of 0.25 N $K_2Cr_2O_7$ solution mix and attach to a clean condenser. Reflux on a hot plate for two hours. Cool and then wash down the condenser with approximately 25 ml of distilled water.

4.6 Remove from condenser and dilute the mixture to approximately 350 ml and cool to room temperature. Titrate the excess dichromate with standard ferrous ammonium sulfate using 2 to 3 drops of ferroin indicator. The color change is sharp, going from green of chromic ion to red coloration.

4.7 Run blank using distilled water through all steps.

4.8 Calculate mg COD per liter as follows:

$$\frac{(A - B)\ N \times 8000}{\text{ml sample}}$$

A = ml $Fe(NH_4)_2\ (SO_4)_2$ used for blank

B = ml $Fe(NH_4)_2\ (SO_4)_2$ used for sample

N = normality of $Fe(NH_4)_2\ (SO_4)_2$

4.9 From COD determined prepare a curve on logarithmic paper COD versus % NaCl in sample.

5.0 DETERMINATION OF COD IN SEWAGE SAMPLE

5.1 Transfer sewage sample to Waring Blender and turn on and stir for 1 minute. Immediately after stirring obtain a 50.0 ml aliquot and transfer this to 500 ml Erlenmeyers.

5.2 Add glass beads to Erlenmeyer flask and repeat steps 4.2 through 4.7.

6.0 CALCULATION OF COD IN SAMPLE

6.1 For samples containing 50 ml of original sample

$$\text{COD mg/l} = \left[\frac{(A - B)\ N \times 8000}{50} - D\right] \times 1.20$$

A = ml $Fe(NH_4)_2\ (SO_4)_2$ for blank

B = ml $Fe(NH_4)_2\ (SO_4)_2$ for sample

N = normality of $Fe(NH_4)_2\ (SO_4)_2$

D = chloride correction from graph

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TABLE XXIII

DETERMINATION OF COD WHEN NaCl IS ADDED

	COD mg/l					
% NaCl Added	0	1	1.5	2	3	3.5
Sample I	135	145	--	--	167	--
Sample II	--	1,064	1,043	1,064	1,056	1,064
Sample III	443	428	450	432	439	--

TABLE XXIV

DETERMINATION OF COD IN SAMPLES CONTAINING 1 PERCENT NaCl

Sample ID M-85-018A	Centrate	PEPCON Run No. 1	2	3	4	No. 1	No. 2	No. 3	No. 4
Standard Procedure, Old Method	635	391	164	417	341	391	374	480	500
DAP, New Method	665	392	162	434	328	385	372	481	432

TABLE XXV

SECOND MATRIX TEST RESULTS
(Measured mg/l COD Shown in Matrix)

$NaClO_3$ (mg/l)	COD Added (mg/l)		
	100	300	500
100	75	260	459
	80	268	474
200	63	205	426
500	37	192	338
	--	183	--
1,000	3	133	286
1,500	Nil	96	240

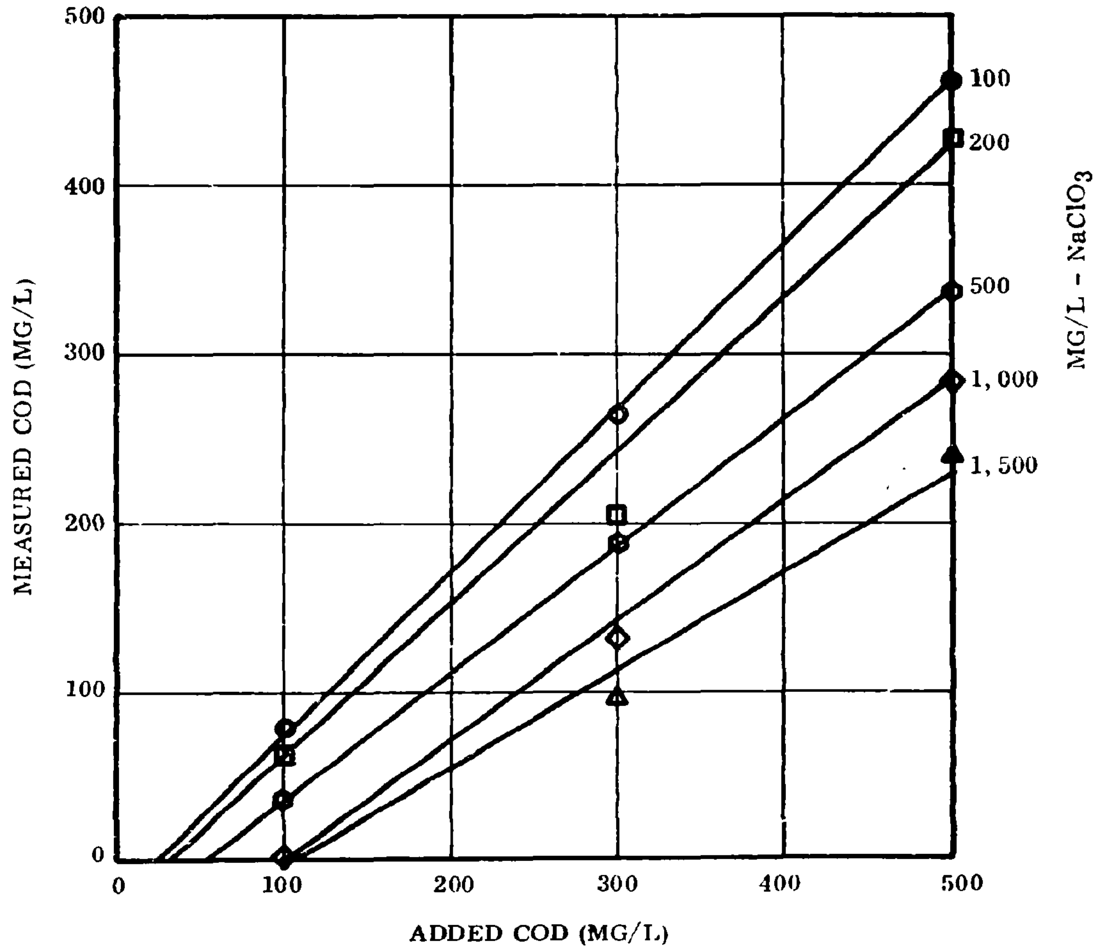

Figure 55. The Effect of Chlorate on COD Values

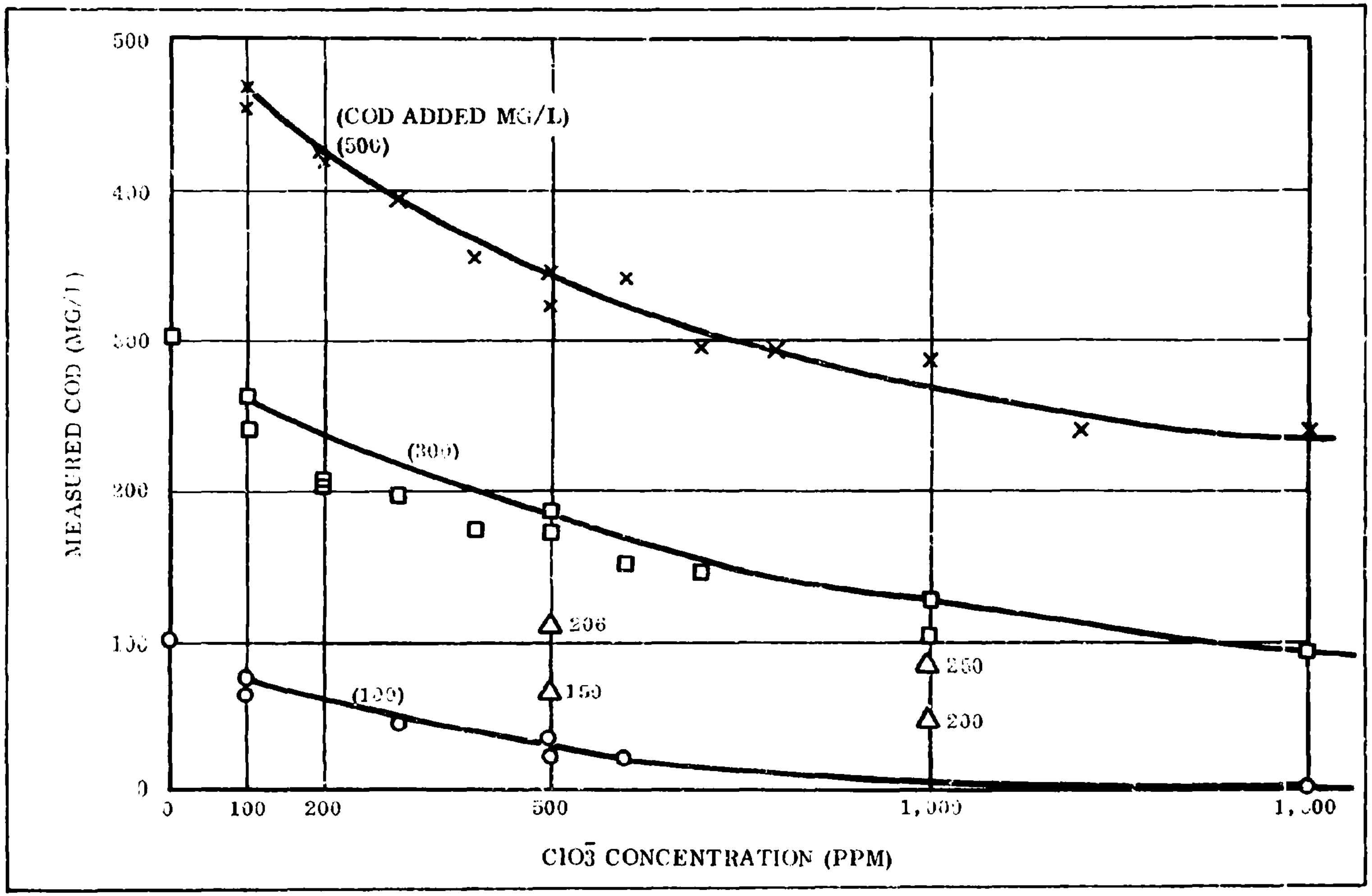

Figure 56. The Effect of Chlorate on COD Values

3.5.3 Biochemical Oxygen Demand

The presence of chlorates has an adverse effect on BOD analyses. However, concentrations of less than 100 ppm exert no observable influence. Since the dilution of samples for BOD reduces the actual chlorate concentration in the sample to well below 100 ppm, there is no measurable effect on our analysis. Figure 57 indicates the straight line relationship and no correction up to 100 ppm chlorate.

3.5.4 Determination of Sodium Chlorate

The method for determination of sodium chlorate received from Pacific Engineering was adapted to use for analysis of sewage samples. The procedure was written as Development Analytical Procedure 0094. Synthetic samples were prepared and tested by this procedure. The results shown in Table XXVI show the procedure to be very good.

3.5.4.1 Sodium Chlorate Determination Procedure

The development analytical procedure used to determine the amount of sodium chlorate in sewage samples is included as follows.

DEVELOPMENT ANALYTICAL PROCEDURE 0094

Determination of Sodium Chlorate in Sewage Samples

1.0 TEST DESCRIPTION

The sample is boiled with a known amount of ferrous sulfate solution to reduce the chlorate and hypochlorite. The excess ferrous sulfate is titrated with permanganate. The hypochlorite is determined on another aliquot by adding potassium iodide. The following reaction will not destroy chlorate at a pH of 4.

$$2I^- + ClO + H^+ \rightarrow I_2 + Cl^- + OH^-$$

The amount of iodine formed is titrated with sodium thiosulfate.

The grams per liter sodium chlorate is then calculated from these titrations.

2.0 REAGENTS

2.1 Ferrous sulfate, solution, weigh 7 g of reagent grade ferrous sulfate ($FeSO_4 \cdot 7H_2O$) into a 250 ml beaker. Add approximately 100 ml of H_2O and 10 ml of concentrated H_2SO_4. When the ferrous sulfate is dissolved, transfer quantitatively into a 1000 ml volumetric flask and dilute to volume with distilled water. Protect against air oxidation.

2.2 Mixed acid, to approximately 500 ml of water carefully add 150 ml concentrate sulfuric acid and 100 ml of phosphoric acid. Dilute to 1 liter with distilled water.

2.3 Potassium permanganate 0.1 N. Dissolve 3.2 g of reagent grade potassium permanganate ($KMnO_4$) in one liter of water heat the solution to boiling, and keep slightly below the boiling point for an hour. Filter the liquid through a sintered glass filter crucible. Transfer filtrate to a clean dark bottle and label. This solution should be standardized regularly as follows:

> Weigh 0.25 To 0.30 g of pure sodium oxalate (dried at 105°-110°) into a 250 ml Erlenmeyer flask, dissolve in 60 ml of water, add 15 ml of 1:8 sulfuric acid, heat to 80°-90° and titrate slowly with permanganate to the first permanent pink tinge. The temperature of the solution should be above 60° at the end point. Calculate the normality of permanganate as follows:

$$N = \frac{\text{Wt } Na_2Cr_2O_4}{\text{ml } KMnO_4 \times 0.067}$$

2.4 Potassium iode (KI)

2.5 Sodium acetate, acetic acid buffer solution pH4, dissolve 243 g of sodium acetate trihydrate ($NaC_2H_3 \cdot 3H_2O$) and 480 g glacial acetic acid in 400 ml distilled water and dilute to 1 liter.

2.6 Sodium thiosulfate solution 0.1N. Dissolve in 1 liter of distilled water 25 g of $Na_2S_2O_3 \cdot 5H_2O$ and add 0.1 g of sodium carbonate to the solution. Allow the solution to stand for a day before standardizing. This may be standardized by any approved method. The following is one method.

> Weigh out 0.2 g of primary standard potassium dichromate ($K_2Cr_2O_7$) and dissolve in 50 ml of water. Add 2 g of potassium iodide (KI) and 8 ml of concentrated hydrochloric acid. Mix thoroughly and titrate with thiosulfate. Swirling the liquid constantly until the brown color has changed to yellowish green. Add a few milliters of starch solution and continue the titration until the color changes sharply from blue to light green. Calculate normality of $Na_2S_2O_3$ as follows:

$$N = \frac{\text{Wt. } K_2Cr_2O_7}{\text{ml } Na_2S_2O_3 \times .049}$$

2.7 Starch solution 1%, mix 10 gm of soluble starch with 50 ml of water. Add this solution to 1 liter of boiling distilled water. Add 0.01 g of mercuric iodide as a perservative, and continue boiling and stirring for a few minutes. Cool to room temperature and transfer to storage bottle.

3.0 DETERMINATION OF HYPOCHLORITE

3.1 After mixing to make sure a representative sample is obtained pipette a 10 ml aliquot into a 250 ml flask. (Note the same, size aliquot should be used for chlorate determination) add 50 ml of distilled H_2O and 2 g of KI. Add 15 ml of acetic acid sodium acetate buffer and mix thoroughly.

3.2 Titrate the liberated iodine with standard sodium thiosulfate until the mixture is a straw yellow in color. Add 5 ml of starch solution and continue titrating until the dark blue color disappears.

3.3 Record titration ml of $Na_2S_2O_3$ used.

4.0 DETERMINATION OF CHLORATE

4.1 After mixing to make sure a representative sample is obtained pipette a 10 ml aliquot into a 250 ml flask filtered with a ground glass stopper. (Note the same size aliquot should be used for the hypochlorite determination) add approximately 75 ml of H_2O.

4.2 Add 75 ml of Fe_2SO_4 solution using a pipette or burret. Add 10 ml of mixed acid solution.

4.3 Add a few glass beads and boil for 5 minutes. Stopper and cool to room temperature.

4.4 Titrate with 0.1 N $KMnO_4$ to the first permanent faint pink end point. Record ml of $KMnO_4$ used.

4.5 Run at least two blanks starting with step 4.2.

5.0 CALCULATION

$$\text{mg/l } NaClO_3 = \frac{\left\{\left[(B - S)\ N\right] - (A \times C)\right\} \times 17.74}{\text{ml of sample}}$$

where

B = ml of $KMnO_4$ used in blank

S = ml of $KMnO_4$ used in sample.

N = Normality of $KMnO_4$

A = ml of $Na_2S_2O_3$

C = Normality of $Na_2S_2O_3$

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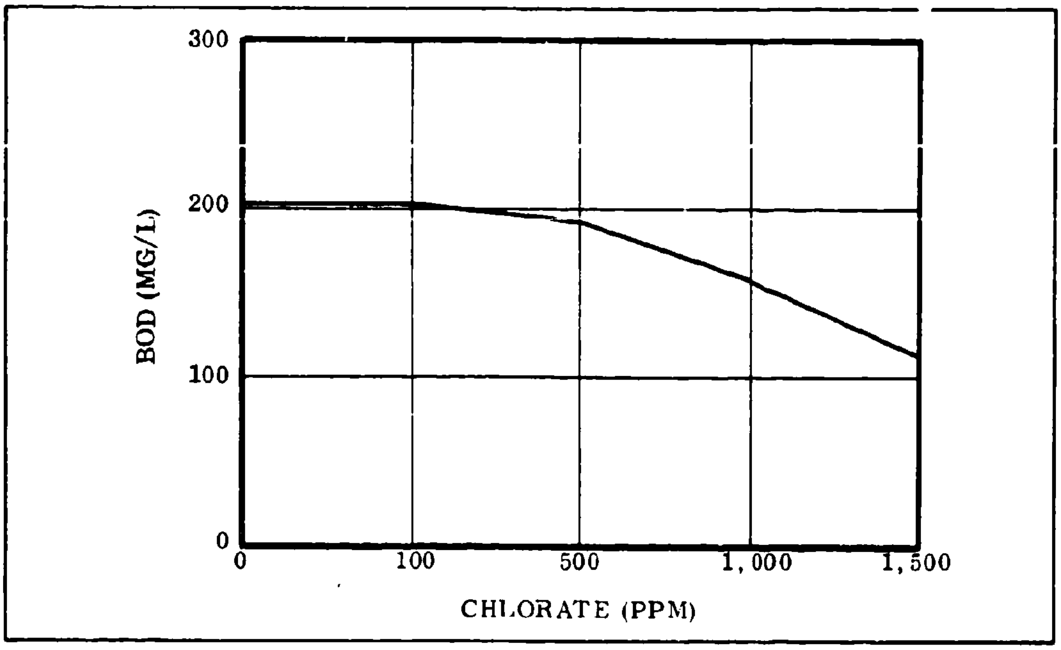

Figure 57. Effect of Chlorate on BOD (Potassium Chlorate)

TABLE XXVI

DETERMINATION OF CHLORATE IN SYNTHETIC SAMPLES

Description of Sample	Total g $KClO_3$ Found	g $KClO_3$ Found in NaOCl	Total $KClO_3$ Minus g $KClO_3$ in NaOCl	g $KClO_3$ Added	Difference (g)
Chlorox + $KClO_3$	0.00395	0.00197	0.00198	0.002	-.00002
Chlorox + $KClO_3$	0.01032	0.00524	0.00508	0.005	+.00008
Centrate + $KClO_3$	0.00968	-	0.00968	0.01	-.00032
Centrate + $KClO_3$	0.00943	-	0.00943	0.01	-.00057
Centrate + $KClO_3$	0.00978	-	0.00978	0.01	-.00022
Centrate + $KClO_3$ + NaOCl	0.0185	0.0063	0.0122	0.01	+.0022
Centrate + $KClO_3$ + NaOCl	0.0226	0.0143	0.0083	0.01	-.0017
Centrate + $KClO_3$ + NaOCl	0.01498	0.00584	0.00914	0.01	-.00086
$KClO_3$ + NaCl	0.00972	-	0.00972	0.01	-.00028
$KClO_3$ + NaCl + NaOCl	0.01524	-	0.01008	0.01	+.00008

3.5.5 Analytical Confidence Studies

3.5.5.1 Navy Sample Exchange

Four sewage samples were exchanged with the Navy Laboratory for analysis. The results of these analyses are recorded in Table XXVII.

It can be noted that the results are very favorable. The only difference in results are in the COD determination. This can be explained due to the fact that the Navy did not use the chloride correction in the COD analysis since they diluted the sample to where the interference would be negligible.

3.5.5.2 Utah State University

Sewage samples were sent to the Water Laboratory of the Utah State University. The data in Table XXVIII shows the relationship of Thiokol data for BOD and COD with the Utah State data for TOC and BOD. The BOD samples were not analyzed until after three additional days. The OCT present had continued to react and produced low results.

3.5.5.3 MRI Exchange

Two samples of sewage were frozen. One of these samples was packed in dry ice and shipped to MRI. Both samples were thawed out and tested the same day by Thiokol and MRI. The COD results are listed below.

	COD (mg/l)	
	Thiokol	MRI
Sample M-85-054	719	683

TABLE XXVII

THIOKOL VS NAVY RESULTS
(mg/l)

		Influent	Centrate	P-2	P-6
COD Wet Method	Thiokol	790	551	242	Nil
	Navy	900	495	340	135
COD AquaRator	Thiokol	--	--	--	--
	Navy	920	480	180	<50
BOD	Thiokol	250	145	55	30
	Navy	340	230	100	35
Suspended Solids	Thiokol	396	146	141	52
	Navy	459	172	180	80

TABLE XXVIII

DATA OF TOC TESTS

Sample Number	BOD (mg/l)	COD (mg/l)	TOC (mg/l)	COD/TOC Ratio	BOD/TOC Ratio	USU/BOD (mg/l)
M-85-118-A1 Influent	298	842	115	7.32	2.59	--
M-85-118-A2 Centrate	288	540	97	5.57	2.97	234*
M-85-118-A-11 UV #4	193	235	70	3.38	2.78	48*
M-85-118-A-13 Cat. Col.	114	80	50	1.62	2.3	48*
M-85-113 #4	--	386	107	3.61	--	--
M-85-114-A-3	97	398	147	2.71	0.66	--
M-85-115-A-11	238	443	93	4.76	2.56	--

---

*Tested 3 days after Thiokol tests were completed.

4.0 PHASE II RECOMMENDATION

4.1 Phase II Design

The Phase I program has resulted in extensive testing of marine waste treatment components and subsystems as well as demonstration of total system performance using various combinations of components and subsystems. After careful review and evaluation of all component, subsystem, and total system data, a recommended design configuration has been selected for the Phase II system to be demonstrated and delivered to the Navy for shore testing. The recommended system is shown schematically on Figure 58. The basic Phase II system utilizes a pretreatment system comprised of a hydrasieve prescreening device, a macerator pump to grind screened sludge which is then pumped to the incinerator using a demonstrated pump, a primary treatment system comprised of a centrifuge for further solids removal, and a secondary treatment system employing a PEPCON cell, catalytic column loop for removal of dissolved solids. The catalytic system was selected over the ultraviolet system on the basis of its simpler more reliable configuration. Both the catalyst and ultraviolet systems were found to yield satisfactory BOD and suspended solids removal.

The recommended design is based on the use of demonstrated components and subsystems. It is anticipated that the major Phase II effort will involve evaluation scale effects on some of the components and evaluation of piping modifications to yield the most efficient performance and packaging. The subsequent sections describe the major subsystems in detail and the considerations leading to the selection of the subsystem.

4.1.1 Pretreatment

The Phase II pretreatment system will be comprised of a hydrasieve to prescreen influent waste material, a sludge tank to collect screenings from the hydrasieve, a primary holding tank to collect hydrasieve underflow, a pump to transfer the underflow from the holding tank to the centrifuge, a macerator pump to grind hydrasieve screenings in the sludge tank and a sludge feed pump to transfer macerated sludge to the incinerator. The above components will be arranged schematically as shown on the system schematic Figure 58.

As discussed in Section 3.3.2.1, the hydrasieve will be equipped with baffles to channel flow to the center of the screen during periods of ship rolling. In addition, screen width will be increased to further

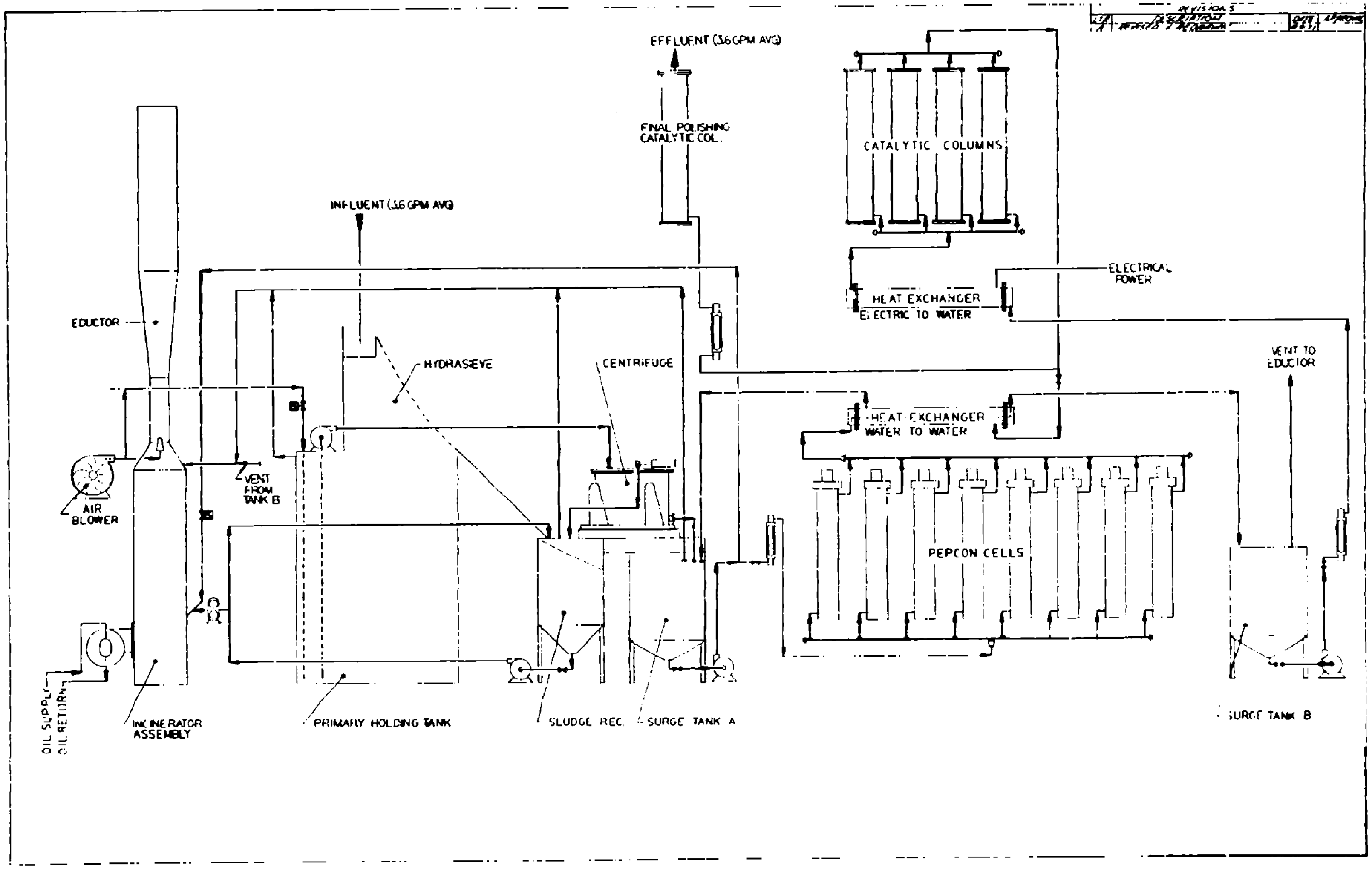

Figure 58. Schematic of Recommended System

insure proper operation during periods of dynamic motion. Also as noted in Section 3.3.2.1, the hydrasieve will be equipped with a double weir to handle hydraulic surges.

The primary holding tank size will be 300 gal providing for a 300 percent surge for a period of 40 min. Outflow from the holding tank via the transfer pump will be at the average 3.6 gpm flow condition. This pump (Model 777-F) is a bronze body, neoprene impeller, self-priming model manufactured by Jabsco Pumps of International Telephone and Telegraph Corporation.

The sludge tank has been sized for 20 gal capacity. The outlet of the sludge tank will be connected to a macerator pump which as shown on the system schematic continuously recirculates and macerates the sludge collected in the tank. Operation of the macerator pump will be sequenced by level controls in the sludge tank. A portion of the recirculated sludge will be bypassed to the incinerator using a sludge pump. Recirculation will be at a rate of 4.7 gpm and feed to the incinerator at a rate of 3.0 gph. Both the macerator pump and sludge pump were demonstrated during Phase I and are manufactured by the Moyno Pump Division of Robbins and Meyers, Inc. The sludge pump is a Moyno Model BA100-BGQ and the macerator pump a Moyno Model EWN-200.

Minor problems have been encountered with stopping and plugging of the Moyno sludge pump. During Phase II the sludge inlet section design will be modified as depicted in Figure 43 and described in Section 3.3.2. Also, a higher torque drive mechanism will be substituted for the low torque used to drive the sludge pump.

4.1.2 Primary Treatment

The primary treatment system will be comprised of a centrifuge for further removal of suspended solids from the influent, a centrifuge base, a 50 gal centrate tank to collect liquid discharge from the centrifuge and a centrate pump to discharge the liquid from the centrate tank through the secondary treatment system. The major component of this subsystem is the centrifuge which was extensively tested during Phase I. The centrifuge is a DeLaval 20 in. diameter by 14 in. high ECM clarifier. Data on the solids removal efficiency of this machine was presented in Section 3.3.2. During Phase II, tests will also be conducted on a "scaled down" version of the 20 in. diameter centrifuge. Data presented in Section 3.3.2 has shown the feasibility of using a smaller centrifuge. An available Thiokol 14 in. centrifuge will be used for the Phase II tests and a firm recommendation for the Phase III system will be made.

The centrifuge stand will be a steel weldment and the centrate pump a Jabsco Model 777F powered by a 1/4 HP electric motor. Specific shape of the centrate tank will be determined during Phase II testing.

4.1.3 Secondary Treatment

The secondary treatment system selected for Phase II utilizes electrolytic (PEPCON) cells to generate hypochlorite from the salts present in sea and brackish water and catalytic columns to catalyze the reaction of the hypochlorite with the dissolved organic material in the centrate discharged from the primary treatment system. The PEPCON cells are manufactured by Pacific Engineering and Production Co. of Nevada and have been extensively tested at Thiokol during Phase I and have been in operation for years at the manufacturer's plant. These 500 sq in. anode cells were described in Section 3.3.2. The catalyst system is a Thiokol development which was evaluated separately during Phase I to provide comparative data with the ultraviolet method of catalyzing the hypochlorite reaction. Both the Thiokol chemical catalyst and the ultraviolet systems were demonstrated during Phase I and both were shown to provide the required BOD and suspended solids removal (See Section 3.3.2).

Using the data obtained during Phase I testing, ultraviolet and catalyst systems were sized for the Phase II 200 man prototype system. It was determined that 16 high pressure ultraviolet lamps of the type demonstrated in Phase I would be required for the Phase II system versus catalytic system containing 800 lb of WNC-1 catalyst. The catalytic system was selected on the basis of its simpler construction. The reliability and maintainability considerations associated with the use of 16 ultraviolet cells containing 16 quartz glass tubes and 16 lights compared to the catalytic columns were the major factors influencing this decision. In addition, 16 ultraviolet lights would require 48 kw of electrical power to operate. While this power requirement might not be excessive for most large ships it could pose a problem for smaller vessels. Further, the catalytic system offered more versatility in packaging; the catalyst reactor can be varied in diameter, length, weight of catalyst per columns, without effecting performance.

The planned piping configuration for the secondary treatment system is shown on the System Schematic Figure 58. This schematic shows both the PEPCON cells and catalytic columns in a parallel piping arrangement. As discussed in Section 3.3.2, both series (PEPCON all catalytic column, PEPCON cell, etc) and parallel piping configurations were evaluated and both provided the required performance. The specific arrangement shown provides for separate venting of hydrogen gases formed as the centrate is circulated through the

PEPCON cells (centrate tank is vented) and venting of oxygen gas formed in the catalytic column as a result of the reaction of the hypochlorite with the catalyst. This venting is accomplished in the recirculation tank. Both tanks will be vented to the incinerator exhaust stack above the air ejector where dilution air is provided from the centrifugal blower to prevent any reaction between the hydrogen and oxygen.

The piping arrangement shown provides for recirculation at a rate of 18 to 20 gpm. Input from the centrifuge is at a rate of 3.6 gpm and discharge from the system at the same 3.6 gpm rate. A heat exchanger is provided between the recirculation tank and catalytic columns to raise the temperature of the centrate to 125° F in order to obtain maximum efficiency of the catalyst. A second heat exchanger is provided to exchange heat between influent and recirculated material from the catalyst columns to reduce the load on the primary heat exchanger. The primary heat exchanger will be designed to operate on electric power. Scaling and/or solids buildup in the heat exchanger will be eliminated by taking full advantage of fluid velocity, temperature control and materials of construction. A final catalyst polishing column is provided to reduce BOD and hypochlorite in the effluent.

At the present time Thiokol has under development a new catalyst which has shown to be capable of operation at ambient temperature. This catalyst is currently being characterized and if future test results verify preliminary data, the ambient catalyst can be introduced into the Navy system, thus reducing the load and/or eliminating the requirement for the heat exchanger. The status of the new catalyst development will be reviewed at the initiation of Phase II and a decision regarding its incorporation made at that time.

4.1.4 Solids Disposal

The solids disposal system proposed for Phase II is the incinerator concept evaluated during Phase I. Results of the Phase I tests were discussed in Section 3.3.2. The same basic incinerator design will be used in the Phase II system. The incinerator will be equipped with a baffle to provide retention time for sludge incineration. The Phase I incinerator system will be modified in one area for Phase II; the exhaust fan will be replaced with an air ejector system, thus eliminating a moving mechanical component from the hot gas stream. The air ejector system will be designed to produce the same negative pressure in the incinerator chamber as the exhaust fan; thus, incincerator performance will not be effected by the proposed modification.

A preliminary design of the ejector was prepared during Phase I.

An analytical model was developed to establish the design parameters required to produce flow rates and pressures compatible with the incinerator system. Steady state flow conditions were assumed and the basic interactions between the primary and secondary streams were considered.

The energy, momentum, continuity equation were utilized to derive expressions for determining the desired operating conditions and basic geometry.

The design requirements imposed on the injector system were as follows.

P_s = pressure in secondary stream immediately downstream of the incinerator - 14.0 psia

W_s = secondary flow rate - 0.11 lbm/sec

D_s = duct inside diameter - 5.0 in.

V_s = velocity downstream of incinerator - 45 ft/sec

T_s = temperature of secondary stream - 2,240° R

P_p = static pressure at exit of primary nozzle - 14.0 psia

T_p = temperature of primary stream - 530° F

The total pressure loss in the diffuser was considered to assure that the total pressure at the diffuser exit is above ambient (P_a = 14.7 psia). This pressure loss was calculated to be approximately 0.03 psi/ft of diffuser length. A duct length of 50 ft was considered in this analysis.

The ejector design for the Phase II waste treatment system requires a primary pressure of 17.04 psia and a primary flow rate of 201 cfm to yield the desired operating conditions. It was determined that a multistage centrifugal turbo-air blower (Reliance Model XT) of the type currently being utilized by the Navy in a shipboard waste treatment system can provide the required air flow and pressure. The current Navy blower has a capacity of 140 scfm at 2.5 psig. It is possible with minor modifications to obtain the required flow and pressure with the same centrifugal air blower.

4.2 Phase II Program Plan

The recommended Phase II program schedule is presented in Figure 59 and supported by a detailed documentation plan in Figure 60. The Phase II program includes eight tasks and covers a time span of 10 months from phase authorization to submittal of the final report. The proposed Phase II program is initiated with an update and finalization of the Phase I prototype system. The design effort is supported with design analysis and a complete reliability and maintainability analysis. The Phase I prototype system will be refurbished and modified as required to provide a prototype system for installation in a Navy facility for testing. Major subsystems will be checked out parallel with the refurbishment effort. The assembled system will be checked out and subjected to reliability testing prior to shipment to the Navy. A description of the individual tasks follows.

4.2.1 Task 1.0 - Design Finalization

The Phase I design will be updated based upon data obtained from the Task I testing. The design will incorporate the features required to provide an efficient and reliable system for the Navy Phase II testing. The design will be supported with analyses as required to predict operation of the modified subsystems. Thiokol presently anticipates that plumbing modifications will be made to the pretreatment system to provide transfer of solids to the incinerator, plumbing optimization in the secondary treatment system and overall systems packaging improvement.

Parallel with the 200 man system design effort, a preliminary design will be prepared for a scaled-up 500 man waste treatment system. This design will include a schematic and preliminary design and performance specifications. Detailed subsystem drawings will not be prepared.

Coordination will be conducted with the Navy on the planned test facility for the waste treatment system. Interfaces will be defined and Phase II prototype system design will incorporate features to provide maximum compatibility with the Navy test facility. A technical manual will be prepared describing the Phase II system design and operating requirements. This manual will be submitted in preliminary form 30 days prior to shipment of the Phase II waste treatment system. The manual will be revised to incorporate Navy comments and resubmitted with the delivery of the equipment to the Navy test facility.

PHASE II NAVY PROGRAM SCHEDULE

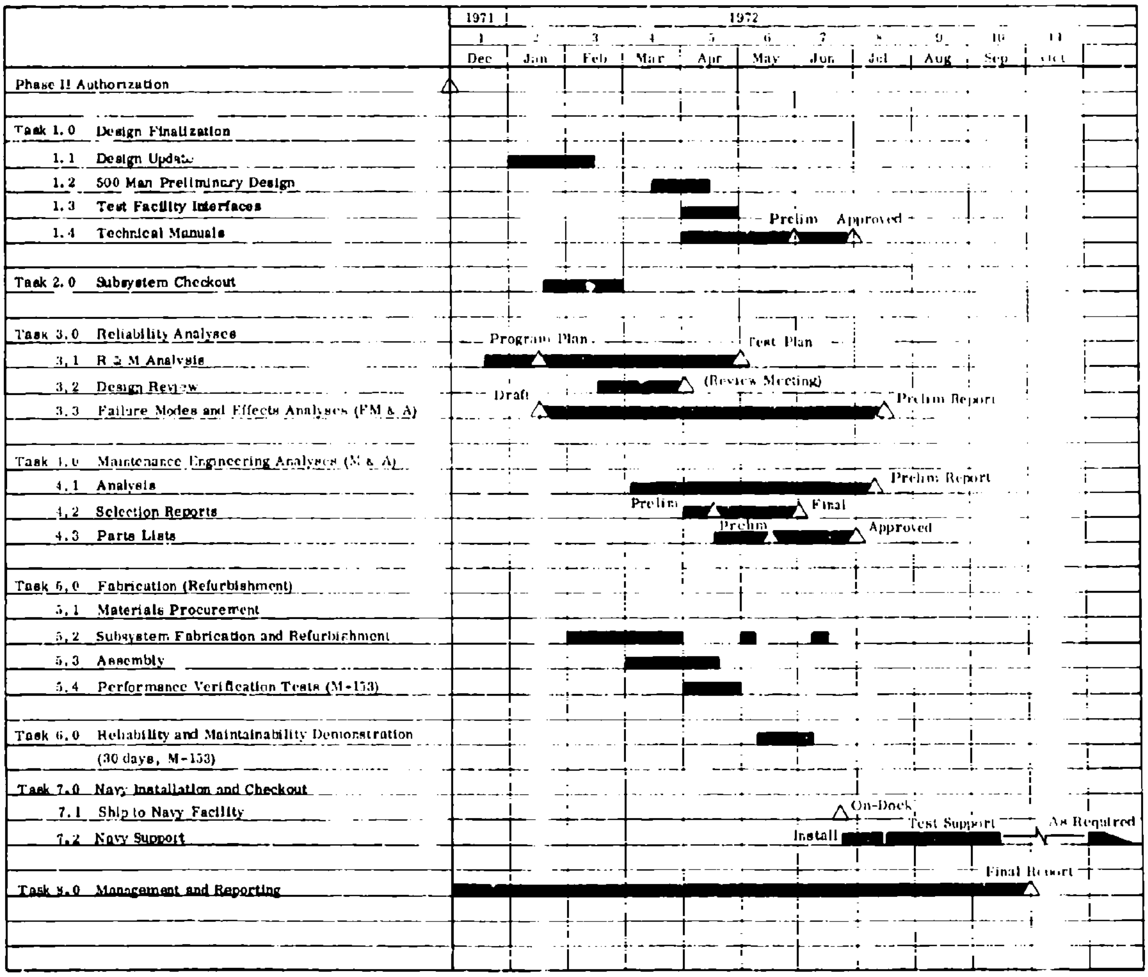

Figure 59. Phase II Navy Program Schedule

PHASE II DOCUMENTATION PLAN

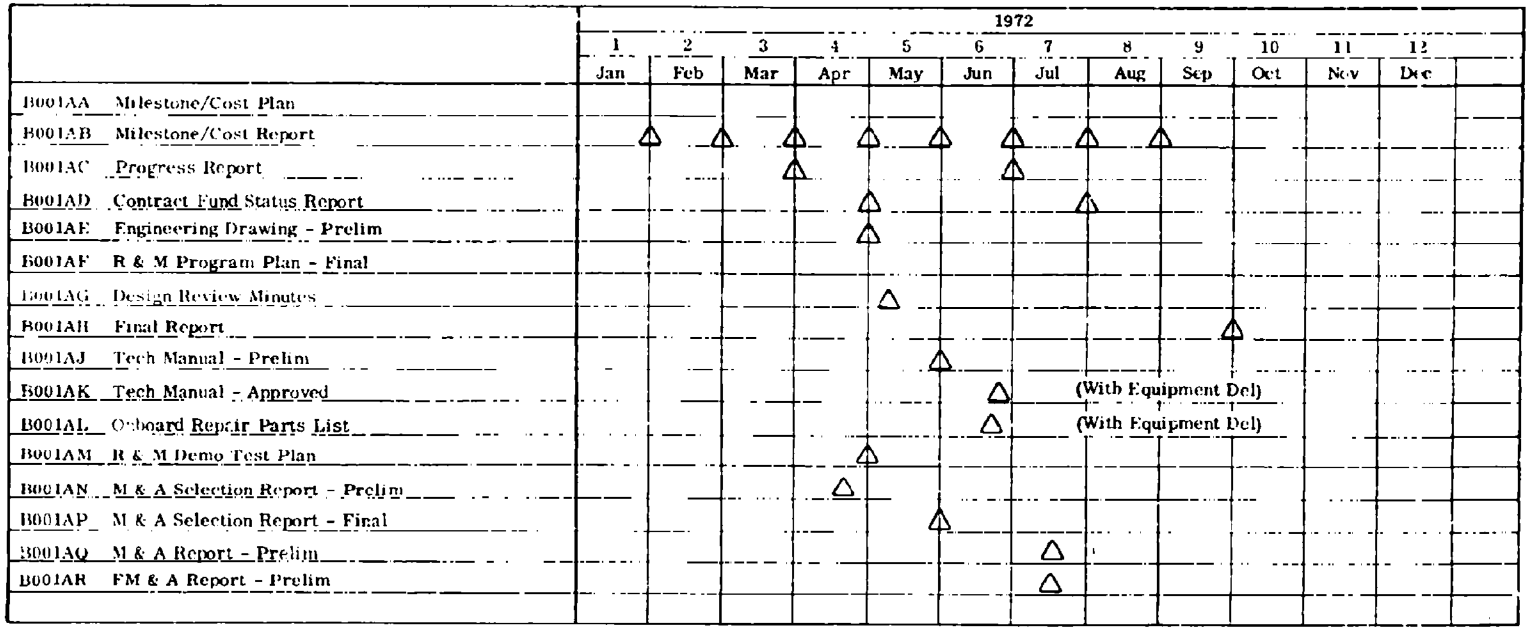

Figure 60. Phase II Documentation Plan

4.2.2 Task 2.0 - Subsystem Checkout

It is anticipated that several subsystems will have plumbing and packaging modifications as a result of the Task I finalized design. The primary modifications will be to the solids handling and disposal system, the secondary treatment system, and overall systems packaging, Modified subsystems will be assembled and tested early in the program to verify the design modifications prior to completing overall systems assembly. Subsystem designs will be finalized based upon testing results. Data will be made available to the Navy verifying subsystem performance.

4.2.3 Task 3.0 - Reliability Analysis

The R & M program plan submitted as Appendix A of Thiokol proposal TWP 08370-40, dated 21 Sep 1970, will be updated and submitted to the Navy 30 days after award of contract. At the same time, a draft of the failure modes and effects analysis will be submitted for coordination with the Navy. This task will include reliability design review meetings and minutes supporting the Task 2.0 design effort. A test plan will be prepared covering full scale Phase II system performance verification and reliability demonstration testing. Based upon this testing, a preliminary FMEA report will be submitted to the Navy 7 months after award of contract.

4.2.4 Task 4.0 - Maintenance Engineering Analysis

A maintainability engineering analysis will be conducted in preparation of maintenance selection reports and maintenance parts lists required to support the systems testing. Maintenance surveillance logs will be accumulated on Thiokol performance verification and reliability demonstration tests. This report will be submitted to the Navy 7 months after award of contract.

4.2.5 Task 5.0 - Fabrication (Refurbishment)

Basically, this task includes the refurbishment of the Phase I full scale advanced waste treatment system. Thiokol anticipates that some new fabrication will be required on subsystems such as the solids transfer system from the pretreatment screen and the catalyst reactor system. Thiokol plans to assemble the refurbished subsystems in a new waste treatment test facility. This facility will enable checkout of the waste treatment system on a full-time, onstream basis. The system will be repackaged to simulate installation in the navy test facility. Parallel performance verification tests will be conducted in this facility on the individual subsystems and on the completely assembled waste treatment system when assembly has been completed. Following this testing and the Task 6.0 reliability demonstration testing, subsystems will be cleaned up and refurbished as required to place in an original condition.

4.2.6 Task 6.0 - Reliability and Maintainability Demonstration

Following assembly and verification testing of the subsystems, a 30 day reliability demonstration test is scheduled in the Thiokol M-153 on-stream waste treatment test facility. This reliability demonstration testing will identify systems variables to be subjected to additional evaluation during the long-term Navy demonstration testing. It is recommended that consideration be given by the Navy to continuing the long-term testing in Thiokol's M-153 test facility. This facility is connected on-stream to the effluent discharge from 200 personnel in an administrative management building. The sewage from this building does not contain kitchen or laundry waste and, therefore, closely simulates the Navy design requirements listed in the Contract N00024-71-C-5332 work statement.

4.2.7 Task 7.0 - Navy Installation and Checkout

This task includes shipment of the waste treatment system to the Navy test facility with an on-dock delivery date schedule during the 7th month of the program. Thiokol will support installation of the system at the Navy facility during a 3 week period of time and will provide support as required for the initial 60 days of testing. Data will be analyzed from the initial 60 days of testing combined with the Thiokol Phase II data and incorporated in the final report scheduled for submission to the Navy 10 months after award of contract.

4.2.8 Task 8.0 - Management and Reporting

Thiokol will provide management and reporting of the program in accordance with Phase II contract requirements. The documentation plan contained in Figure schedules the submission for the 16 CDRL items required by the Navy contract. These reports will be prepared on a timely basis and submitted to document the Phase II effort and to provide a basis for Phase III of the program.