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TRANSPORTABLE WASTEWATER ADVANCED REFINEMENT AND DEMONSTRATION SYSTEM

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CIVIL AND ENVIRONMENTAL ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
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Refinement	Trickling Filter	Activated Carbon	Chlorination
Demonstration	Clarifier	Fluidized Bed	Contact Chamber
System	Rapid Mix Basin	Ultrafiltration	Ultraviolet

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This report documents the design of the Transportable Wastewater Advanced Refinement and Demonstration System (TWARDS). The unit features advanced concepts in wastewater treatment such as induced laminar flow, fixed position sludge collection, fluidized bed and biodisc denitrification, and automated instrumentation. A recommended development plan is included with the report which outlines the fabrication schedule and cost estimates for all phases of the project.

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Block No. 19 (Continued)

Laminar Flow	Automated	Instrumentation
Baffles	Data Processing	

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PREFACE

This report was prepared by Neil D. Williams and James Matthews under contract F29601-76-C-0015, Job Order Number 21037W85, for Detachment 1 (CEEDO) ADTC, Tyndall Air Force Base, Florida 32403.

This report summarizes work done between November 11, 1977, and May 15, 1978. Captain Robert G. Perry was the project officer.

This report has been reviewed by the Information Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

BACKGROUND

The Civil Engineering Research Facility (CERF) of the University of New Mexico has designed a Transportable Wastewater Advanced Refinement and Demonstration System (TWARDS). The TWARDS trailer was developed to evaluate the effluent from existing or proposed USAF wastewater treatment facilities (Figure 1).

The Federal Pollution Control Act Amendment of 1972, Public Law 92-500, has established July 1, 1983 as the date by which all treatment facilities must be upgraded to achieve zero waste discharge.

TWARDS trailer analyzes wastewater effluent data in order to provide information which will assist in the design of new, upgraded, or modified facilities to meet the 1983 Federal Pollution Requirements.

OBJECTIVES

The purpose of this task was to provide detailed plans and specifications from which the TWARDS trailer could be fabricated. The following design considerations were provided to CERF by the USAF:

(1) The system shall be capable of being ground transported to any USAF base for on-site evaluation of the effluent wastewater (Figure 2).

(2) Provide all or any combination of conventional or advance treatment techniques needed to determine which base treatment processes are deficient.

(3) Operate at a design flow rate of 2 gallons per minute but be capable of operating at flow rates that vary from 0.5 to 3.5 gallons per minute.

(4) Each unit process should be capable of operating when organically overloaded.

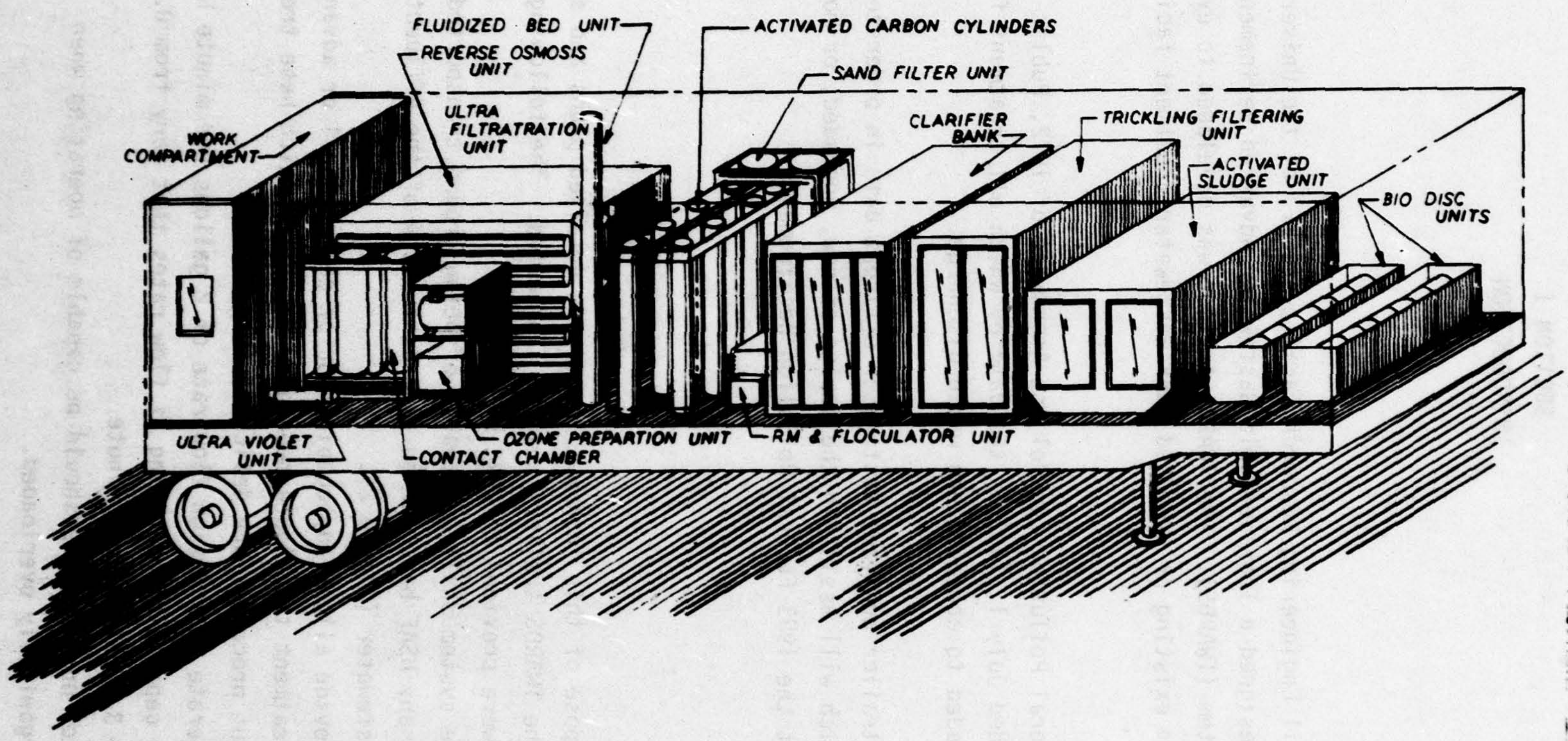


Figure 1. TWARDS Trailer

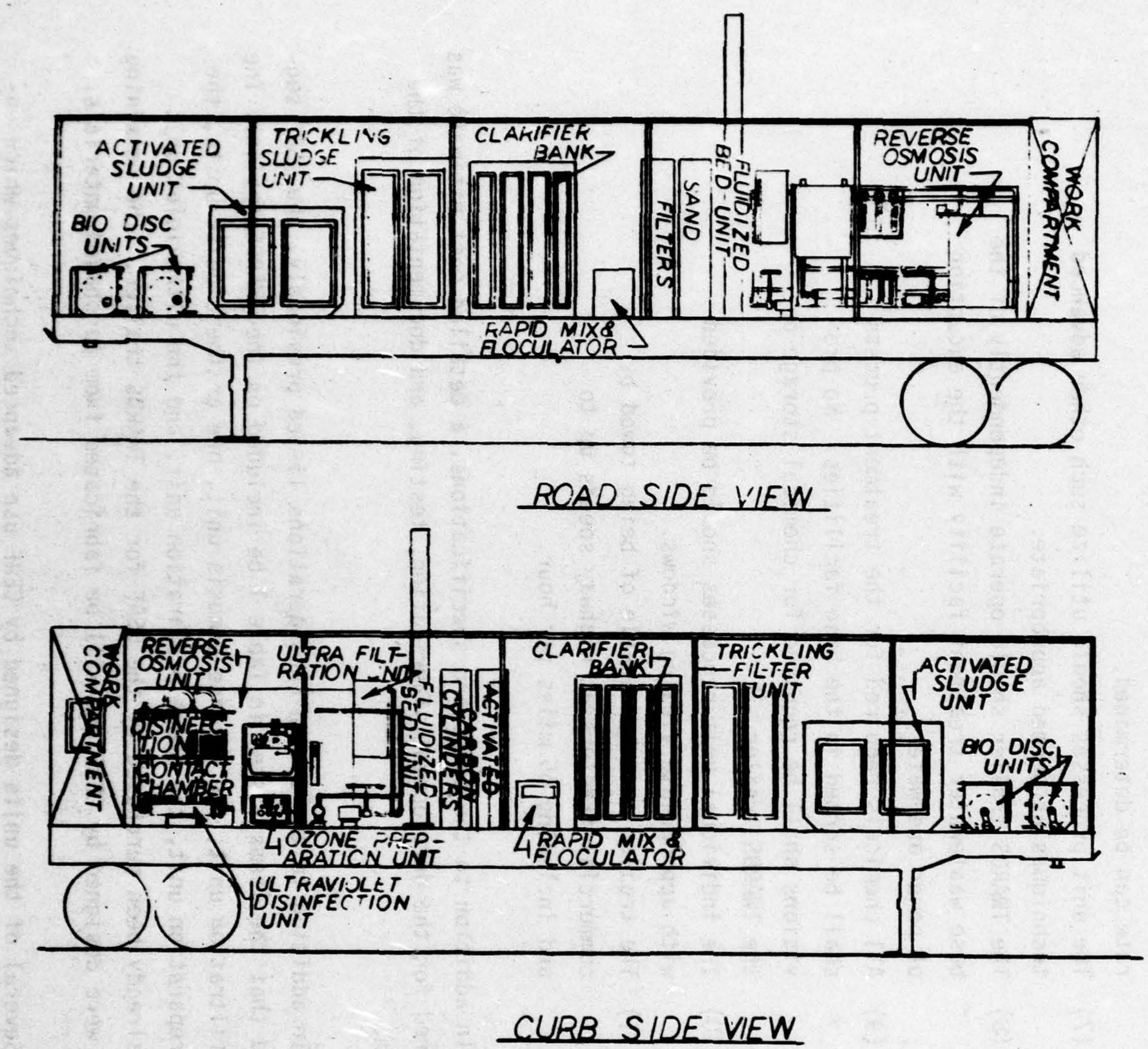


Figure 2. TWARDS Elevations

(5) The unit process internal designs should accommodate new hydraulic concepts such as induced laminar flow and increased settling rates.

(6) The unit processes should be capable of being operated at variable recycle rates so that the optimum flow rate can be determined.

(7) The unit processes should utilize such other advanced techniques as deemed appropriate.

(8) The TWARDS trailer should operate independently of the base wastewater treatment facility with the exception of power and water.

(9) All chemicals required for the treatment process shall be sorted in the base facilities. No provisions shall be required for chemical storage on the TWARDS trailer.

(10) The individual unit processes should be provided with appropriate viewing windows.

(11) The trailer must be capable of being towed by commercial tractors at highway speeds up to and including 55 miles per hour.

In addition to the plans and specifications, a detailed cost estimate was prepared for the development, fabrication, testing, and documentation of the system.

In addition to the design considerations listed previously, the USAF suggested that the items listed in Table 1 be included on the TWARDS trailer. The ultrafiltration unit, the reverse osmosis unit, one of the biodisc units, the air preparation unit, the ozone preparation unit, and the ultraviolet unit have already been purchased by the USAF for the TWARDS trailer. The remaining units were designed by CERF and will be fabricated from purchased materials.

Several of the units designed by CERF use advanced techniques which enhance the ability of the unit to model field conditions. The clarifier unit uses a sludge collection system developed at CERF. The collection system is fabricated from steel plates sloped at 60-degree angles in order to prevent

TABLE 1. TWARDS UNIT PROCESSES

PRELIMINARY TREATMENT 1. Pressurized Air Flotation
SECONDARY TREATMENT 1. Trickling Filter 2. Bio-Disc 3. Activated Sludge
TERTIARY TREATMENT 1. Rapid Mix & Flocculation 2. Sand Filtration 3. Carbon Adsorption 4. Bio-Disc 5. Fluidized Bed 6. Ultra-Filtration
DISINFECTION 1. Ultraviolet Light 2. Ozonation 3. Chlorination

sticking and to improve the sludge compaction. The activated sludge unit and the clarifier unit have baffles which induce laminar flow through the units. The wastewater distribution system for the trickling filter unit was developed by CERF and uses a perforated pipe and perforated plate assembly which maintains a constant, thin sheet of flow across the media. The flocculator paddle design was also developed by CERF to provide improved mixing characteristics. All of the designs developed by CERF reflect emphasis on the reliability of data produced and low maintenance costs.

SECTION II
SYSTEM CONFIGURATIONS

The sequence of treatment units onboard the TWARDS trailer was developed from compatibility relationships between processes, optimal influent characteristics to a unit for efficient operation, and consideration of the probable modes of use in performing treatability studies at USAF installations (Figure 3). It is assumed that the domestic and industrial wastewater will have received pre- and primary treatment before treatment evaluation studies at the trailer. Preliminary design guidelines from USAF project supervisory personnel indicated that all major units were to be hydraulically capable of operating within a traditional treatment train of units or independently by connection through inlet and outlet tees.

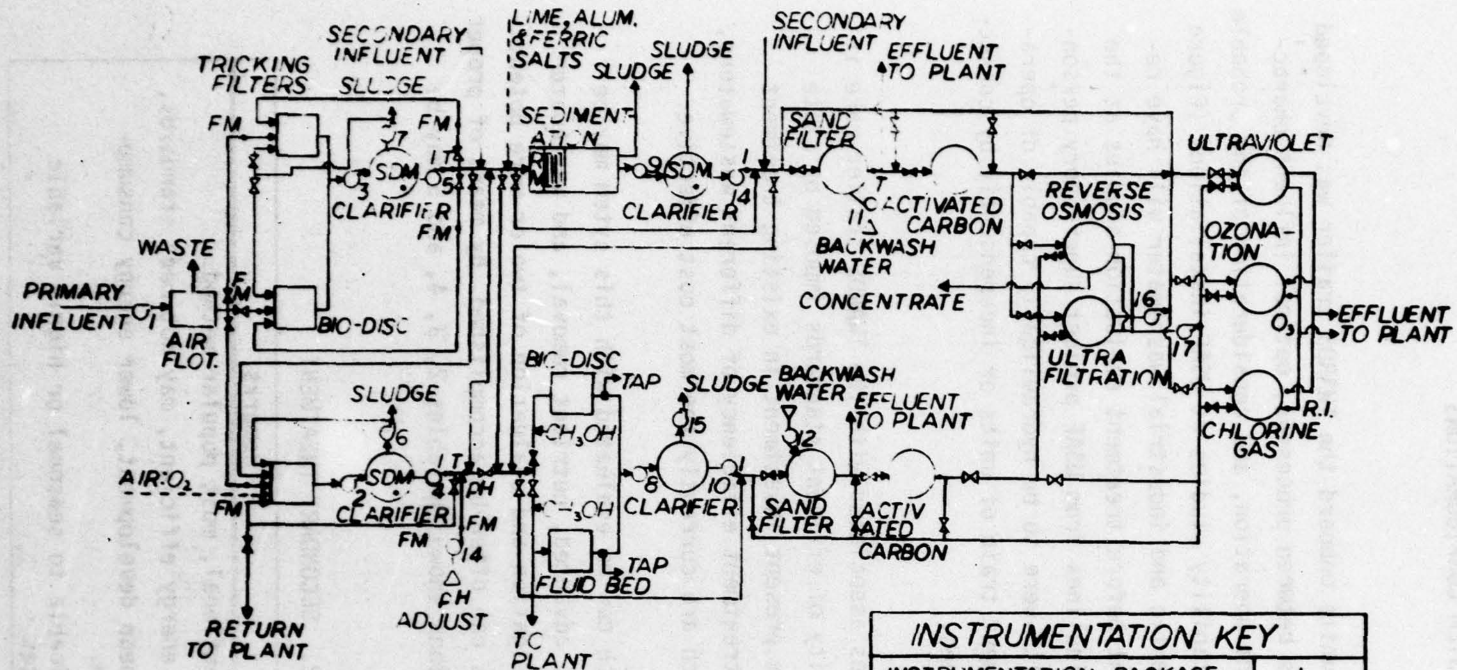
The pilot plant capabilities associated with the TWARDS trailer make it possible to consider the diversity of effluent standards imposed by state regulatory agencies, the sizable present investment in existing treatment facilities, the variability in treatment efficiency of different wastewaters, and the treatment processes which are currently the most cost effective.

The types of treatment which can be evaluated with this sytem may be broadly classified as secondary, advanced, nutrient removal, and wastewater renovation. Simultaneous investigation and evaluation of two or more potentially promising treatment schemes can often be accomplished. By means of proper hydraulic control, the combinations shown in Tables 2, 3, 4, and 5 may be studied.

TABLE 2. SECONDARY TREATMENT

Process	Remarks
Activated Sludge[a]	Conventional, most popular method.
Trickling Filter[a]	Most energy efficient, may not meet standards.
Biodisc[a]	European development, lower energy consumption.
Chemical Treatment	Applicable to seasonal or highly variable wastes.

[a]Two of the three units may be tested simultaneously.



INSTRUMENTATION KEY	
INSTRUMENTATION PACKAGE	I
FLOW METER	FM
SLUDGE DENSITY METER	SDM
TURBIMETER	T
pH METER	pH
PORTABLE INSTRUMENTATION	P I
CONDUCTIVITY METER	C
RESIDUAL CHLORINE	R.I.

NOTE:
PROVIDE TEES WITH TAPS BEFORE & AFTER ALL PROCESSES.

Figure 3. TWARDS Flow Diagram

TABLE 3. ADVANCED WASTEWATER TREATMENT

Process or Operation	Remarks
Sand Filtration	Additional removal of colloidal BOD and S.S.
Activated Carbon	Efficient adsorption of colloidal and dissolved organics.

TABLE 4. NUTRIENT REMOVAL

Process	Remarks
Biological Denitrification	Units must receive a nitrified influent.
Biodisc	Enclosed unit for anaerobic environment.
Fluidized Bed	Promising method, limited pilot plant data.
Phosphorous Removal	May be tested with suitable chemicals such as lime, alum, iron, salts, or others.

TABLE 5. WASTEWATER RENOVATION

Process	Remarks
Reverse Osmosis	Effluent contains low solids, organic or mineral.
Ion Exchange	Usually expensive with high flows; has industrial waste treatment potential.
Ultra Filtration	Recent development, versatile process.

The efficiency of disinfection by ozonation, residual chlorine, and ultraviolet light can also be evaluated after most of the conceivable treatment sequences. If upstream disinfection is to be evaluated, flexible tubing can be used to route the waste to the appropriate initial process.

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SECTION III
TWARDS TRAILER

The TWARDS trailer is a steel trailer designed and fabricated specifically for this use. The vehicle weight rating is 40 tons in transit and 60 tons static, inplace. The static, inplace load is supported by eight jacks permanently attached to the body of the trailer. The trailer is towed by a commercial tractor with a conventional fifth wheel connection. The trailer is 44 feet long, 8 feet wide, and 12 feet 9 inches high. The cargo area will be totally enclosed. The minimum interior cargo area is 43 feet 5 inches long, 7 feet 10 inches wide, and 8 feet high.

The suspension system for the trailer may be either spring or air bag, whichever the trailer manufacturer determines will best isolate vibration. All of the unit processes are mounted to the structural members of the trailer by 3/4-inch bolts spaced as shown in the plans. The trailer manufacturer must provide a suspension system which prevents damage to the instrumentation, the data processing equipment, and the unit processes.

The cargo area of the trailer is totally enclosed. The side panels fold out to form a catwalk and canopy. The catwalk and canopy are supported by 2-inch-diameter structural steel pipe stored underneath the trailer. The top panels are removable so that the individual unit processes can be removed by a crane if necessary.

The trailer is equipped with all safety equipment required by law and meets all code requirements for the continental United States. The trailer lighting required for safe operation is provided with the trailer.

The trailer has an open frame floor with transverse structural members to support all of the unit processes continuously along four sides. Steel plate which has been surface treated to prevent slipping will be installed in all areas which are 9 inches or greater between unit processes. The transverse structural members are capable of supporting the unit process loads in the locations shown in Figure 4.

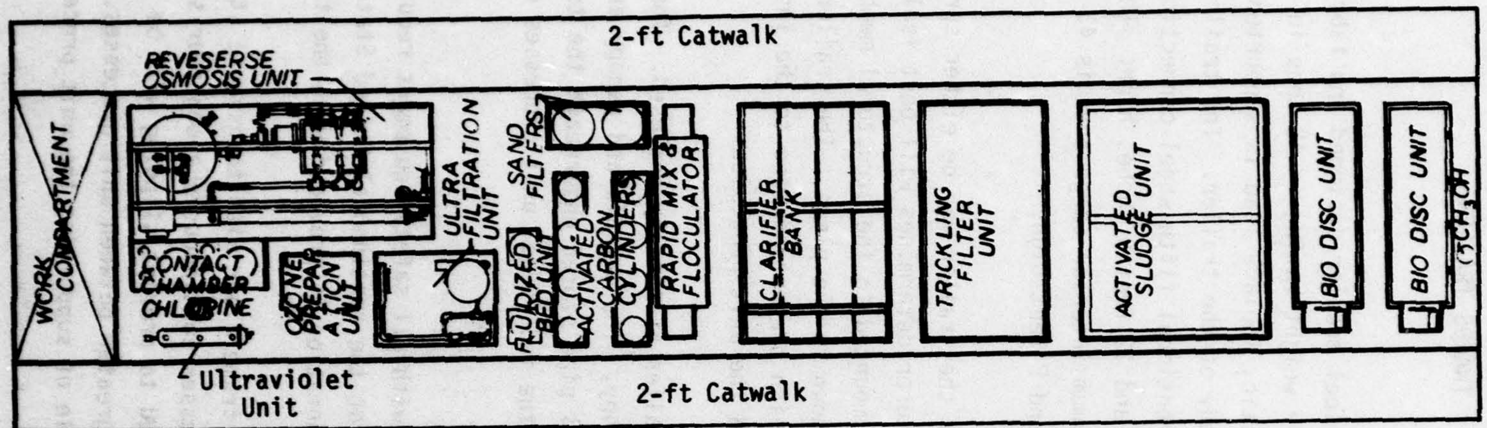

Figure 4. TWARDS Layout

The TWARDS trailer was put out for bids on March 2, 1978. The low bid was submitted by Calumet Coach Company of Chicago, Illinois. Their bid was 46,000 dollars and their estimated construction time was three months. The Calumet Coach Company also provides a full set of construction drawings for inspection prior to the actual manufacture of the trailer.

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SECTION IV
BIODISC UNITS

INTRODUCTION

The biodisc units operate in a manner closely approximating the operation of a trickling filter unit (Figure 5). The unit consists of several compartments in series, each of which houses a plastic disc. The individual compartments are typically designed so that they never flow more than 40 to 50 percent full. The disc, which is within the compartment, is mounted on a central shaft driven by a motor. This motor causes the shaft to rotate at a low velocity. The rotation of the disc through the wastewater and then the air simulates the dosing which a trickling filter receives from a rotating arm distributer. As the disc emerges, a thin film of wastewater remains on its surface and is exposed to the air. The alternate exposure of the disc to wastewater and air creates an environment favorable to the development of a microbial culture. After a start-up period of about one week, a microbial film about 2 to 4 millimeters thick develops on the surface of the disc.

The excess biomass generated by the attached culture is stripped off the disc by the shearing forces exerted as the media are rotated through the wastewater. The stripped solids are kept in suspension by the mixing action of the rotating disc until they are pumped into a sedimentation tank.

There are several advantages to the biodisc process. First, the unit is reliable; and the results which are obtained are predictable. Second, the unit requires very little supervision. Third, the unit is not expensive to operate. Fourth, the unit is easy to maintain (Reference 1).

<u>Reference</u>

1. Antonie, Ronald L., Kluge, David L., and Miekle, John H., "Evaluation of a Rotating Disk Wastewater Treatment Plant," *Journal WPCF*, Vol. 46, No. 3, March 1974.

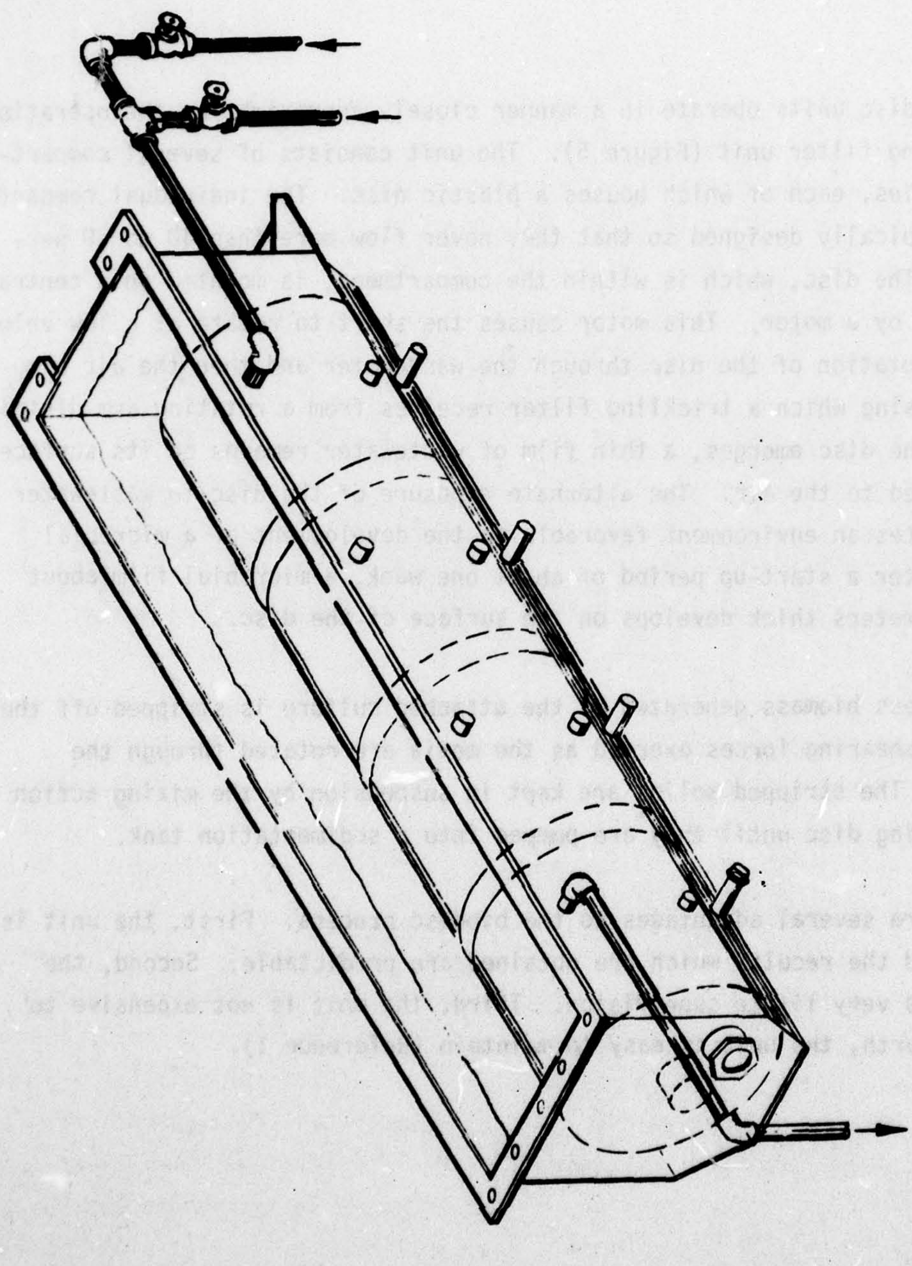


Figure 5. Biodisc Unit

Biodisc units are designed on the basis of hydraulic loading. However, several parameters affect the unit's performance. The temperature of the influent should never be allowed to fall below 55°F. To this end, the influent can be heated or the unit insulated. The effects of temperature on the quality of the effluent from the biodisc unit should be carefully examined to determine if preheating of the effluent is required. The rotational velocity of the discs also has an effect on the quality of the treatment. Furthermore, the pH of the influent wastewater affects the performance of the unit. The optimum biological removal of BOD will occur when the pH is within the range of 6.5 to 8.5 pH units.

The biodisc unit may also be adapted for use as a denitrification unit. When the biodisc unit is so used, the HCO_3^- concentration becomes important. The concentration of HCO_3^- must be kept at a minimum of 50 mg/ℓ. If this concentration is maintained, the pH is prevented from declining below 7, a condition which retards denitrification efficiency. The optimum pH is 8.3 for maximum denitrification of municipal sewage.[1]

The USAF purchased a biodisc unit from Autotrol Corporation, Bio-Systems Division of Milwaukee, Wisconsin. Since two units are required for TWARDS, one for secondary treatment and one for denitrification, it is recommended that a second unit be purchased from the same company. The unit which was purchased was the 0.5-meter model. This unit operates on 110 V, single phase; and a 0.25-hp motor rotates the shaft. The area of the individual compartments is 2.113 ft^2, and it is recommended that an initial hydraulic loading of 2.0 gal/day/ft^2 be used as a general rule for all domestic applications.

The specifications for the biodisc unit follow.[1] These specifications give a description of the unit and provide detailed information on the BIO-SURF media, the bucket feed system, the drive unit, the hydraulic design, and the tank dimensions. They are followed here by detailed recommended operating instructions.

Footnote

1. Memorandum from Robert J. Hynek, Manager, Autotrol Corporation, BIO-SURF Pilot Plant Program, Milwaukee, WI, August 15, 1974.

BIO-MODULE SPECIFICATIONS: 0.5-METER BIO-MODULE PILOT UNIT (ALUMINUM TANK MODELS)

This specification includes a definition of the key features of mechanically-driven, 0.5-meter Autotrol pilot plant for wastewater treatment studies. The pilot plant consists of a tank containing a central steel shaft which supports radially-corrugated plastic media. Viewed cross-sectionally, the internal passages are hexagonally shaped, resembling a natural honeycomb structure. The entire shaft is slowly rotated with the plastic media approximately 35 percent submerged in wastewater. The shaft is supported in the tank by permanently sealed, pre-lubricated ball bearings. The tank and media are divided into four stages; but the bulkhead between the first two stages is removable, providing an optional three-stage configuration.

The tank also has a feed chamber (wet well). Water enters the feed chamber and is picked up by buckets on the feed arms attached to the rotating shaft. Water passes *through the feed arms* over the first of four bulkheads and thereafter passes from stage to stage through circular openings in each stage bulkhead. The shaft is rotated by a gearmotor and a suitable chain sprocket drive to provide the proper rotational velocity.

Organisms in the wastewater attach to and grow on the media, utilizing dissolved oxygen and soluble organic material for energy and further cell growth. Rotation of the media produces a film of wastewater on the surface where it absorbs oxygen from the air. Organisms in the biomass then utilize the dissolved oxygen to convert the soluble organic material to additional biomass solids, carbon dioxide and water. Nitrogen in the form of ammonium ions can also be biologically oxidized to nitrate ions through a process referred to as *nitrification*.

Rotation eventually causes excess biomass to be sheared from the media into the mixed liquor. The settleable biomass solids are kept in suspension by rotational mixing forces until the hydraulic flow carries them out of the unit. These solids are large and settle rapidly.

This pilot plant is furnished without a clarifier. The operator may elect manual clarification of grab samples or furnish his own test clarifier.

Reference

The 0.5-meter Bio-Module assembly is described by Autotrol Drawing Number 38-000-154-401.

Design Parameters

(a) BIO-SURF media (standard). BIO-SURF media are constructed by welding together vacuum-formed discs of high-density polyethylene. Each compartment contains a stack of convoluted discs. These stacks are reinforced with polyethylene molded hubs with square holes. Polystyrene foam spacers are used to align the stacks properly on the shaft. The steel shaft is coated with epoxy paint to resist corrosion.

(b) BIO-SURF media (high-density). High-density BIO-SURF media are created by inserting flat sheets of polyethylene between alternate convolutions of the standard BIO-SURF media. This reduces the inner convolution dimension and radial passage orifice by 50 percent. (Application is restricted to nitrification of a wastewater containing less than 30 mg/ℓ total BOD_5.)

Media Extenders: Polyethylene extenders attached to the media prevent sludge accumulations (0.5-meter media cannot duplicate full-scale mixing character).

Stages: Four in series standard.

Surface Area: 250 ft^2 total of all four stages standard; 303 ft^2 for high-density versions.

Volume-to-Surface Ratio: 0.12 gal/ft^2 with biomass (nominal); 0.11 gal/ft^2 with biomass (nominal) high-density version.

Disc Diameter: 0.5 meter (18-5/8 inches).

Number of Discs: Nine per stage standard; eight per stage in high-density versions.

Media Stack Length: 11.7 inches per stage standard; 10.4 inches for high-density versions.

Nominal Layer Thickness: 1.2 inch standard;
0.6 inch for high-density versions.

(c) Bucket feed system.

Number of Buckets: Four maximum.

Maximum Pumping Capacity: 1,625 gallons per day.

Additional Overflow Capacity: Over bulkhead between wet well and first stage.

(d) BIO-SURF drive.

Motor: Westinghouse

Voltage: 115 V

Horsepower: 0.25

Phase: 1

Frequency: 60

RPM: 1,725

Reducer: Morse 18 GCT

Output r/min: 29.2

Driven Sprocket: 60 teeth

Chain: RC 35

Shaft RPM: 7

Media Peripheral Velocity: 30 feet per minute nominal

Hydraulic Design

The liquid level is established by the effluent weir and usually runs 2-1/2 inches below shaft centerline. The first stage is fed by rotating feed buckets attached to the BIO-SURF shaft. The flow to the second, third and fourth stages is through 1- or 1/4-inch openings near the bottom of the bulkheads. Alternatively, flow can be routed normally to the shaft through each compartment in a serpentine fashion. Sidewall orifices (1 inch NPT), normally stoppered, are utilized. This option facilitates special experimentation (e.g., intermediate clarification) and *would require closing* of the openings located near the bottom of each bulkhead. (Consult factory for detailed instructions should closure be required.)

Tank

The tank is fabricated from 1/8-inch and 3/16-inch aluminum. Inlet and outlet connections are 1 inch NPT (female). The tank surface is completely coated with blue epoxy paint.

RECOMMENDATIONS FOR INITIAL PHASES OF BIO-SURF PILOT STUDY

The Bio-Systems Division of the Autotrol Corporation has offered the following recommendations to assure smooth progress during the initial phases of a BIO-SURF pilot study:

(1) Establish a location within a building close to the wastewater source. To simulate full-scale coverage, sunlight should be excluded and artificial illumination should be applied only when personnel are in attendance.

(2) Space and electrical requirements are as described in Table 6.

TABLE 6. BIO-SURF SPACE AND ELECTRICAL REQUIREMENTS

Unit Size	Floor Space, ft^2	Overhead Clearance, ft	Electrical and Horsepower Ratings
0.5 m	100	10	110-v, 1-phase, 0.25 hp
2.0 m	400	15	220-v, 3-phase, 1.5 hp
3.2 m	600	18	220-v, 3-phase, 3.0 hp
Full-Scale	600-1000	20	220-v, 3-phase, 7.5 hp

(3) Daily flow rate requirements will vary with BOD concentration and degree of treatment. An initial flow recommendation should always be obtained from the Bio-Systems Division office in industrial waste applications. An initial loading of 2.0 gal/day/ft^2 applies as a general rule to all domestic applications.

(4) Provide pilot plant program manager with all pertinent information regarding the following:

(a) Wastewater characteristics.

(b) Design objectives, EPA and/or State requirements.

(c) Extent of laboratory facilities and personnel available for sampling and analysis.
(d) Names of project supervisor and other key personnel.
(e) Telephone numbers at pilot location and at other important locations.

OPERATING INSTRUCTIONS: BIO-SURF PILOT PLANT PROGRAM

Installation: 0.5-Meter Units

The unit should be positioned near the wastewater source and in a uniformly horizontal position to assure normal immersion of the rotating media. Placement of the unit on a raised elevation will simplify problems associated with tank drainage at a later date.

Protection from the elements must be provided. This will simulate the effect of integral BIO-SURF covers or buildings over full-scale shafts. (Heat losses to the atmosphere, particularly during winter months, must be prevented. In southern regions, competitive growth and sludge protection from algae must also be avoided.)

If an existing building is not available, purchase a metal shed (southern regions) from a local hardware store or construct a temporary structure of exterior plywood (northern regions) of sufficient size to provide adequate working space (100 ft^2 minimum) around the unit. For a 0.5-meter unit, 2 feet of wall clearance should be provided on three sides (influent end, effluent end, and media immersing side) with the remainder distributed along the media emerging, or front side. This arrangement will provide for direct access to the wastewater in the stage compartments (very important), and provide needed space for location of miscellaneous tools, refrigeration equipment and a table for personnel responsible for sampling, testing and routine surveillance. Place the unit on the shipping carton, which is first covered with a thin plastic sheet, to facilitate sampling, observations, and drainage. *A vent fan is recommended to control humidity, particularly if the wastewater will be in the range of 25-35°C (77-95°F).*

Electrical Connections: 0.5-Meter Units

Electric power sufficient to operate the 0.25-hp, 115-V, 1-ph motor should be routed through a circuit breaker and/or control box near the unit. Two 20-A circuits should be adequate for all electrical needs during the tests.

To operate the unit, merely plug in the three-wire, grounded cord attached to the drive motor.

Rotational speed is fixed by the drive unit and sprocket combinations at 7 r/min.

Hydraulic Start-Up Procedure: 0.5-Meter Units

Hydraulic start-up consists of providing wastewater to the unit by connecting a feed line to the feed chamber. The feed chamber is emptied by buckets attached to the rotating shaft. Pumping rate is regulated by varying the heighth of fluid in the bucket chamber, and varying the number and/or capacity of the buckets. (Consult the Pilot Specification for nominal flow rates as a function of these parameters for 0.5-meter units.) Level control in the feed chamber is accomplished with a standpipe in the feed line to the wet well. Excess fluid is discharged through the standpipe tilted at an appropriate angle.

Initial flow to the unit should be such that the applied soluble BOD load is 2 $lb/1000\ ft^2$ on Stage I. As the hydraulic loading will vary with BOD strength, use the following formula to calculate the hydraulic loading on a 4-stage unit that conforms to the 2 $lb/1000\ ft^2$ organic loading on Stage I:

$$\text{Hydraulic Loading, gal/day/ft}^2 = \frac{2\ \text{lb}/1000\ \text{ft}^2}{(\text{Soluble BOD}_5,\ \text{mg}/\ell)(0.00834)(4)}$$

This loading is recommended to promote development of biomass on the media with a minimum of difficulty associated with start-up problems and at the same time provide a high degree of treatment as soon as possible. This loading will also permit early assessment of performance at higher loadings from stage sample analysis.

The rotating bucket method of flow control is usually quite reliable, but one can expect a gradual lessening of flow as biomass grows within or on the bucket surfaces. Daily flow checks early in the initial phase are therefore recommended to assure proper documentation and flow maintenance until experience justifies a less rigorous schedule. An alternative method of regulating flow can be used at the operator's discretion (a small metering pump, for example).

Effluent from the pilot unit should be drained into a sewer nearby. As a flow measurement is frequently required, the piping arrangement should be constructed in such a way as to allow one to measure flow rates by placing a 1-ℓ graduate under the outfall pipe. One can utilize a 4-inch funnel permanently inserted into a short vertical length of 3/4-inch garden hose connected to the drain line. The effluent drains continuously into the funnel until a flow measurement is desired. At that time, one merely pushes the funnel aside with the upper end of a 1-ℓ graduate and then collects the desired quantity while measuring the time interval with a stopwatch. When the graduate is quickly removed, the funnel will snap back into its normal vertical position.

To obtain hydraulic loading directly, when using a 1-ℓ collection volume, this formula should be used:

$$\frac{91.3}{\text{s to obtain } 1\text{-}\ell} = \text{gal/day/ft}^2 \text{ (250 ft}^2 \text{ basis)}$$

Samples should not be taken from a distant and final outfall point. Biomass accumulations occur in line and frequently dislodge erratically, particularly when the line is disturbed. It is preferable to obtain a sample from a point as close as possible to the effluent weir box on the unit but on the discharge side of the effluent weir box.

Biological Start-Up

If the wastewater is sterile, or highly industrial, seed with primary clarifier effluent obtained from a local treatment plant. One gallon per day applied to each stage over an 8-hour period should suffice. Seeding should be discontinued when a slime can be felt on the first stage of media.

If the wastewater is not sterile, start-up will not require seeding with organisms. A biological slime would develop within one to three days. Within a week there should be a significant growth on Stage I with gradually lessening biomass coverage in the latter stages. An occasional sloughing may occur, producing a patchy appearance. This occurrence is normal; and as time progresses, a shaggy growth will form a uniform layer on Stage I. Subsequent stages will develop similar, but gradually thinner growths. When nitrification occurs, the biomass will take on a brown color.

pH, Nutrient and Temperature Control

(a) pH control. Optimum biological removal of BOD and concurrent formation of readily settleable sludge (MLSS) is obtained by control of pH to the region 6.5 - 8.5 units. Sodium hydroxide solution (10 to 50 percent) administered through positive displacement pumps is preferred. The pump is to be activated automatically through electrical synchronization with a pH recorder. A pH probe should be located in a mixing chamber ahead of the pilot unit to assure that properly neutralized influent enters the first compartment (stage).

(b) Nutrient control. Nutrient control is best accomplished with automatic additions of ammonium phosphate as indicated in Table 7.

TABLE 7. BIO-SURF AMMONIUM PHOSPHATE IN NUTRIENT CONTROL

Unit Size, m	BOD_5, mg/ℓ	Hydraulic Loading	Nominal Daily Requirements, Liters		
			NH_4OH[a]	H_3PO_4[a]	Dilution Water[a]
0.5	1.000	1.00 gal/day/ft^2	0.22	0.007	0.77

[a]NH_4OH: 29 percent NH_3, 0.9 Sp. Gr.; H_3PO_4: 85 percent H_3PO_4, 1.7 Sp. Gr. Dilution water added to prevent crystallization under 50°F (10°C). This solution should be fed into the system over a 24-hour period. For alternate BOD strength or hydraulic loadings, calculate N and P needs algebraically from numbers given here.

When nitrification is of interest, control of HCO_3^- concentration becomes important. Since seven parts of HCO_3^- (as $CaCO_3$) are consumed for each part of NH_3-N, and nitrification approaches zero when HCO_3^- concentrations approach zero, one must add a solution of HCO_3^- to maintain its concentration above a minimum of 50 mg/ℓ in the effluent. (A minimum of 50 mg/ℓ prevents pH declines to less than 7, another condition which retards nitrification efficiencies.)

The source of HCO_3^- preferred and recommended is $NaHCO_3$. This salt is 73 percent HCO_3 and has the additional benefit of buffering ph to the value of 8.3 favored for maximum nitrification of municipal sewage. (Industrial wastes will require individual evaluation as to pH when NH_4-N exceeds 30 mg/ℓ.)

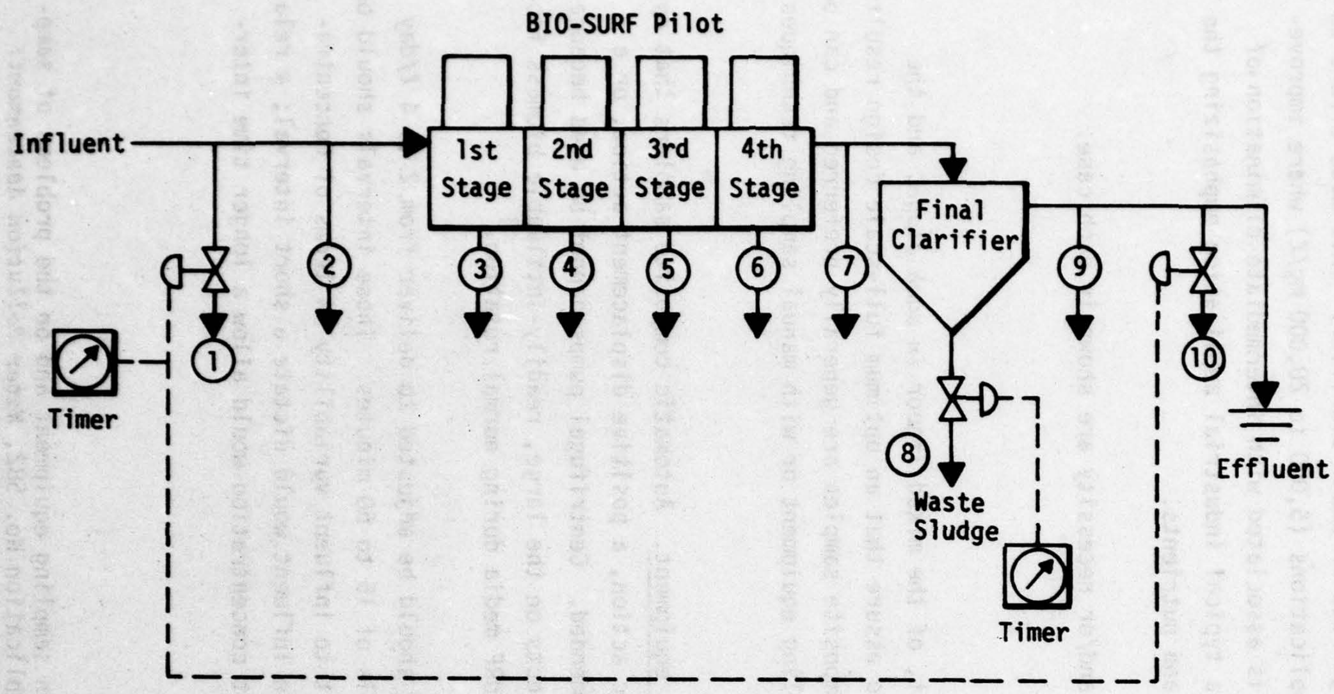
(c) Temperature control. Temperature control will be an important factor and should duplicate full-scale realities as indicated earlier. As housing of BIO-SURF is required to prevent adverse effects on biological activity in winter months, temperature losses during flow through the BIO-SURF reactors will be minimal (1 to 2°C). As operating temperatures full-scale will probably always exceed 50°F (10°C), minimum temperatures during a pilot study should always be maintained in excess of these values.

Upper temperature limits for the mixed liquor in Stage I are established in recognition of decreased oxygen transfer kinetics, undesirable biological species, and temperature effects on polyethylene media. Previous pilot experience dictates a preferred upper limit of 90°F (32°C).

Control of temperature in the building will usually control heat losses. Insulation alone may suffice during winter months; if not, some heat may be necessary.

Equipment and Process Schematics

Various BIO-SURF process schematics for BOD removal and nitrification are provided for general review. Figure 6 illustrates BOD removal in a variable-stage and/or in a standard four-stage mode which will be used to generate



Note: Samples 1 and 10 are composites sampled automatically. Others are generally grab-composite or single-grab samples.

Figure 6. BOD_5 Removal and/or Nitrification Standard Four-Stage Mode

initial performance parameters. Figure 7 illustrates BOD removal using a large first stage to provide additional capacity against transient changes in concentration or flow. Figure 8 illustrates operation with a large first stage and an intermediate high-rate or small clarifier. This mode offers advantages in very high BOD applications (5,000 to 20,000 mg/ℓ) where improvement in soluble BOD removal is associated with intermediate elimination of MLSS. Figure 9 illustrates a typical industrial application emphasizing the need for good control of pH and nutrients.

Sampling points of interest and/or necessity are shown in each case.

Sampling Requirements

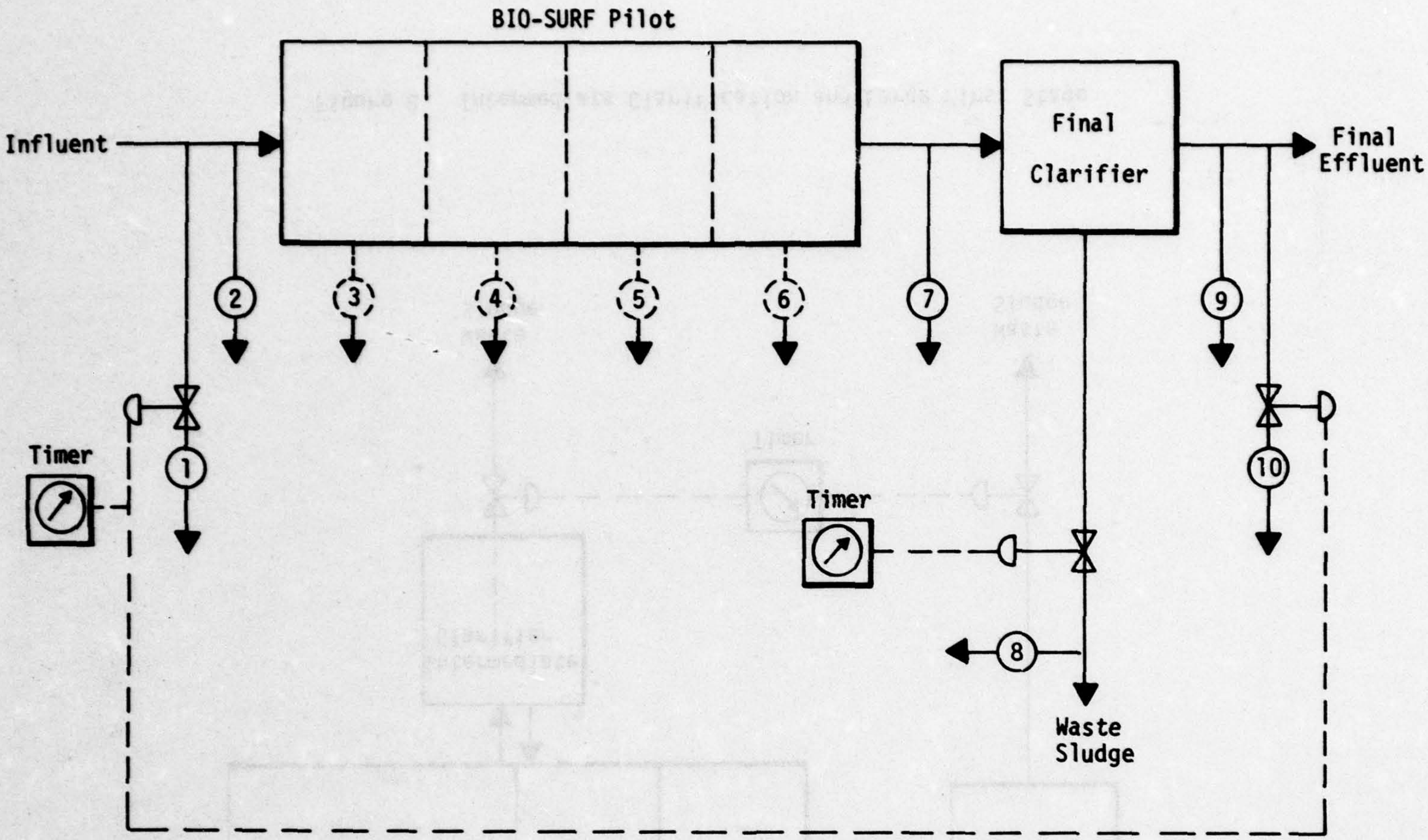
Sampling of the influent, of the mixed liquor *in each stage*, and the final effluent is required to assure that an optimum full-scale design results from this pilot project. Composite samples are generally preferred and can be prepared with automatic sampling equipment or with manual sampling techniques discussed below.

(a) Automatic sampling equipment. Automatic composite samplers that operate with a peristaltic action, a positive displacement action, or a vacuum system are recommended. Centrifugal pumps cannot be used because of adverse shearing effects on the large, readily-settleable biomass floc released from the BIO-SURF media during normal rotation.[1]

Sampling frequency should be adjusted to deliver from 2 to 4 ℓ/day by operation at intervals of 15 to 60 minutes. These intervals should be established with respect to influent variability in terms of concentration. A highly variable influent would dictate a short interval; a relatively constant influent concentration would allow a longer time interval.

Footnote

1. An excellent reference on sampling equipment and on the problems of sampling is found in ASTM Publication No. 582, *Water Pollution Assessment: Automatic Sampling and Measurement*, 1974.



Note: Samples 1 and 10 are composites sampled automatically. Others are generally grab-composite or single-grab samples.

Figure 7. BOD_5 Removal and/or Nitrification Variable-Stage Mode

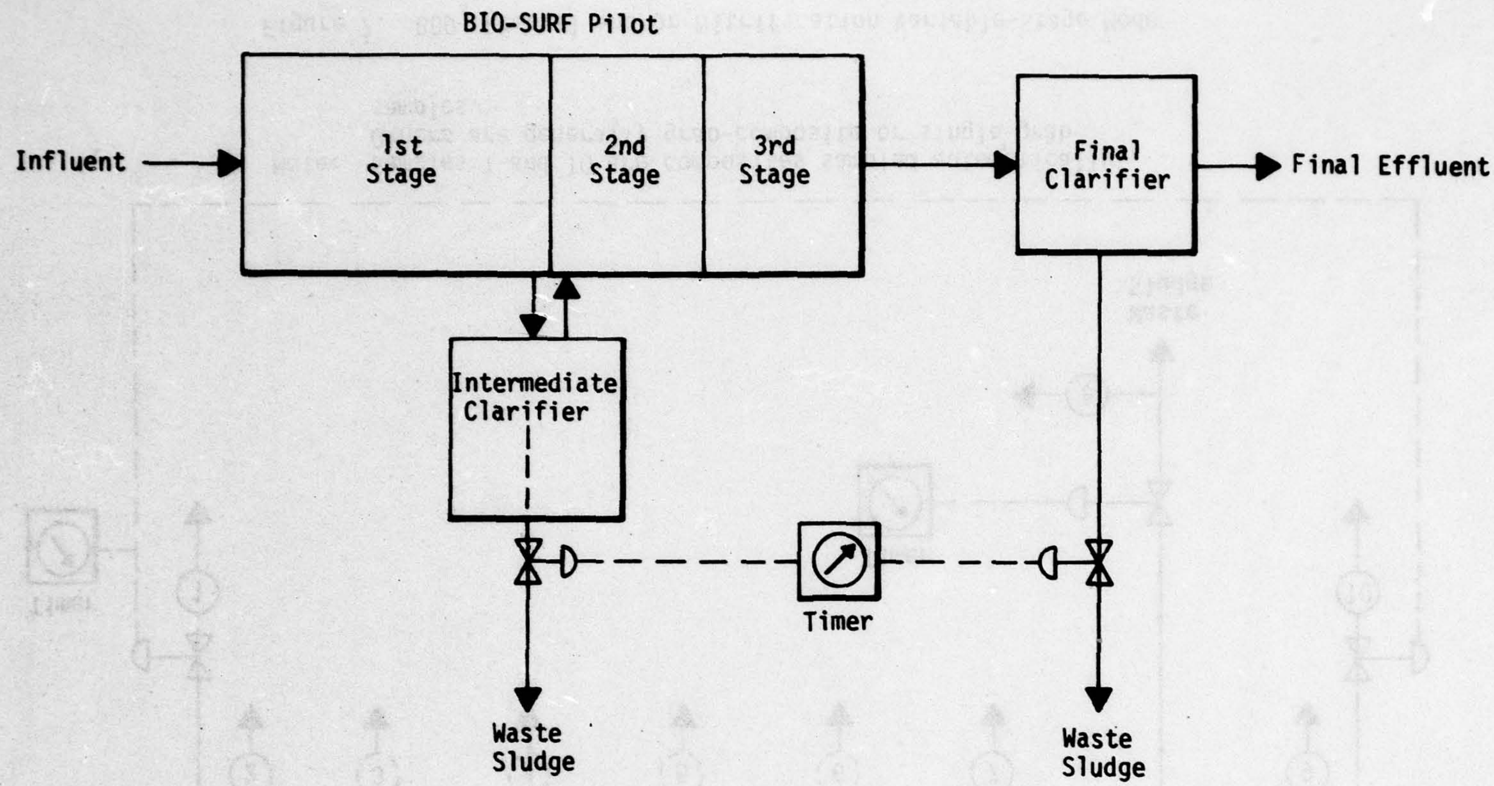
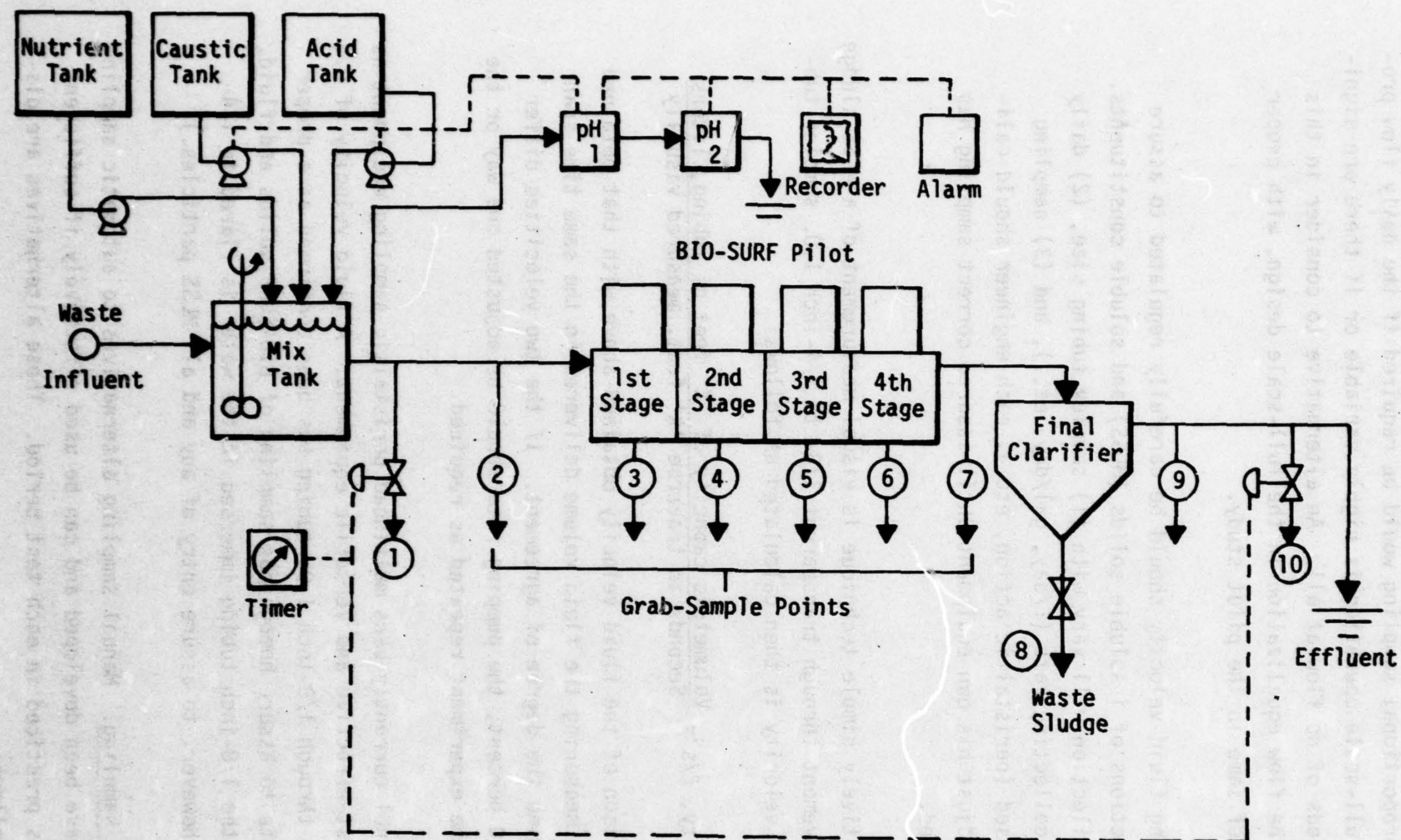


Figure 8. Intermediate Clarification and Large First Stage



Note: Samples 1 and 10 are composites sampled automatically. Others are generally grab-composite or single-grab samples.

Figure 9. Industrial Wastes

Flow proportional sampling would be required if the daily flow profile in a full-scale operation is highly variable or if there are significant periods of no flow at all. An alternative to consider in this case would be flow equalization in the full-scale design, with proper simulation of same in the pilot study.

Sampling fluid velocity should be carefully regulated to assure equal collections of insoluble solids (MLSS) and soluble constituents. As equal collection will vary with (1) sampler tubing size, (2) daily volumetric collecting rate (ℓ/day, gal/day, etc.), and (3) sampling principle used (peristaltic action, etc.), each engineer should calibrate and adjust his own equipment until assured correct sampling has been achieved.

A relatively simple technique is visual measurement of a MLSS sludge particle movement through transparent 1/8- to 1/4-inch I.D. sampler tubing. Fluid velocity is then calculated as follows:

$$\text{Fluid velocity, } \ell/\text{s} = \frac{\text{Volumetric capacity of 'X' feet of tubing, liters}}{\text{Seconds to traverse 'X' feet, measured visually}}$$

Comparison of the fluid velocity obtained above with that obtained by actually measuring the fluid volume delivered in the same time span will determine the degree of agreement. If the two velocities differ more than 10 percent, the pumping rate should be adjusted one way or the other and the experiment repeated as required.

(Autotrol currently uses multihead peristaltic sampling equipment as the most cost-effective and versatile equipment. A fluid velocity of 0.5 to 0.6 ft/s through 1/8-inch I.D. tubing has been confirmed as a proper sampling rate to assure homogenous sampling of BIO-SURF solids and fluid. The end of the 1/8-inch tubing immersed in the water is flared to 1/4-inch I.D., however, to assure entry of any and all MLSS particles.)

(b) Manual sampling. Manual sampling alternatives to automatic sampling equipment have been developed and can be used effectively if sufficient frequency is practiced in each test period. These alternatives are discussed as follows:

(1) Several grab samples taken over a 24-hour period. (Samples are usually taken at 1-, 2- or 4-hour intervals.) A composite sample is prepared from the grab samples.

(2) A 3-grab composite sample prepared within a normal 8-hour shift for analysis for the next day. A minimum of three grab sample *sets* is taken with respect to plug-flow retention time characteristics in a BIO-SURF reactor. (A set is defined as an influent sample, stage samples and an effluent sample.) Although retention time in the unit will vary with hydraulic loading rates (22 minutes between stages at 2.0 gal/day/ft^2), the time span between the first influent sample of the first set and the last effluent sample of the last set can be 7 hours when the flow pattern is typically domestic or if equalization has been incorporated into an industrial process being studied.

The last stage sample and the effluent sample are interchangeable in municipal applications and in industrial applications at hydraulic loadings above 1 gal/day/ft^2. Below 1 gal/day/ft^2, there is a slight holdup of MLSS in the last stage associated with flow over the effluent weir. Again, the total quantity of sample collected should be 2 to 4 ℓ.

(c) Preservation of samples. Preservation of samples during collection is required to prevent continuation of degradation mechanisms. A used refrigerator is generally obtainable for 30 to 50 dollars, and small holes through one of the sides can be easily opened to admit sampling tubing lines. Collector bottles are stored inside, and full bottles are exchanged with empty bottles each day.

Alternatively, large insulated containers of the *picnic* variety can be used in conjunction with thin, rectangular refrigerant, or *ice* substitutes. These ice containers are refrozen daily after each use over the previous 24 hours. Continuous daily sampling would obviously require a double set of these ice containers. While one set is cooling samples, the other set is being refrozen.

Both techniques have been used and carefully evaluated. Either is satisfactory, but a refrigerator is the obvious choice.

As a final general precaution, transparent sampler tubing should be made opaque with either tape or paint. This will prevent algae development in the lines and undesirable spurious effluent BOD concentrations at high levels of treatment.

(d) Preparation of samples for analysis. Effluent samples from a BIO-SURF pilot must be prepared for analysis in three different forms to provide for proper performance evaluation and full-scale projections. These three forms are (1) clarified, or settled effluent, (2) soluble, or filtered effluent, and (3) unsettled, or non-clarified effluent; their descriptions are as follows:

(1) Clarified or settled effluent. Clarification of samples prior to analysis is required to allow an estimation of treatment quality in terms of suspended solids (VSS, TSS) *issuing* from a full-scale clarifier. Clarification is simulated by allowing the sample to settle in an Imhoff cone or similar device. The upper 50 percent of the supernatant is decanted and analyzed. The remainder is discarded or used only for soluble constituent analysis.

Note: A sample from any BIO-SURF stage compartment can be regarded as an "effluent." Thus, one can evaluate the BIO-SURF process in up to four stages of configuration at each hydraulic loading.

(2) Soluble or filtered effluent. Since conversion of soluble matter to insoluble bacteria is ultimately related to the quantity of BIO-SURF media needed full-scale, a portion of all samples (influent as well) must be filtered prior to analysis for soluble constituents.

Of usual principle interest is soluble BOD_5, as the gradual reduction of this parameter on passage of the wastewater through the BIO-SURF unit allows one to properly assess oxygen transfer to the rotating biomass film. Filtration through glass fiber discs is now the industry standard for obtaining soluble wastewater fractions. These discs are obtainable from:

(1) Gelman Instrument Company (Glass Fiber Type A/E)

(2) Reeve-Angel (Type 934 AH)

Filtration equipment for 47-millimeter-diameter discs is available from Millipore Corporation.

(3) Unsettled, or nonclarified effluent. A nonclarified sample is evaluated in terms of mixed liquor solids (MLSS) *entering* a full-scale clarifier. The difference (MLSS-TSS) is used to predict sludge *handling* quantities. This sample usually requires pretreatment before aliquotting and filtering, however. Pretreatment consists of "homogenizing" the sample in a household blender, or equivalent, to reduce the size of the large floccular BIO-SURF solids to assure representative sampling during the act of filling the pipet. This pretreatment step is not required when taking a similar sample of the decanted portion for the TSS determination, since the non-settleables are sufficiently small in size to allow one to pipet a representative sample without difficulty.

When using automatic sampling equipment some precaution is urged in using composite samples to simulate clarification by decantation. As excessive settling has already occurred in any compositor equipment collecting samples over periods of 4 to 24 hours, it becomes necessary to stir or mix the composite sample just prior to resettling or reclarifying.

The proper mixing technique is described as a slow, gentle action to invert the entire sample bottle two to three times or stirring the contents with a stirrer which reaches to the bottom. The mixed sample should be carefully transferred immediately to a 1-ℓ Imhoff cone and allow to settle for 45 minutes. It should then be decanted as described above. (The composite should not agitated excessively with a strong mixing action. Vigorous agitation will result in abnormally high suspended solids in the supernatant fluid.)

When manual compositing techniques are employed, and/or sludge production rates are of secondary or only occasional interest to BOD or NH_3-N removal, it is preferable to settle and decant each sample *before* adding it to the composite. In these cases, the settling time can be reduced to 30 minutes, as settleability of the fresh sample is superior to that of a refrigerated 24-hour composite sample.

Influent samples are *not* decanted, whether collected automatically or manually, when issuing from a primary clarifier or screen. If full-scale clarification or screening is not already a reality, simulation of this process step must be incorporated into the pilot study.

Shutdown Procedures

At the termination of the pilot study the unit should be stripped of active biomass. Influent flow should be discontinued and tap water flow substituted at 250 gal/day (0.17 gal/min) with continued rotation for two days. While rotating, the media should be hosed with water to strip as much of the remaining biomass as possible. The unit should be stopped and drained through the drain plug at the drive end. The unit should then be tilted on its side and the tankage flushed free of remaining sludge. The unit can then be restored to its normal position and rotation started. The unit is then allowed to dry for one to two days. The unit should be stopped and firmly wedged back in the original shipping carton.

Safety Suggestions

It is definitely advised that adequate precautions be taken to avoid equipment damage and/or human injury. The area should be plainly marked with signs to warn observers to stand clear of the unit during operation. Persons involved in sampling duties should be warned against the use of glassware for sampling.

SECTION V
ACTIVATED SLUDGE UNIT

INTRODUCTION

The activated sludge unit utilizes a biological process which stimulates the oxidation of organic matter to aid in the formation of flocculent settleable solids. The process provides intimate contact between sewage and biologically active sludge. The biologically active sludge is developed by prolonged aeration in an environment which accelerates the growth of organisms having the capacity to oxidize the organic matter in influent sewage. The biologically active sludge is brought in contact with the influent sewage and mixed in a gentle rolling motion created by bubbling compressed air through a diffuser pipe. The stable environment is maintained for an extended period of time (about 8 hours), during which time the organic matter in the sewage is oxidized. The colloidal-sized particles then coagulate to form a precipitate which settles out.

The activated sludge process is an aerobic process; and, as such, it requires close supervision by personnel familiar with conducting it effectively. If the unit is allowed to become anaerobic, the organisms which oxidize the organic matter in the sewage will be killed. The entire contents of the compartment which becomes anaerobic or soured would then have to be wasted, the compartment cleaned, and a new batch of raw sewage introduced to restimulate the growth of the organisms.

The spiral flow must be maintained continually to assure that the system does not become anaerobic and that the gentle mixing required for the oxidation of organic matter occurs. The spiral flow must be sufficiently large to assure that all areas of the tank are circulated in order that no settlement occur. If there is settlement in small areas of the tank which become anaerobic, the results obtained from the process will be misleading.

The velocity and character of the spiral flow must be such that turbulent conditions are not created in the compartment. If the flow of air creates turbulent conditions in the tank, the contact between the biologically active sludge and the sewage will not be conducive to the formation of settleable flocculent solids.

The theoretical oxygen requirements of the organisms can be determined if the BOD of the waste and the amount of organisms wasted from the system are known. A portion of the waste is converted into new cells. In order to determine the theoretical oxygen demand of the system, the BOD_L of the wasted cells must be subtracted from the total. The total oxygen requirement may be calculated from the following formula (Reference 2):

$$\text{lb } O_2/\text{day} = \left(\frac{dF}{dt}\right)_L \quad 1.42\left(\frac{dX}{dt}\right)$$

where

$\frac{dX}{dt}$ = sludge production ratio

$\frac{dF}{dt}$ = food utilized per day

If the oxygen transfer efficiency is determined, the actual air requirements for the system can be estimated. Due to the fact that the influent BOD will vary from location to location, the air compressor selected for the TWARDS trailer has a variable flow rate capable of supplying air ranging from 0 to 2 ft^3/gal. The air supply must be adequate to assure that the endogenous respiration by the organisms is satisfied and the spiral flow of the compartment maintained.

It is not usually necessary to add nutrients to the activated sludge unit. The influent sewage generally contains adequate nitrogen, phosphorous, and other elements which the cells need to sustain life. However, if the waste being analyzed is from an industrial source, additional nutrients may be needed.

Reference

2. Metcalf and Eddy, *Wastewater Engineering: Collection, Treatment, Disposal*, McGraw-Hill, 1972.

DESIGN OF ACTIVATED SLUDGE UNIT

The activated sludge unit was designed as a complete mix reactor (Figure 10). At the time the design was initiated, the USAF requested that the following options be in the activated sludge process: (1) tapered aeration, (2) step aeration, and (3) pure oxygen. Due to the square geometrical configuration of the individual compartments in the activated sludge unit, the effectiveness of the tapered aeration and step aeration units must be seriously questioned. The raw sewage may be added at four points along the unit, but the compartments are so small that the unit would function the same as if it were operating in the complete mix mode.

The flow of air may be continuously varied along the length of the tank by varying the spacing of the air diffusers. Again, however, the compartments are too short for the effect of varying the air along the tank to have much impact on the quality of the effluent; and the tank would operate essentially as if it were in the complete mix mode.

The pure oxygen assembly will operate efficiently within the geometrical configuration of the tanks. However, the baffles which are used to induce laminar flow in the complete mix mode may interfere with the mixing process of the pure oxygen system and may have a negative impact on the character of the effluent from the unit.

OPTIONS

Pure Oxygen Option

A pure oxygen activated.sludge system option was included in the design of the unit. The activated sludge unit may be altered for the pure oxygen mode of operation by installing the impeller units located above each compartment (Figure 11). The impellars selected for this option are fixed mount, 1/3-hp, gear drive units, similar to the LIGHTNING Impellar model No. N33G-33. The impellar is used to agitate the liquid and increase the amount of oxygen which the liquid can absorb. For a given set of conditions, assuming that the

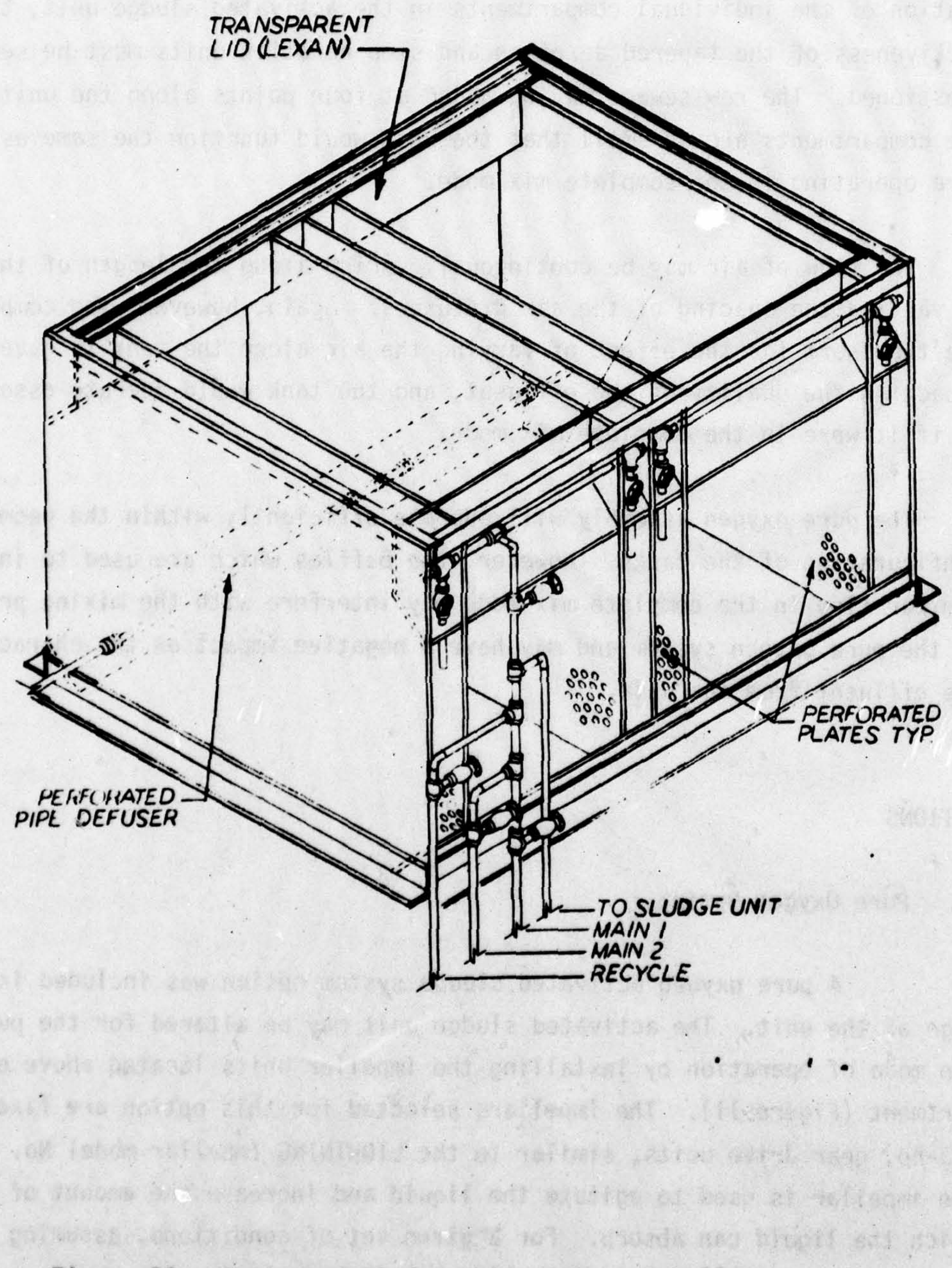


Figure 10. Activated Sludge Unit without Impellars

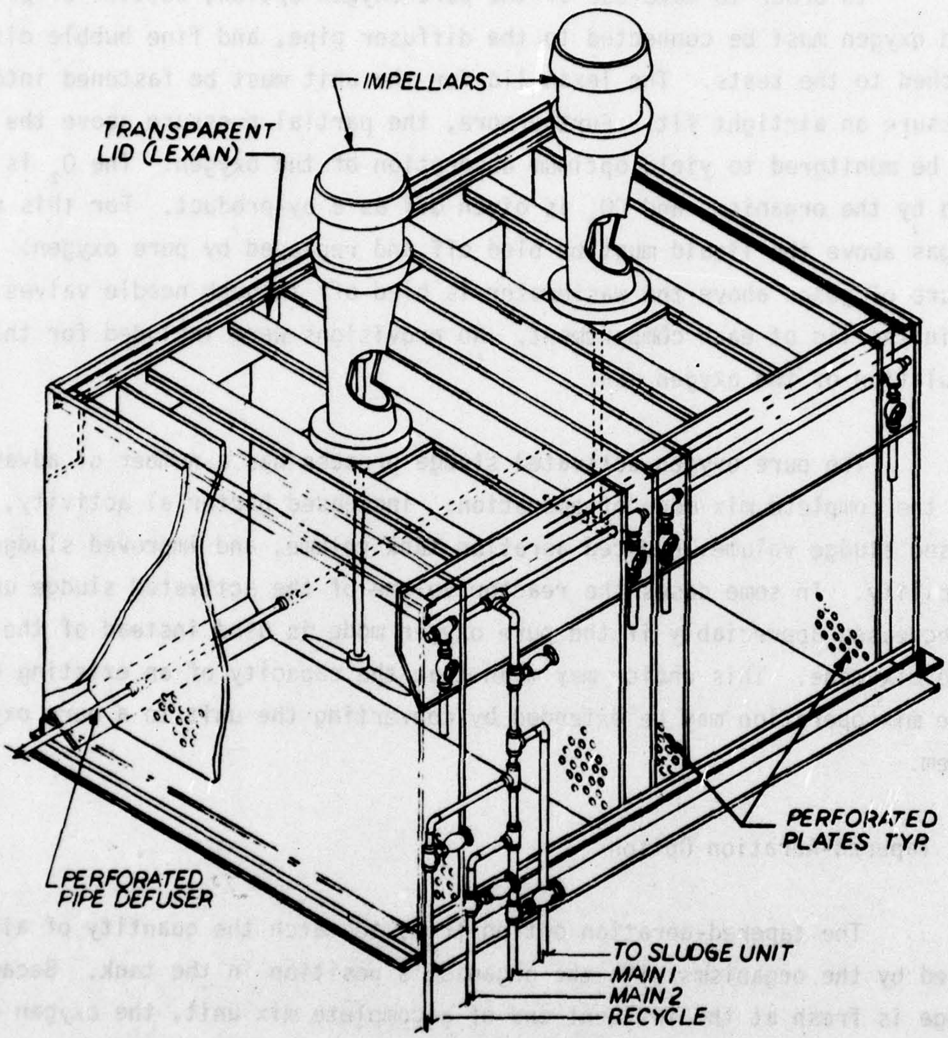


Figure 11. Activated Sludge Unit with Impellars

partial pressure above the liquid is about 0.8, the amount of oxygen that is absorbed by the liquid is about four times that which would be put into the liquid in a complete mix operation.

In order to make use of the pure oxygen option, bottles of pressurized oxygen must be connected to the diffuser pipe, and fine bubble diffusers attached to the tests. The lexan lid for the unit must be fastened into place to assure an airtight fit. Furthermore, the partial pressure above the liquid must be monitored to yield optimum absorption of the oxygen. The O_2 is utilized by the organisms and CO_2 is given off as a by-product. For this reason the gas above the liquid must be bled off and replaced by pure oxygen. The mixture of gases above the wastewater is bled off through needle valves located in the lid of each compartment. No provisions were included for the recirculation of the oxygen gas.

The pure oxygen activated sludge process has a number of advantages over the complete mix mode of operation: increased bacterial activity, decreased sludge volume, reduced aeration tank volume, and improved sludge settleability. In some cases the reactor volume of the activated sludge unit may be decreased appreciably if the pure oxygen mode is used instead of the complete mix mode. This choice may mean that the capacity of an existing complete mix operation may be extended by converting the unit to a pure oxygen system.

Tapered-Aeration Option

The tapered-aeration option tries to match the quantity of air required by the organisms with the organism's position in the tank. Because the sewage is fresh at the influent end of a complete mix unit, the oxygen demand is very high. As the tank is traversed, the oxygen demand decreases as the relative age of the sewage increases. In the unit designed for the TWARDS, the flow of air may be varied as desired by the operator. However, due to the square geometrical configuration of the individual compartments, it is doubtful that varying the flow of air along the tank will have any impact on the quality of the effluent or the quantity of air used.

Step-Aeration Option

The step-aeration option, which consists of introducing the influent sewage at several points along the length of the tank in order to reduce the peak oxygen demand, is a modification of the complete mix process. This option was provided for in the design of the TWARDS; but because the compartments are very short, it is doubtful that the oxygen requirements for step aeration would be significantly different from the oxygen requirements for the complete mix mode of operation.

In summation, the activated sludge unit as designed for the TWARDS will yield good results for the modeling of the complete mix or pure oxygen modes of operation. The unit will operate in the tapered-aeration and step-aeration modes of operation but will not model these options effectively.

DESCRIPTION OF ACTIVATED SLUDGE UNIT

The activated sludge unit is 7 feet long, 4 feet 6 inches high, and 5 feet 6 inches wide. The sidewater depth is 3.54 feet, leaving nearly 1 foot of freeboard. There are longitudinal baffles extending the full length of the unit which are placed at 45-degree angles and are located in the four corners of the unit to assure that a spiral flow will be created.

The air diffuser pipe is located at the lower left-hand corner of the unit as the unit is viewed from the influent end. The diffuser consists of a 1/2-inch pipe on which 1/4-inch capped tee's have been equally spaced at intervals of 6 inches. Plastic or ceramic diffusers may be attached to the diffuser pipe in any desired configuration. The air diffuser pipe may be cleaned in place by backflushing the assembly with water or by forcing a rod down through the pipe. The end of the air diffuser pipe is capped, but the cap may be removed for cleaning. The entire air diffuser assembly may also be removed if necessary.

The overall unit is divided into two separate compartments. If the contents of one of the compartments becomes anaerobic, then only half of the unit load will have to be wasted, and the other half will continue to operate as before.

The influent sewage enters the unit in the upper right-hand side as the unit is viewed from the influent end. The influent sewage is injected downward into the spiral flow from four points along the unit. The inflow points are located at each end of the compartment, between the end plates and the baffles. The flowrates into the individual entry points may be varied or closed off entirely.

The baffles are located 6 inches from the ends of the compartments. The baffles consist of steel plates with 1/2-inch holes equally spaced at 1-1/2-inch intervals, the rows being staggered. The baffles are located in these positions to induce laminar flow through the unit.

The effluent is pumped from the unit at a position midway up the left side as the unit is viewed from the influent end. There are two exit locations, one in the middle of each compartment. The effluent is then pumped into the clarifier where the settlement process takes place. A portion of the settled sewage is returned to innoculate the influent sewage. The recycle rate of the settled sewage is continuously variable from 0 to 2 gallons per minute.

The bottom of the unit is sloped at 2 percent in the two major axis, and 2-inch drain lines are located in the low corners of each compartment. The baffles extend down to 3 inches from the bottom of the unit, leaving a free drainage path to the corner of the compartment.

Access for cleaning the inside of the unit is from the top at each end of the unit. The activated sludge unit should be relatively easy to maintain, and no major maintainance problems are envisioned.

SECTION VI

TRICKLING FILTER UNIT

A trickling filter unit operates by providing a favorable growth environment for oxidizing bacteria. After a period, a thin growth of bacteria will envelop the filter media. As thin sheets of sewage flow around the media and past the bacteria, the organics in the sewage are stabilized by oxidation. The rate at which this process occurs is a function of the size of the filter media and the relative strength of the sewage. In order for the filter to operate efficiently, it is essential to provide both primary treatment in the form of grit and oil removal, and then primary sedimentation. It is generally assumed that primary treatment removes 35 percent of the BOD_L (Reference 3).

The filter medium is composed of a substance that will yield a high surface area per unit volume. Many different filter media are commonly used: crushed stone, slag, cinders, hard coal, and plastic disks or grids. In this particular application, the total weight of the filter medium was also a prime consideration. For this reason the plastic disk filter medium was selected for use on the TWARDS trailer. The medium is generally piled to a depth of 5 to 9 feet. Depths of 5 to 6 feet have been found to be the most efficient.

The influent sewage is usually applied to the unit in the form of a fine spray or in thin sheets. The most commonly used distributor system is a hydraulic powered, center-feed, rotating distributer arm which is either perforated or on which a series of diffusers are located, depending on the type of flow desired. This system creates an intermittent flow. The system which was designed for TWARDS utilizes a fixed-place perforated pipe diffuser system which evenly distributes the wastewater over a perforated plate. The effect of the perforated plate is to distribute the sewage evenly over the filter medium in the form of thin sheets. The trickling filter unit as designed for TWARDS will not, therefore, model the effect of intermittent flow over the filter medium.

Reference

3. Hardenbergh, W. A., and Rodie, E. B., *Water Supply and Waste Disposal*, International Textbook Company, 1960.

A system of underdrains is usually provided in the trickling filter units. The underdrains, generally made of vitrified clay blocks, perform three main functions. These functions are to provide structural support for the filter media, conduct the flow of wastewater to the drain, and provide ventilation for the unit. The blocks are generally about 6 inches deep and have slotted tops designed to allow the maximum expected flow to pass through. The blocks are hollow cored and are aligned to conduct the flow to the main drain line. The central core area of the blocks is designed so that the channel flows no more than half full for the maximum expected flowrate, allowing air to pass freely through the entire depth of the filter medium.

The bacteria that stabilize the organics in the trickling filter unit are the same type as those which oxidize the organics in the activated sludge process. In the activated sludge process the growth is promoted in the sludge, and the oxygen required by the organisms is provided by bubbling air or oxygen through the sludge. In the trickling filter process the bacteria grow in a gelatinous film over the filter particles, and the oxygen is provided by the circulation of air through the full depth of the filter media.

The circulation of air through the filter media is affected by three main factors. The first factor is the difference in temperature between the influent wastewater and the ambient air. This temperature gradient causes a heat exchange process in the filter bed, which in turn causes a density change in the air and leads to the creation of convection currents. The second factor is the pressure gradient caused by the wind sweeping across the surface of the tank. Convection currents are created as the pressure within the unit seeks to come to equilibrium with the ambient pressure. The third factor is the design of the underdrain system. The underdrains are designed to flow half full at the maximum flowrate the system is expected to encounter. The air is thus allowed to circulate through the entire depth of the filter media.

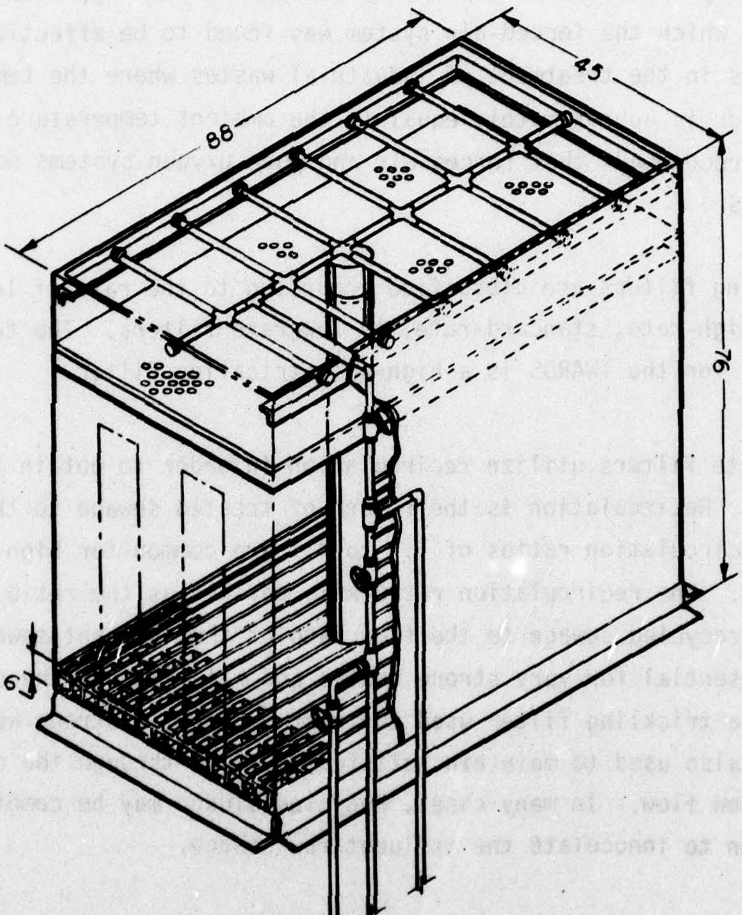
The circulation of the air through the filter media may also be enhanced by mechanical means. Trickling filter units are often provided with ventilation risers or stand pipes. These are pipes which extend vertically from the surface of the unit to the top of the vitrified clay blocks. The pipe allows for free passage of air from the atmosphere down through the ventilation riser and up through the filter media, and the reverse. When the ambient temperature is below freezing, the ventilation risers must be covered to prevent the wastewater from freezing and killing the oxidizing bacteria.

Forced-air and pure oxygen systems have been tested to determine their effect on the trickling filter efficiency. It has been found that the performance of forced-air and pure oxygen trickling filter systems does not differ appreciably from that of a properly designed trickling filter unit. The only case in which the forced-air system was found to be effective and cost-efficient was in the treatment of industrial wastes where the temperature of the wastewater is approximately equal to the ambient temperature. For this reason CERF recommends that forced-air and pure oxygen systems not be included on the TWARDS.

Trickling filters are classified according to the rate of loading and are denoted as high-rate, standard-rate, or low-rate filters. The trickling filter designed for the TWARDS is a high-rate trickling filter.

High-rate filters utilize recirculation in order to obtain the required BOD removal. Recirculation is the return of treated sewage to the treatment process. Recirculation ratios of 1:1 to 4:1 are common for high rate trickling filters. The recirculation ratio R is defined as the ratio of the flow rate of the recycled sewage to the flow rate of the influent sewage. Recirculation is essential for very strong wastes and will improve the operating efficiency of a trickling filter used to treat moderately strong wastes. Recirculation is also used to maintain satisfactory flow through the unit during periods of low flow. In many cases, recycled sludge may be combined with the recirculation to innoculate the influent raw sewage.

The trickling filter unit designed for the TWARDS utilizes a fixed distribution system (Figure 12). This system consists of a 1-inch main feed line, from which twelve 1/2-inch lines emanate. The 1/2-inch distribution arms are equally spaced along the length of the tank, six on each side of the main distribution line. These 1/2-inch lines are perforated with five 1/4-inch holes equally spaced along the length of each pipe. The end of each pipe is capped, and the connection to the main line is flexible so that the entire



Dimensions in inches.

Figure 12. Trickling Filter Unit

distribution assembly can be removed or lifted up to be cleaned. The system has been designed so that a rod can be forced through every pipe, should a pipe become clogged.

The wastewater is evenly distributed over a perforated plate made of 1/4-inch lexan sheet. The perforated plate produces sheet flow uniformly over the entire surface of the filter medium. The flow over the medium will be continuous and will not model an intermittently fed field unit. The unit, as it has been designed, can use many different types of media; but it is suggested that a plastic disk medium be used.

The filter medium is supported by a layer of vitrified clay blocks. The blocks are slotted to allow for a vehicle flow of 3.5 gallons per minute plus a recycle ratio of 4:1. The floor of the unit has a 2-percent slope along the major axes, and the blocks are aligned to carry the wastewater down the longitudinal incline. The wastewater will then be carried down the transverse slope to the drain.

A ventilation riser has been included with the unit. The ventilation riser is a 6-inch-diameter PVC pipe which extends from the top of the clay blocks to within 1 inch of the pipe distribution system. The riser extends through the perforated plate where there is a close fit but not a watertight seal. The purpose of the standpipe is to increase the circulation of air through the unit. Temperature and pressure gradients would not create an adequate convection current without the ventilation riser for two major reasons. First, the unit will be located in a trailer where it will be partially protected from wind and direct sunlight. Second, a perforated plate will cover the entire surface of the unit, lessening the effects of wind and temperature on the creation of convection currents. The vitrified clay blocks were designed to permit the free flow of air through the collection system.

Lexan viewing windows are provided on both ends of the unit. The windows extend almost the entire depth of the media in order that the entire process may be viewed from the side.

The unit is fabricated from steel plate of the thicknesses specified in the plans. The individual plates were designed for a simple support condition. In actuality, the edges of the plates will be fixed and will sustain a moment. Therefore, the design of the individual plates is conservative.

The effluent will be pumped out from a 1-inch drain line located in the low corner of the unit. The effluent line will have a valve and a tee located on it immediately below the corner of the unit. This valve and tee will be used to dispose of any waste resulting from the cleaning of the unit. A valve and tee will also be placed on the influent line so that samples may be taken, pipes flushed, the filter medium flooded with fresh water, and the unit used independently of the flow regimes provided on the TWARDS trailer.

The subtask statement requested that the trickling filter unit utilize the pure oxygen or forced air options for treatment. When the literature was reviewed for the project, a reference was found which states that the pure oxygen and forced air systems do not significantly increase the performance of the trickling filter unit and therefore are not cost-effective (Reference 2). For this reason the pure oxygen and forced-air options were not included with the trickling filter unit.

The trickling filter unit should be relatively simple to maintain. The pipe distribution system and the perforated plate can be removed without difficulty and cleaned by hand. The filter media can be cleaned by flooding through the distribution system or by flooding from a hand-held hose. If it is necessary to remove the medium and clean the inside of the tank, the medium will have to be taken out by hand and scrubbed clean of wastes.

The unit will be supported on the trailer along the edges by 4- by 4- by 1/2-inch angle irons welded to the body of the unit and bolted to the support members of the trailer. No provision was made for vibration isolation in the individual unit support. An air bag suspension system was specified for the trailer in order to reduce the amount of vibration felt by the individual unit.

SECTION VII
CLARIFIER UNIT

INTRODUCTION

The prime objective of the clarifier unit is to separate the suspended solids, which are heavier than water, by means of gravitational settling. The solids that are removed may be small particles of mineral or organic matter or activated sludge solids which must be separated from the mixed liquid. The settling velocity of the solids is affected by the shape, size, and density of the particles; the viscosity of the fluid; the temperature of the fluid; and the frictional resistance of the particles to settling.

The tank used in the TWARDS trailer is a rectangular, horizontal-flow unit. The influent is admitted at one end of the tank and exits over an overflow weir at the top of the other end of the tank. The detention time must be adequate for the settlement process to occur. The solids will gradually settle to the bottom of the tank and form a blanket of varying thickness. In order to obtain efficient clarification and sludge removal, the following conditions should be achieved: (1) The flow through the settling tank should be uniform. (2) No currents should be induced in the tank which might interfere with the settlement process. (3) A suitable detention time should be utilized which is appropriate for the sludge to be separated. Density currents, induced by differences in the specific gravity of the influent, will also have a negative impact on the settling characteristics of the sedimentation tank. These currents may be eliminated by designing an inlet which properly distributes the influent sewage across the tank.

The most important variable in the design of the sedimentation tank is the overflow rate. The overflow rate is computed by dividing the influent flowrate by the surface area of the sedimentation tank. The overflow rate is generally specified in terms of the number of gallons per day per unit area. The detention time is also important in the design of the sedimentation tank. It has been found that the best results for gravity clarification generally occur for a detention time of approximately 2 to 3 hours and an overflow rate of less than 800 $gal/day/ft^2$ (Reference 3). Experimental results also show that the performance of the sedimentation tank is not improved for detention times of greater than 2 to 3 hours. The rate of loading of suspended solids in sewage also has no effect on the efficiency of the unit.

Four types of settlement may occur in the sedimentation tank separately or together (Reference 3). The first is *type one settling* which describes discrete particle settling in a dilute solution. In this system there is no interference between particles, and the specific gravity of the particles is usually significantly greater than 1. The parameters primarily responsible for the settling efficiency are the settling properties of the particle and the overflow rate.

Type two settling applies to the settling of flocculent particles in a dilute solution. Particles which have a very small mass coalesce or flocculate and form particles of larger mass which settles out at a faster rate. Performance of the system is affected by the settling properties of the particle, the overflow rate, the detention time, the depth of the tank, and the initial concentration of the sewage.

Type three settling is also known as *zone settling*. Zone settling occurs in suspensions of intermediate concentrations. Particles tend to settle in positions which are fixed relative to each other. The efficiency of this type of settlement is affected by the settling properties of the particle and the concentration of the slurry.

Type four settling occurs when particles form a structure like the blanket of sludge which forms at the bottom of the clarifier. Further settlement can take place only by the compression of the structure. This compression takes place in the bottom layers of the sludge mass and is caused by the weight of the sludge on top. Performance of the system is affected by the rheological properties of the suspension, i.e., shear stress, viscosity, and yield strength.

DESCRIPTION OF CLARIFIER UNIT

The clarifier unit was designed to follow the trickling filter, the activated sludge, the biodisc, the fluidized bed, and the flocculator units. The purpose of this clarifier unit is to provide a quiescent basin with sufficient detention time for sedimentation to occur in order to provide a clarified effluent and to produce sludge with a high solids concentration. In order to achieve these goals, the clarifier unit was designed with an overflow rate of 700 gal/day/ft^2 and a detention time of 2 hours.

The clarifier unit will be fabricated from steel plate (Figure 13). The overall unit will be divided into four compartments. The first compartment can receive the effluent from the trickling filter or the biodisc unit. The second compartment will receive the effluent from the activated sludge unit. The third compartment will receive effluent from the fluidized bed unit of the biodisc denitrification unit. The fourth compartment will receive effluent from the rapid mix and flocculator units.

The clarifier unit is 4 feet 4 inches wide, 7 feet long, and 6 feet 4 inches high, provided the sludge collection system is not included in the height. The side walls will be fabricated from 5/8-inch steel plate so that each compartment will be just over 1 foot wide. The end plates, bottom plates, and baffles will be fabricated from 3/8-inch steel plate. Lexan viewing windows have been provided on the ends of each compartment.

Each major compartment is subdivided into three smaller compartments in lengths of 1, 2, and 3 feet along the length of the tank. The subcompartments are designed to accommodate flowrates of 0.5, 2.0, and 3.5 gal/min with a constant overflow rate of 700 gal/day/ft^2. The compartments are subdivided by perforated steel plates which serve a dual purpose in the clarifier unit. First, the perforated plates will induce laminar flow through the unit and eliminate currents which might be caused by differences in temperature or density of solids or by the velocity of the influent sewage as it enters the compartment. Second, the perforated plates also serve as a structural support for the PVC sheets which subdivide the compartments for the different flowrates. A neoprene gasket has been provided around the edge of the perforated

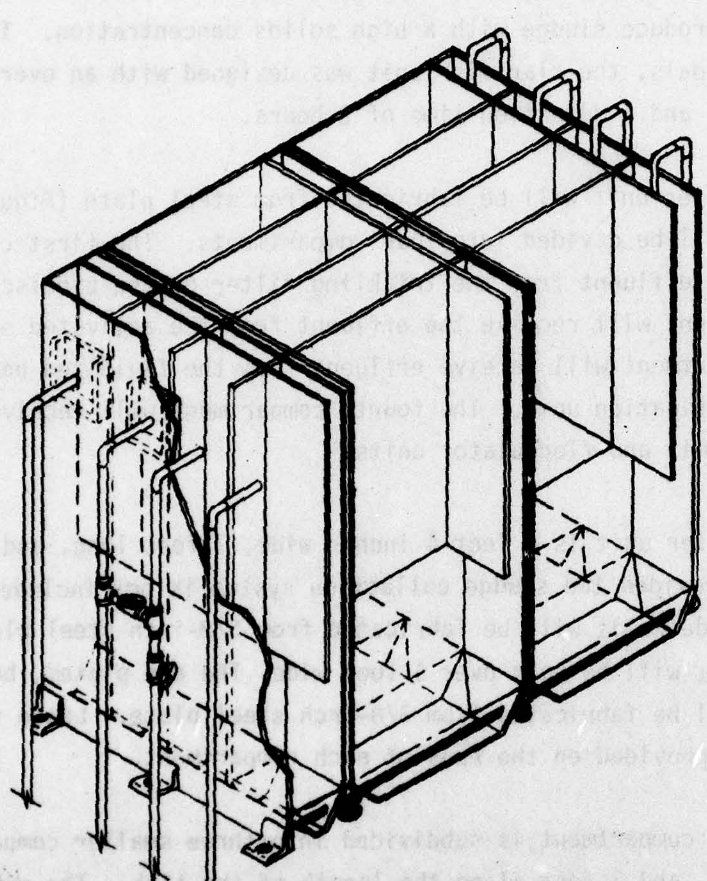


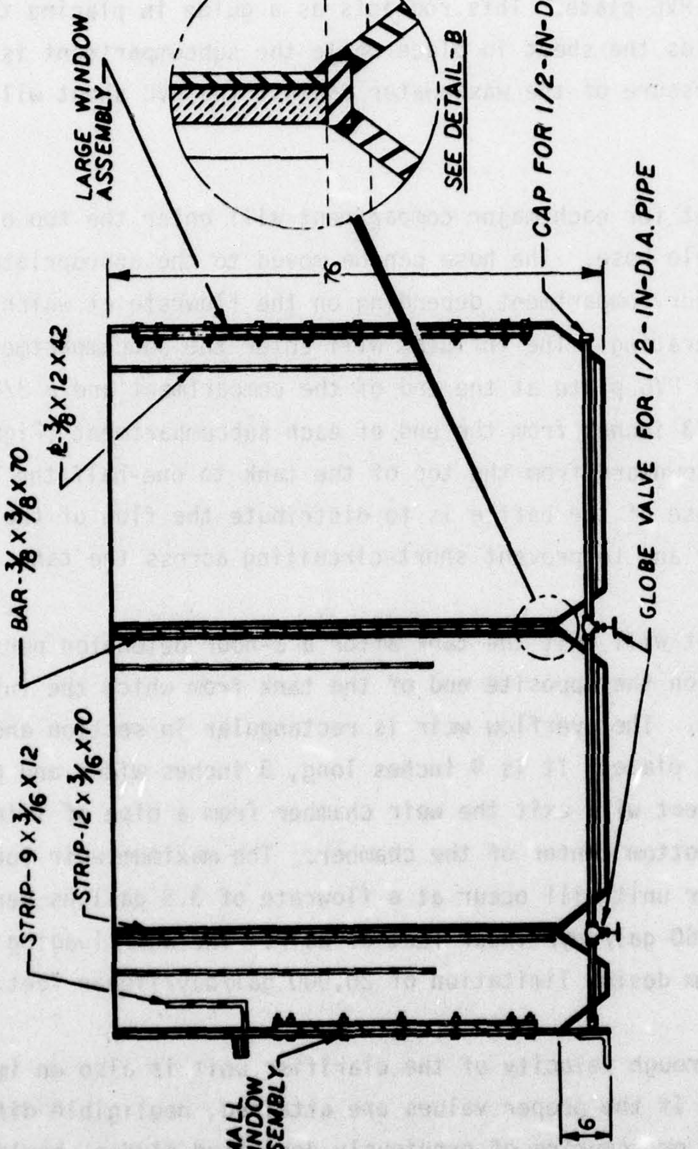
Figure 13. Clarifier Unit

steel plate. If a flowrate of 2 gallons per minute is being used, a PVC sheet should be inserted next to the baffle to seal off the compartment and prevent wastewater from entering the next subcompartment. A guide block, fabricated from 1/2- x 1/2-inch square steel rod, extends from the top of the tank to the seat of the PVC plate. This rod acts as a guide in placing the PVC sheet in place and holds the sheet in place while the subcompartment is being filled. The pressure of the wastewater against the PVC sheet will form a watertight seal.

The influent for each major compartment will enter the top of the unit through a flexible hose. The hose can be moved to the appropriate subcompartment of each major compartment depending on the flowrate at which the clarifier unit is operating. The influent will enter the subcompartment vertically down between the PVC plate at the end of the compartment and a 3/8-inch steel baffle which is 3 inches from the end of each subcompartment (Figure 14). The baffle extends downward from the top of the tank to one-half the height of the tank. The purpose of the baffle is to distribute the flow of the influent sewage uniformly and to prevent short-circuiting across the tank.

The effluent will exit the tank after a 2-hour detention period over a weir positioned on the opposite end of the tank from which the influent entered the tank. The overflow weir is rectangular in section and is fabricated from steel plate. It is 9 inches long, 3 inches wide, and 6 inches deep. The effluent will exit the weir chamber from a pipe of 1-inch diameter located at the bottom center of the chamber. The maximum weir loading rate for the clarifier unit will occur at a flowrate of 3.5 gallons per minute; this value is 3360 gal/day/linear feet of weir. The weir loading rate is well below the maximum design limitation of 20,000 gal/day/linear feet.

The flow-through velocity of the clarifier unit is also an important design parameter. If the proper values are attained, negligible difficulty from density currents or scouring of previously deposited sludge should occur. The maximum allowable flow-through velocity is 100 ft/hour. The flow-through velocity for the TWARDS clarifier unit is 3.89 ft/hour which will provide a safety factor of about 25 against the formation of density currents and scouring of previously deposited sludge. The baffle at the influent, the low flow-through



Dimensions in Inches

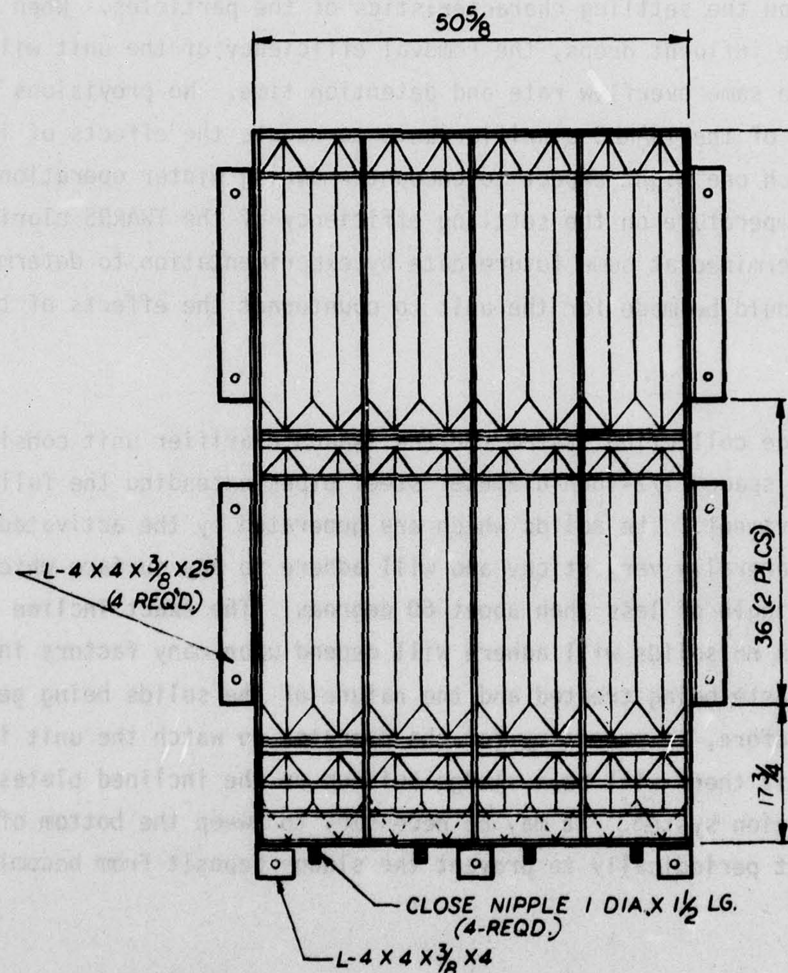
Figure 14. Clarifier Section

velocity, and the perforated plates along the length of the tank should ensure that no problem will be created by adverse currents and scouring.

The activated sludge solids have a specific gravity which is very near to that of water. For this reason the viscosity of the water will have a very large effect on the settling characteristics of the particles. When the temperature of the influent drops, the removal efficiency of the unit will decrease for the same overflow rate and detention time. No provisions were made in the design of the TWARDS clarifier unit to negate the effects of low temperatures, which one might expect to encounter during winter operation. The effects of temperature on the settling efficiency of the TWARDS clarifier unit should be determined at some future date by experimentation to determine what provisions should be made for the unit to counteract the effects of temperature.

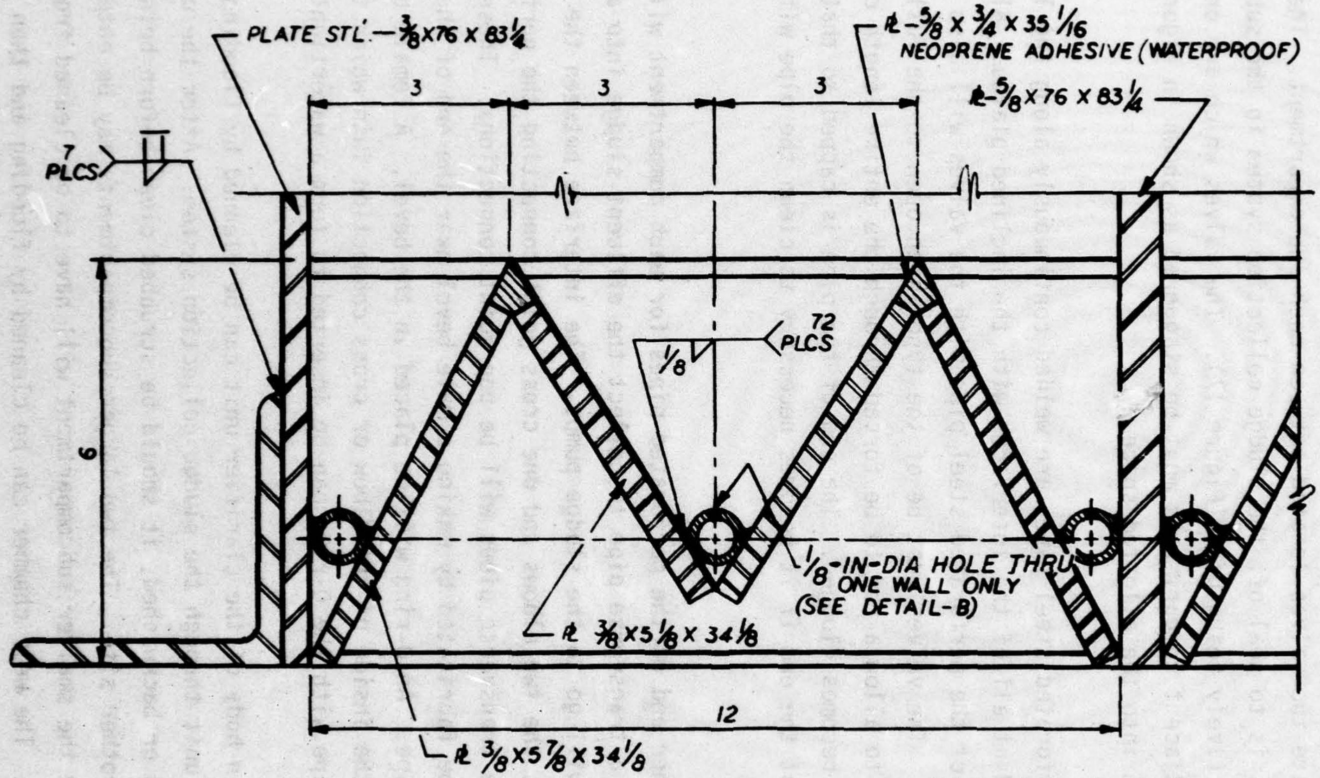
The sludge collection system for the TWARDS clarifier unit consists of three equally spaced 1/2-inch-diameter steel pipes extending the full length of each compartment. The solids which are generated by the activated sludge process are generally very sticky and will adhere to any surface which is inclined at an angle of less than about 60 degrees. The exact incline of a plate to which no solids will adhere will depend upon many factors including the type of waste being treated and the nature of the solids being generated. It will, therefore, be necessary for the operator to watch the unit initially to determine if there will be a sludge buildup on the inclined plates of the sludge collection system. It may be necessary to sweep the bottom of the clarifier unit periodically to prevent the sludge deposit from becoming anaerobic.

The bottom of the clarifier unit is fabricated from 3/8-inch plates. A plan view of the clarifier unit is shown in Figure 15. A detail of the transverse section of the clarifier compartment is shown in Figure 16. The plates are inclined at an angle of 60 degrees. A prism of PVC will be affixed to the ridges of the inclined plates to provided a sharp interface between the inclines. The sludge will slide down the inclines to the perforated steel pipes at the bottoms of the inclines and be pumped out of the compartment.



Dimensions in inches.

Figure 15. Clarifier Plan View



Dimensions in inches.

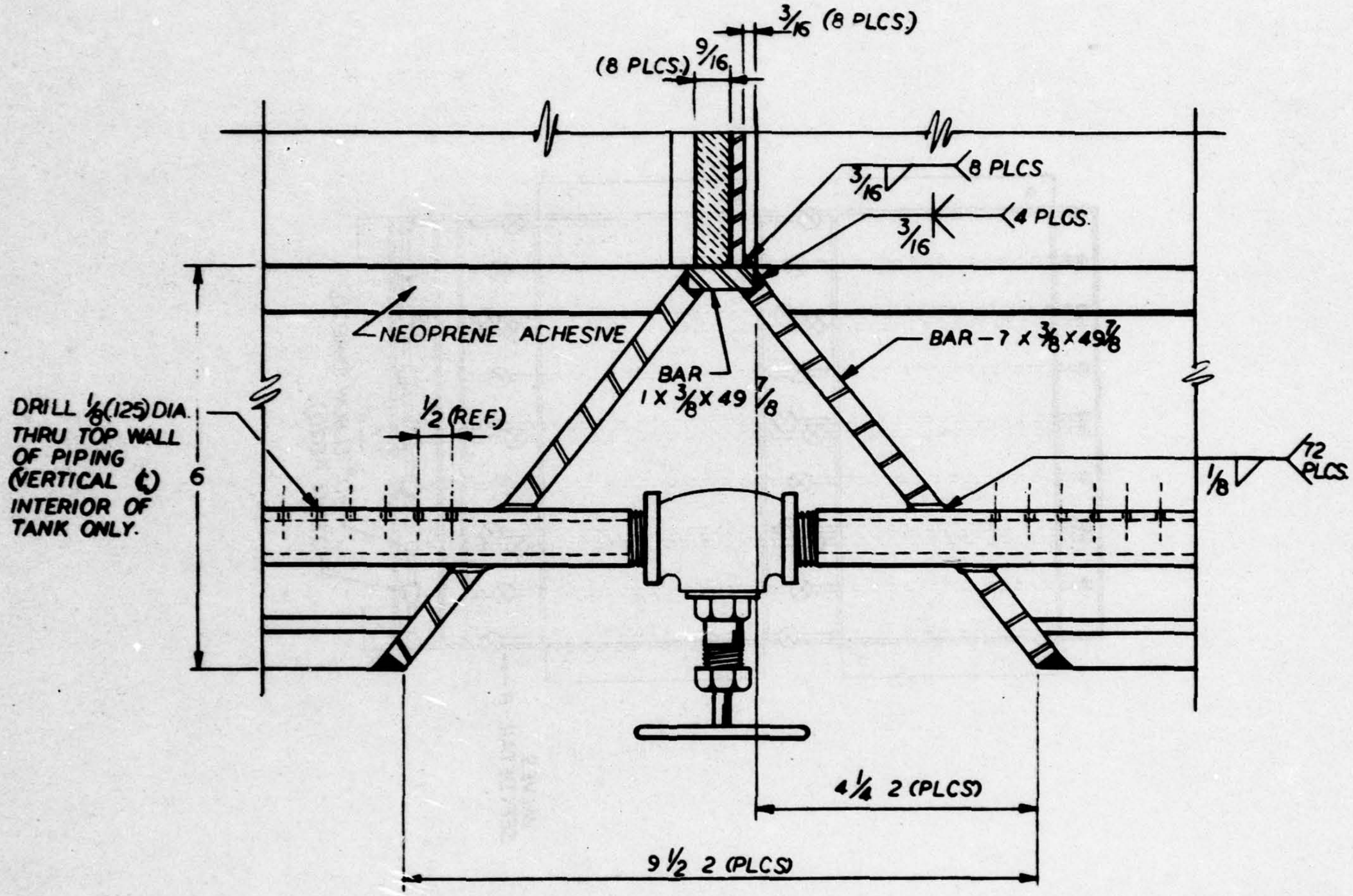
Figure 16. Sludge Collection Detail

At the interfaces between the subcompartments in each compartment there is a 1-inch-wide horizontal plate, from which inclined plates slope down at an angle of 45 degrees. The plates had to be inclined at an angle of 45 degrees to accommodate the valves located between each subcompartment. The purpose of these valves is to seal off the sludge collection system in the subcompartments not actively being used (Figure 17). The valves which are on lines between the adjacent compartments must be staggered as shown in Figure 18 in order to fit into the allotted space.

The perforated steel pipes are welded continuously along the length of the pipe and at all of the interfaces with the inclined plates. All of the connections of the perforated steel pipe with the valves will also be welded connections. The valves must be of the type which open to the full diameter of the pipe to allow a rod to be forced through the entire length of the pipe if the pipe becomes clogged. The end of the pipe is capped so that solids can be forced out the end if it becomes necessary to clean the pipe with a rod (Figure 19).

The other end of the perforated pipes for each compartment will be connected with a transverse pipe to collect the effluent sludge into a 1-inch line which will go to the sludge pumps. The interface between the perforated steel pipes, the two elbows and one cross joint connecting the perforated pipes to the transverse pipes will be pop joint connections. These connections will be fabricated by making a male bevel near the end of the perforated steel pipe. An O-ring will be placed in the bevel. A female bevel will be made in the inside of the elbow or cross connection into which the perforated steel pipe with the O-ring can be inserted to form a watertight seal.

The main body of the clarifier unit can be cleaned by flooding or backwashing the unit through the sludge collection system. After the unit has been flooded or backwashed, it should be scrubbed clean before being transported to another site. The two larger subcompartments may be entered to be cleaned, and the smaller subcompartment will have to be cleaned from the top of the unit. The weir chamber can be cleaned by flooding and then scrubbing. The sludge collection system can be cleaned by backwashing and, if necessary, by forcing a rod through each individual pipe to remove any solids which might be deposited.



Dimensions in inches.

Figure 17. Valve Placement Detail

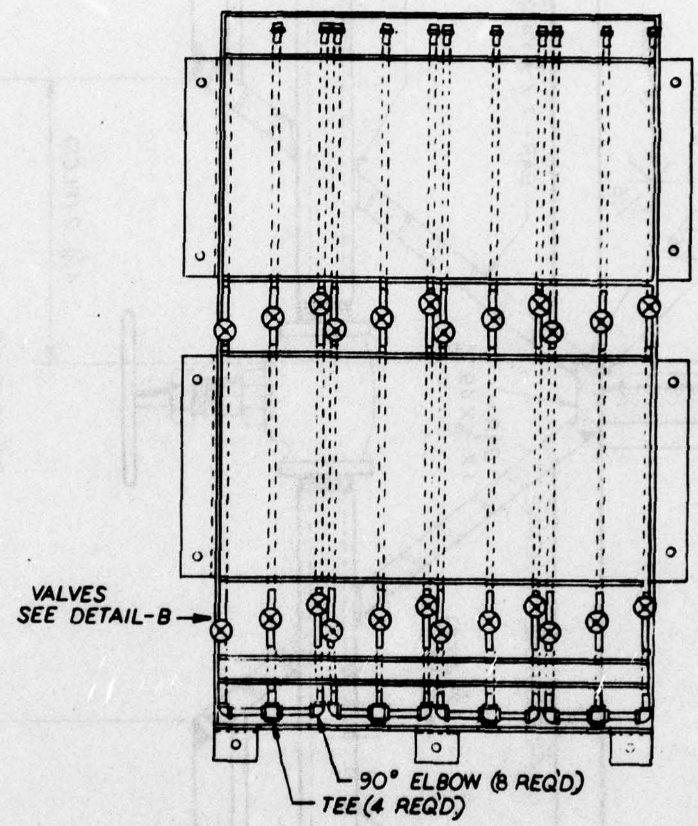
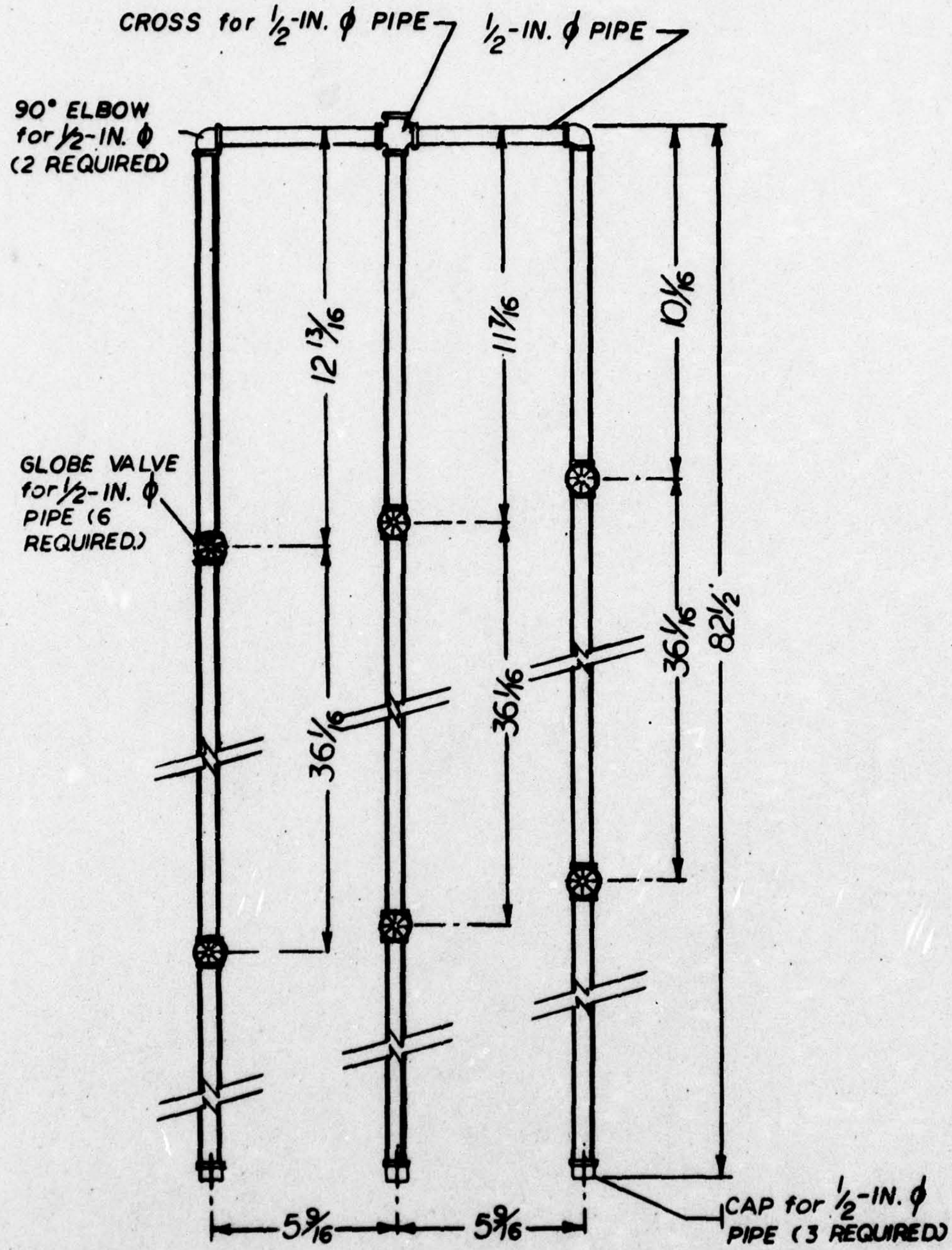


Figure 18. Clarifier Bottom View



Dimensions in inches.

Figure 19. Clarifier Piping Diagram

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SECTION VIII
RAPID MIX BASIN AND FLOCCULATOR UNIT

The purpose of the rapid mix basin and flocculator unit is to provide an environment in which chemical coagulation can take place efficiently. The purpose of chemical coagulation is to neutralize the charge on the colloid which will allow it to form precipitates. The individual particles can then coalesce to form sticky flocs which, being of larger mass, will settle out more readily. As the flocs settle to the bottom of the tank, they absorb other impurities in the water. The flocs can be removed by sedimentation.

To neutralize the charge on the colloid, the chemical additives must overcome the effect of the electrical double layer. Negatively charged colloids are surrounded by the positive hydrogen atoms of the polar water molecule, exposing the negative oxygen atom, which will attract positive ions and other water molecules in the solution. When the positive ions in the solution migrate to the colloid, they leave a high concentration of negative ions in solution. This concentration creates an electrically stable solution. The repulsive forces can be classified in two categories: (1) *Electrostatic*--the repulsion between like forces (decreases with the square of the distance); and (2) *Hydrostatic*--the attraction of water molecules to form a cushion. The attractive forces between the particles are Van der Waals forces which decrease with the seventh power of distance. A graph showing the potential energy versus the distance from the particle demonstrates the dominant nature of the repulsive force a very short distance from the particle (Figure 20). When chemical coagulants are added to the solution, the effect of the repulsive forces can be partially negated so that flocs can form.[1]

The compression of the electrical double layer will occur for solutions of high alkalinity according to the following net equation:

$$A\ell_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2A\ell(OH)_3 + 3CaSO_4 \downarrow + 6CO_2$$

Footnote

1. Lecture Notes, CEE 364, Dennis George, Utah State University.

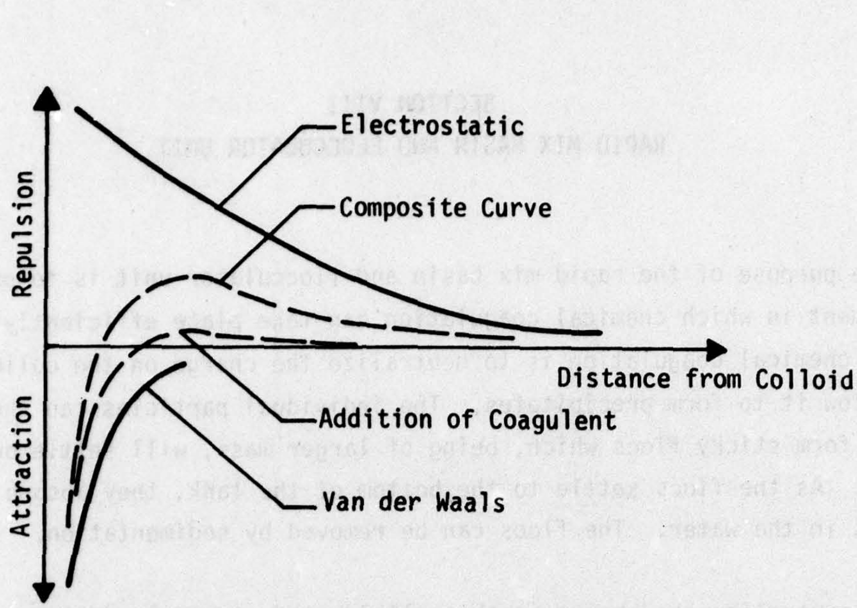


Figure 20. Potential Energy versus Distance from the Colloid

Solutions which have a low alkalinity can be precipitated with the addition of aluminum sulfate according to the following equation:

$$A\ell_2(SO_4)_3 + 6H_2O \rightleftarrows 2A\ell(OH)_3 + 3H_2SO_4$$

As the equations show, the amount and type of chemical coagulant which should be added to the sewage is pH-dependent; and it should be determined on a daily basis at least during the first two weeks of operation.

The effectiveness of the coagulant can be enhanced if the dosage is such that *olation* or *oxolation* occurs (Reference 2). *Olation* is the formation of hydroxyl bridges as shown in the equation below:

$$[(H_2O)_5 \cdot A\ell \genfrac{}{}{0pt}{}{\diagup OH \diagdown}{\diagdown OH \diagup} A\ell \cdot (H_2O)_5] + 4$$

Oxolation is the formation of oxygen bridges as shown in the equation below:

$$[(H_2O)_5 \cdot A\ell - O - A\ell \cdot (H_2O)_5] + 4$$

The particles of larger diameter formed by bridging colloids will expedite precipitation during the sedimentation phase.

If the amount of flocs formed is plotted against the coagulent dosage (Figure 21), there are four distinct zones of effectiveness. In Zone 1 the

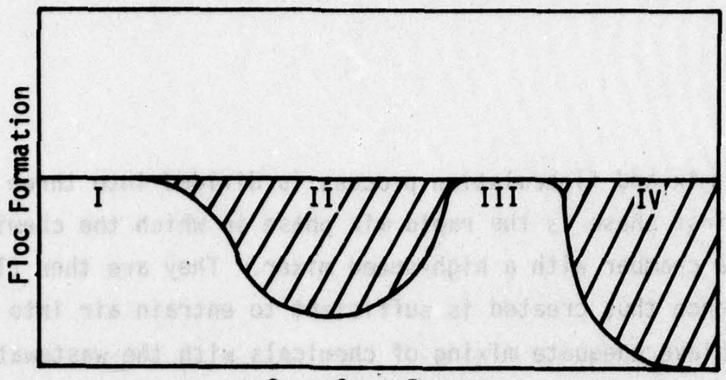


Figure 21. Zones of Coagulation

dosage of the coagulent is insufficient for flocs to form. In Zone 2 there is induced destabilization of the colloid, and the flocs form. In Zone 3 there is restabilization of the flocs, and the solution becomes electrically stable. Flocs form because there is too much coagulent and all of the attached sites are occupied. In Zone 4 supersaturation occurs. The flocs bridge between colloids to form particles of larger diameters and greater specific gravity so they can settle out in the sedimentation process. The coagulent will form a precipitate which will settle out and sweep the floc.

PHOSPHOROUS REMOVAL

Phosphorous removal can be accomplished by precipitation in the rapid mix basin and flocculator unit as an option to the treatment process. Chemicals used for phosphorous removal are alum, ferric chloride, ferric sulfate, lime, and polymers. Tests must be conducted on each waste in the pH range at which treatment takes place. The chemicals may be added in the rapid mix basin or the flocculator tank, whichever yields the best results. The pH of the influent sewage must be tightly controlled if the phosphorous is to be removed efficiently (Figure 22).

MIXING

The rapid mix and flocculation process is divided into three distinct phases. The first phase is the rapid mix phase in which the chemicals are introduced into a chamber with a high-speed mixer. They are then flash-mixed, and the turbulence thus created is sufficient to entrain air into the slurry formed. To achieve adequate mixing of chemicals with the wastewater and to provide the necessary air entrainment, a Reynolds number greater than or equal to 10,000 should be provided. The Reynolds number can be calculated from the following formula:

$$R_e = \frac{D_a^2 n \rho}{\mu}$$

where

D_a = diameter of impellar
n = r/s of impellar
ρ = mass density of liquid
μ = viscosity of liquid (lb mass/ft-s)

Care should be taken in the design of the rapid mix basin to assure that a vortex is not formed that will prevent vertical mixing. In a rectangular mixing chamber, it is not necessary to provide baffles to eliminate the formation of a vortex because the mass rotary motion is broken up by the corners of the tank, where the flowrate is slower, and no vortex will form.

The impellar used in the rapid mix basin on the TWARDS trailer is a flat six-blade turbine. The impellar is mounted in the geometrical center of the unit and is located 2 inches from the bottom of the chamber. The depth of the liquid in the rapid mix basin is 0.4 feet. The design Reynolds number is 50,000. By the use of the previous formula, the shaft speed of the impellar can be calculated (n = 5.48 r/s = 328.7 r/min). If the shaft speed of the

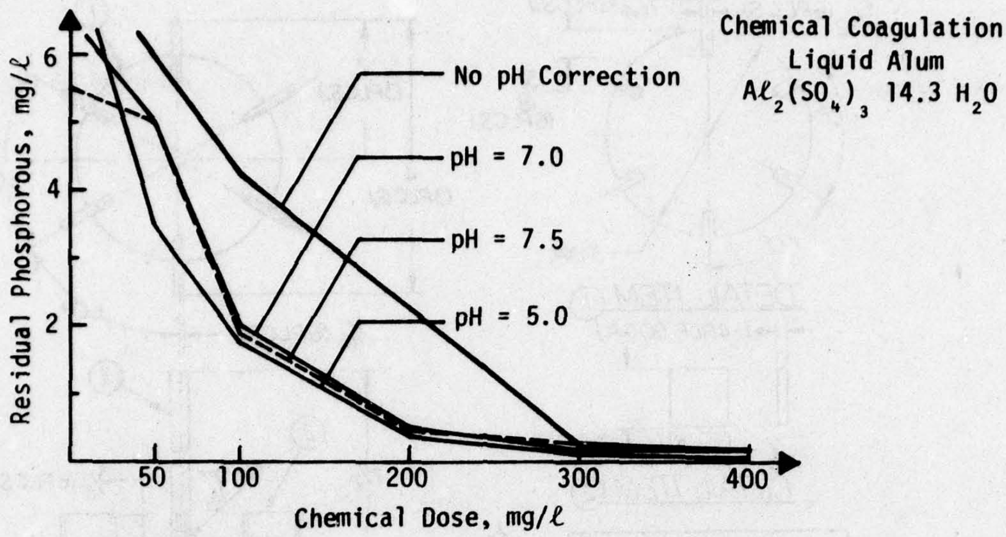


Figure 22. Residual Phosphorous Concentration

impellar is known, the power requirements can be calculated according to the following formula:

$$P = \frac{k}{g_c} \rho n^3 D_a^5$$

where

P = power required for impellar drive unit in ft-lb/sec

k = constant (6.3)

g_c = Newton's Law conversion factor, 32.2 ft-lb mass/sec² = lb

The required power for the impellar unit used on the TWARDS trailer is 1/50 hp. The area required for the paddle blades may be calculated from the following formula:

$$A = 2P/C_D \rho v^3$$

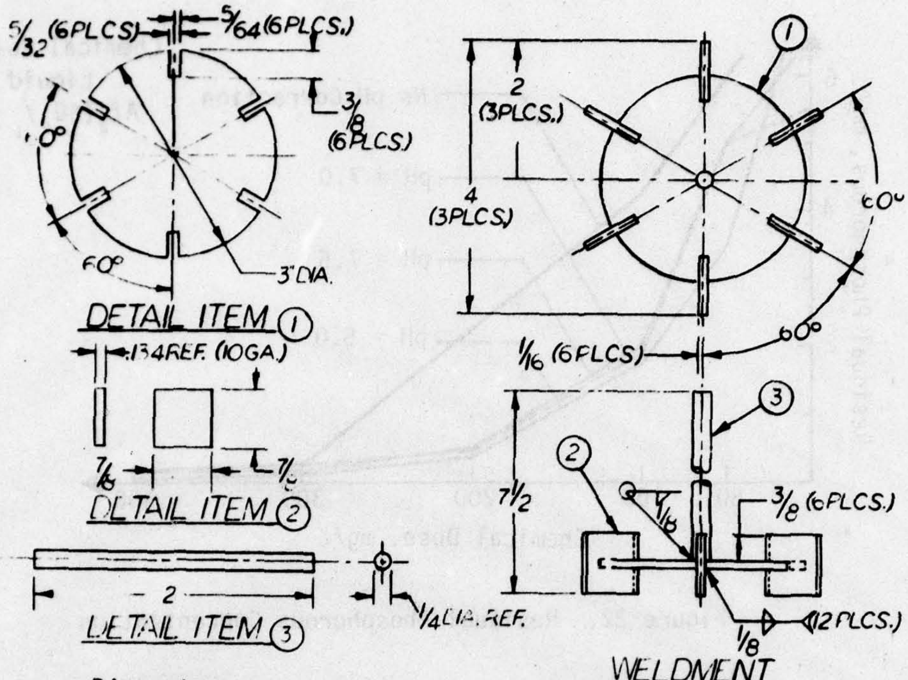
where

C_D = coefficient of drag of flocculator paddles moving perpendicular to fluid (1.8)

v = relative velocity of paddles in fluid, ft/sec, usually about 0.75 v_p

v_p = tip velocity of the paddle

Figure 23 shows the dimensions of the paddles used on the impellar in the TWARDS.



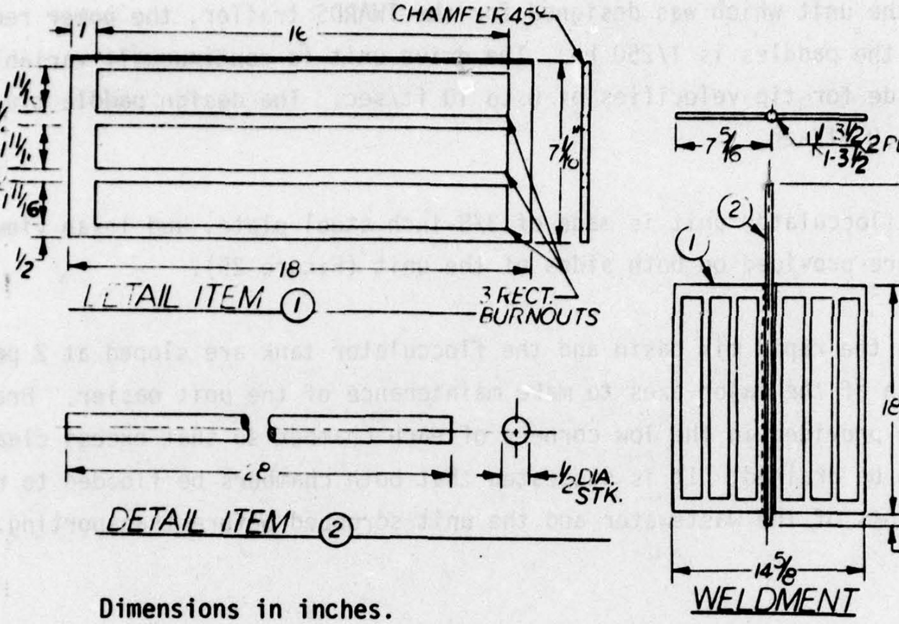
Dimensions in inches.

Figure 23. Impellar Detail

The detention time for the unit is 1 minute. Flow enters the bottom of the compartment from a 1-inch nipple and flows upward through the impellar to an overflow weir at the top of the compartment.

The second phase of the mixing process is the slow-mix region of the flocculator. The flocculator unit on the TWARDS trailer is divided into three compartments of equal size. Each compartment in turn is divided by two sets of baffles which traverse the unit at one-third points along the length of the tank. The baffles are made of 1/4-inch steel plate and are 2 inches wide, extending the full width of the tank and being alternately spaced at 2-inch intervals.

Each compartment has a paddle placed in the geometrical center of the unit. The paddle configuration and assembly are shown in Figure 24. It is desirable to achieve complete mixing without breaking up the flocs which are forming as a result of the chemical admixtures. In the geometrical configuration of the paddle, six large rectangular sections have been cut out of each



Dimensions in inches.

Figure 24. Flocculator Paddle Detail

paddle. These sections allow certain areas of the flow to remain somewhat stationary while areas which are immediately adjacent to them are moved by the paddles. This gentle mixing provides an excellent environment for the formation of flocs. The direction of rotation of the center paddle can be changed in order to eliminate the problem of short circuiting.

The power requirements for the drive unit of the slow-mix chamber can be calculated from the following formula:

$$P = \mu G^2 \forall$$

where

G = mean velocity gradient in fluid, usually about 20 to 75 s^{-1}

$\forall$ = volume of flocculation tank

Once the power requirement has been determined, the required paddle area can be determined from the following formula:

$$A = \frac{2P}{D_D \mu v^3}$$

In the unit which was designed for the TWARDS trailer, the power required to drive the paddles is 1/250 hp. The drive unit is continuously variable and can provide for tip velocities of 0 to 10 ft/sec. The design paddle tip velocity is 1.0 ft/sec.

The flocculator unit is made of 3/8-inch steel plate, and lexan viewing windows are provided on both sides of the unit (Figure 25).

Both the rapid mix basin and the flocculator tank are sloped at 2 percent along both of the major axes to make maintenance of the unit easier. Drain lines are provided in the low corners of each chamber so that excess cleaning water can be drained. It is suggested that both chambers be flooded to remove any remnants of the wastewater and the unit scrubbed before transporting.

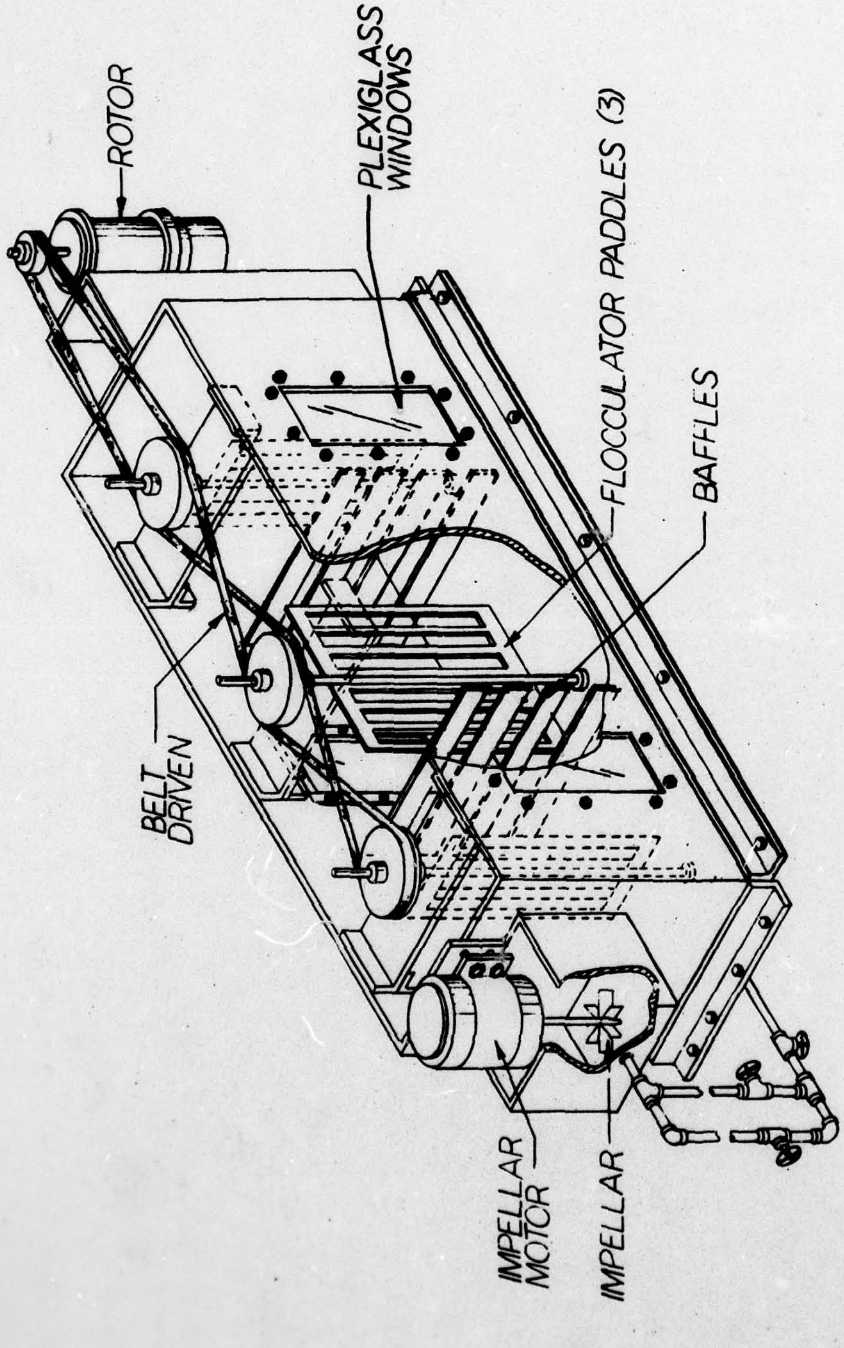


Figure 25. Rapid Mix Basin and Flocculator Unit

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SECTION IX
SAND FILTER UNITS

INTRODUCTION

There are several reasons why a sand filter unit might be used in the treatment of wastewater. The unit can be used to remove turbidity in the water prior to advanced filtration treatments in order to extend the life of the membranes used in such treatments. The sand filter unit can also be used to achieve a higher degree of clarification. In many cases the sand filter unit has been used to follow the coagulation-sedimentation process. Some industrial sites use sand filters in preparation of the effluent to be handled by a municiple wastewater treatment facility.

The process which the sand filter uses to remove turbidity and BOD from the influent is not well understood, but is probably a combination of many different removal mechanisms. Some of the leading theories regarding the mechanism by which suspended matter is removed from the influent are: straining, sedimentation, inertial impaction, interception, chemical adsorption, physical adsorption, adhesion and adhesion forces, coagulation-flocculation, and biological growth. The most important variables which affect the sand filtration efficiency are: filter-medium grain size, shape, density, and composition; filter-medium porosity; medium head loss characteristics; filter-bed depth; filtration rate; allowable head loss; fluid characteristics; and influent characteristics.

The effectiveness of the suspended solids removal by the sand filter is generally measured by the change in turbidity of the wastewater during application. The parameters which have the greatest effect on the performance of the unit are the size of the filter materials, the size and distribution of the particles to be filtered, the suspended solids concentration, and the strength of the floc.

DESCRIPTION OF SAND FILTER UNIT

The sand filter units designed for the TWARDS trailer are fabricated out of clear acrylic. The main body of the unit will be an acrylic tube of 14-inch diameter and a wall thickness of 0.125 inch. The top of the cylinder is glued to a 1/2-inch-thick PVC plate which has been beveled and shaped to receive the cylinder. A 1/8-inch neoprene gasket is used to form a watertight seal between the PVC plate attached to the cylinder and a second PVC plate attached to a 1-inch-diameter nipple. This nipple is attached by a screw-clamp to a 1-inch-diameter flexible PVC pipe. The flexible PVC pipe is attached to the influent pipe of the sand filter unit.

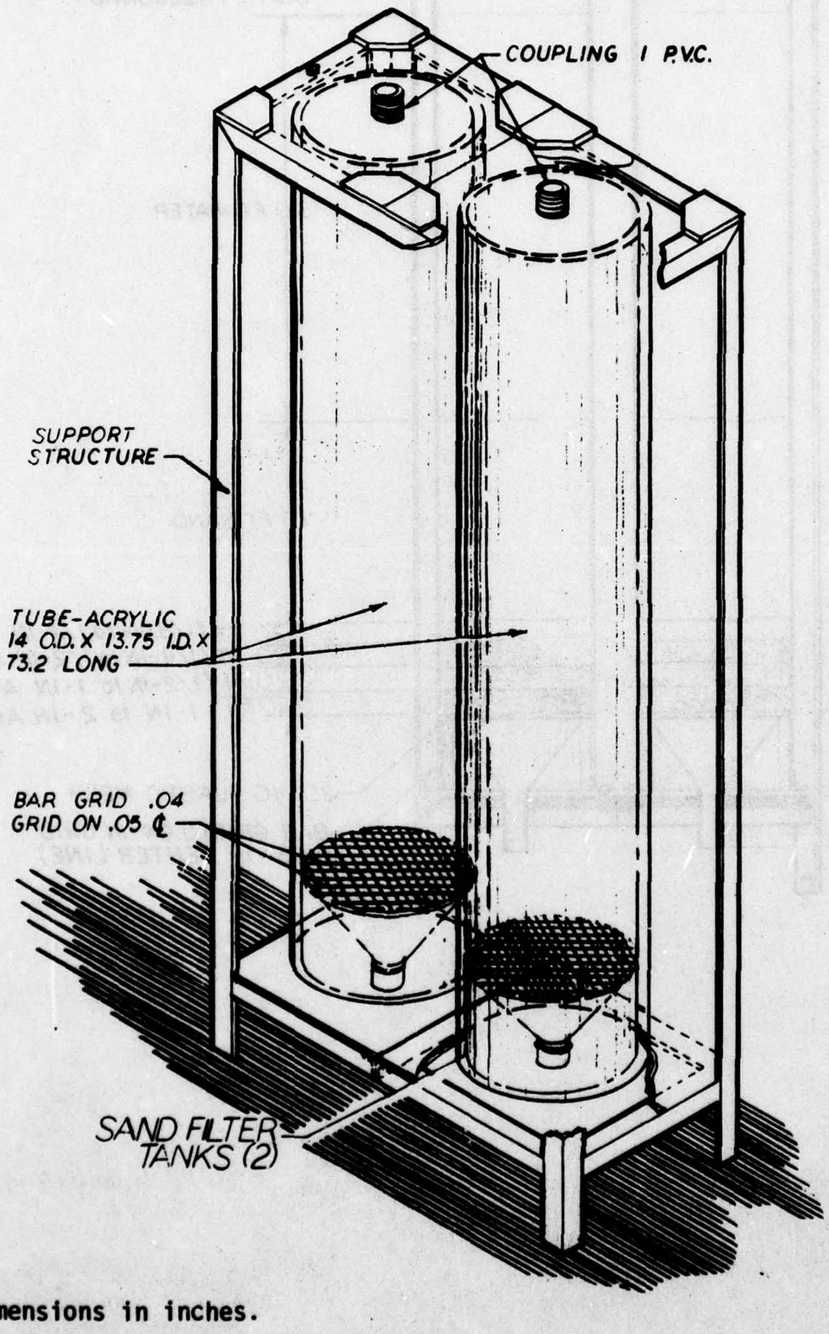
At the bottom of the unit is a bar grid screen to prevent the filter medium from flowing out with the effluent (Figure 26). Below the bar screen is a steel bar grid which is fabricated from 1/2-inch by 1/8-inch bars spaced at 1-inch intervals. The steel bar grid provides the structural support for the medium and wastewater loads.

The bar grid rests on the lip of a steel funnel which converges from 13 inches to 1 inch in a 6-inch length along the tube. The steel funnel is connected at the small end to a 1-inch-diameter nipple. The nipple is connected to a vertical length of steel pipe which leads to a tee located below the bed of the trailer. One side of the tee is connected to the main effluent line. The other side of the tee is the connection for the backwash water.

The lip of the funnel assembly rests on a 1/8-inch neoprene gasket which in turn rests on a 1/2-inch by 6-inch sheet of plexiglass glued to the inside of the acrylic cylinder (Figure 27).

The bottom of the acrylic cylinder is glued to a 1/2-inch sheet of PVC which has been fitted to receive it and the plexiglass plate glued to its inside. The PVC plate is bolted with an eight-hole bolt pattern to another 1/2-inch PVC plate which distributes the load to the supporting frame.

The supporting frame is fabricated from 2- by 2- by 1/4-inch angle irons. The units are bolted to a 1/4-inch steel plate which is bolted to the frame.



Dimensions in inches.

Figure 26. Sand Filter Unit

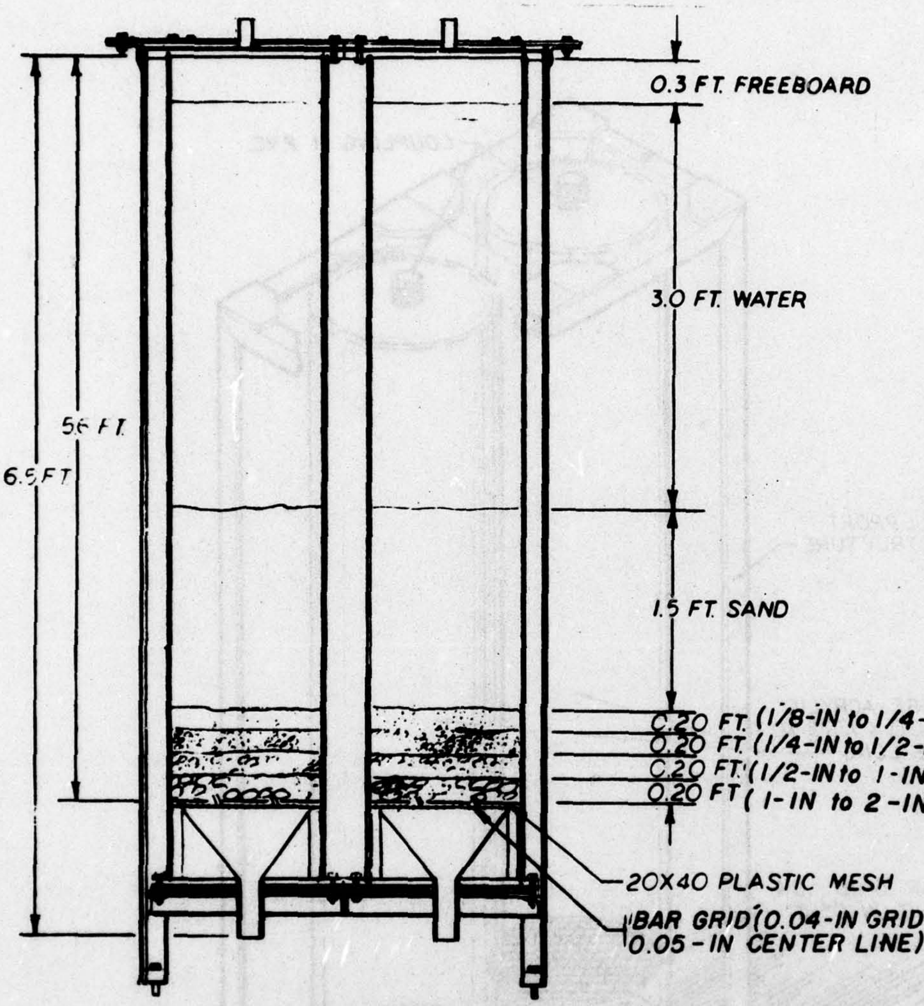


Figure 27. Sand Filter Section

The units are supported 8 inches above the bed of the trailer, allowing free access to the bottom of the sand filter unit. The frame assembly allows for the removal of each sand filter unit independently of the other.

The main purpose of the sand filter units designed for the TWARDS is to remove most of the remaining turbidity, grit, and some of the BOD before the effluent reaches the reverse osmosis and ultrafiltration units. By placing the sand filter units in front of the advanced filtration units, the life of the filter membranes should be increased. The units have been designed so that they can be used independently of the trailer flow schemes if they are not being used for on-line treatment.

The sand filters are cleaned by backwashing the filter medium with one of the two portable pumps provided for the backwashing and cleaning processes. The life of the unit between backwashes is to be determined in the field. Before the unit is transported, the medium should be thoroughly cleaned by a combination of backwashing and flooding. Any necessary removal of the medium will have to be done from the top of the cylinder by scooping. The cylinder is made of clear acrylic which will allow for continuous viewing of the filtration process.

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SECTION X
ACTIVATED CARBON UNITS

INTRODUCTION

Activated carbon units work by the process of adsorption. This is a process whereby colloidal- or molecular-size particles bond to the surface of the carbon particle by chemical or physical bonding. If the bond formed is strong enough to be irreversible, the process is called *chemisorption*. If the process is reversible, it is called *adsorption*. Van der Waals forces are usually present when the process is reversible or if adsorption occurs.

The molecules which are adsorbed to the surface of the particle are called the *adsorbate*, and the particle to which they adhere is called the *adsorbent*. The adsorbate can be removed from the adsorbent by varying the concentration of the adsorbate. The quantity of the adsorbate which can be removed from the surface of the particle is a function of concentration and temperature. The amount of adsorbate which can be adsorbed as a function of the concentration at a constant temperature is defined as the *adsorption isotherm*.

There are two fundamental assumptions of adsorption theory (Reference 4). The first, discussed previously, is that adsorption is reversible. The second is that there are a fixed number of sites available to which a particle may attach itself. It is also assumed that each of the sites has the same amount of energy available. The rate of adsorption is proportional to the difference between the amount of adsorbate adsorbed at a particular concentration and the maximum amount that can be adsorbed at that concentration.

The adsorption process is generally divided into three categories or steps.

(1) Transfer of adsorbate molecules through the film which surrounds the adsorbent. Because the film will vary in thickness and

Reference

4. Weber, Walter J., Jr., *Physiochemical Processes for Water Control*, Wiley Interscience, 1972, pp. 211-212.

penetrability, this process will vary with time.

(2) Diffusion through the pores if the adsorbent is porous. This process will also be variable with time.

(3) Adsorption of the adsorbate on the interior surfaces bounding the pore and capillary spaces of the adsorbent. This process will occur almost instantaneously if there are sites available.

Activated carbon is an excellent adsorption media because of its high surface area per unit volume of material. Activated carbon is prepared by making a char out of an organic material such as wood. The material is brought to a temperature sufficient to drive off the hydrocarbons, but oxygen is withheld so that combustion cannot take place. The material is activated by exposing it to an oxidizing gas at a high temperature. The process develops porous structural characteristics which are a function of the material used for the char and the oxidizing gas.

The activated carbon system is used to remove dissolved organic matter and suspended particles from the wastewater in preparation for the filtration processes. This is done to extend the life of the membranes used in the reverse osmosis and ultrafiltration systems.

There are two major types of activated carbon systems--the downflow or gravity feed system, and the upflow or expanded bed system. Initially the Air Force suggested that the gravity flow system be used on the TWARDS trailer. However, several problems associated with the gravity feed system led to its elimination from the project. In gravity flow systems there is a severe problem with bridging and clogging. Also, there is a continuous decrease in head through the unit. These problems are eliminated with the expanded bed system. The flow for the expanded bed system is from the bottom to the top of the unit. As the flow enters the unit, it passes through a perforated plate which distributes the flow and increases the flow velocity at the bottom of the unit in order to fluidize the medium. The particles of activated carbon are held in suspension so that the entire surface area is available to adsorb particles. The head loss for the expanded bed system remains constant once the operating point has been reached.

DESCRIPTION OF ACTIVATED CARBON UNITS

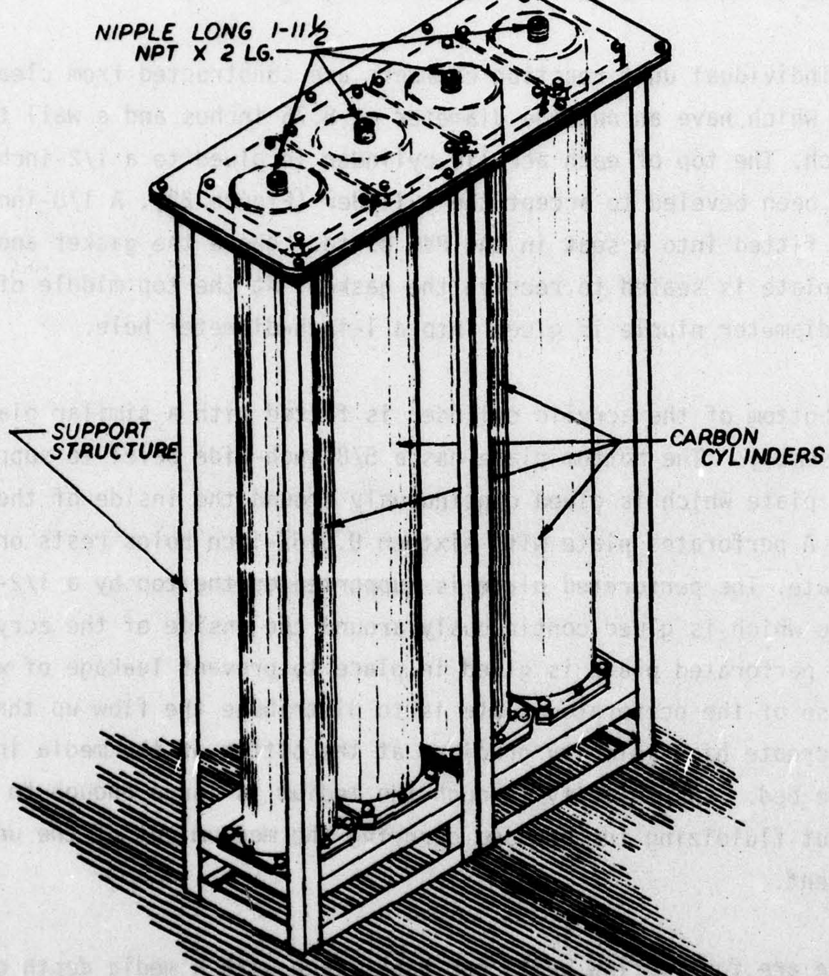
There are two banks of four units each, on the TWARDS trailer. For upflow units each bank is connected in series and is held upright in an angle iron frame 8 inches above the bed of the trailer (Figure 28).

The individual unit reaction chambers are constructed from clear acrylic cylinders which have an outside diameter of 8.75 inches and a wall thickness of 1/8 inch. The top of each acrylic cylinder is glued to a 1/2-inch PVC plate which has been beveled to accept the cylinder (Figure 29). A 1/8-inch neoprene gasket is fitted into a seat in the PVC plate. Above the gasket another 1/2-inch PVC plate is seated to receive the gasket. At the top middle of the plate a 1-inch-diameter nipple is glued into a 1-inch-diameter hole.

The bottom of the acrylic cylinder is fitted with a similar plate and gasket assembly. The bottom plate has a 5/8-inch-wide bevel to support a 1/2- by 3-inch plate which is glued continuously around the inside of the acrylic cylinder. A perforated plate with sixteen 0.0167-inch holes rests on the plexiglass plate. The perforated plate is supported on the top by a 1/2-inch by 1-inch plate which is glued continuously around the inside of the acrylic cylinder. The perforated plate is glued in place to prevent leakage of wastewater. The purpose of the perforated plate is to distribute the flow up through the unit and create high velocity gradient at the bottom of the media in order to expand the bed. The velocity through the medium is large enough to expand the bed without fluidizing the bed and carrying the medium out of the unit with the effluent.

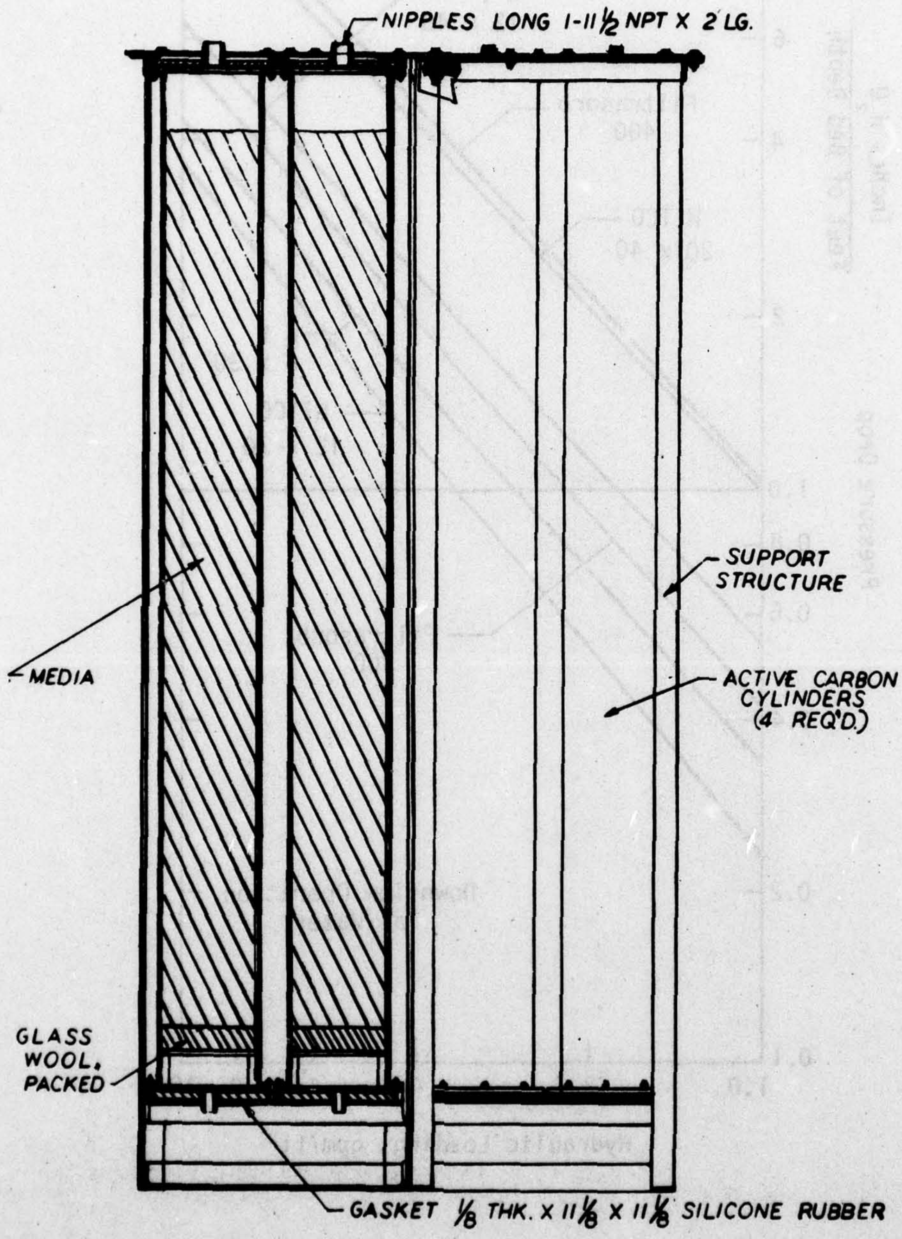
There are four upflow units per bank, each with a media depth of 5 feet, 1 inch. The head loss through the bank will depend on the hydraulic loading and the type of media used in the reaction chamber. Figure 30 shows the head loss through the unit as a function of the hydraulic loading for several different types of media.

The individual units are connected by a 1-inch-diameter flexible PVC hose. The units are connected in such a way that any one unit can be bypassed if desired. The units may be connected in a gravity flow configuration or a combination of gravity flow and upflow cylinders with a minimum amount of effort.



Dimensions in inches.

Figure 28. Activated Carbon Unit



Dimensions in inches.

Figure 29. Activated Carbon Section

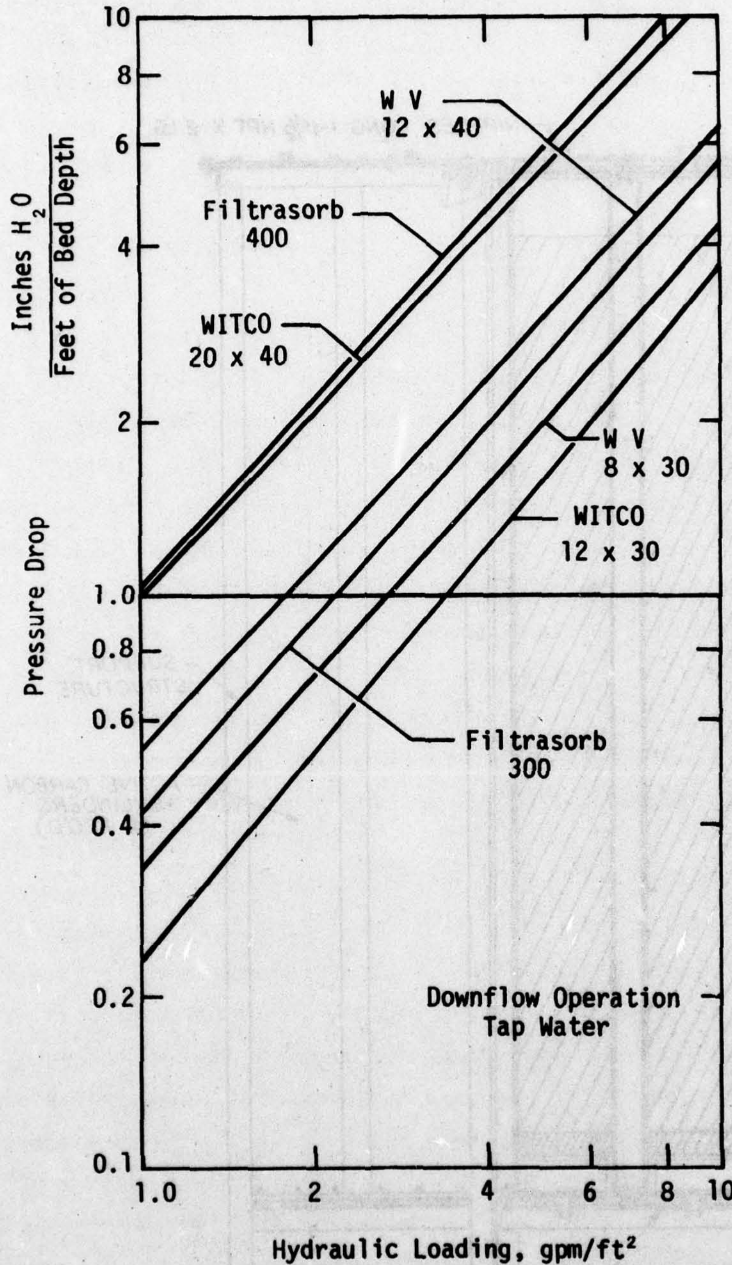


Figure 30. Pressure Drop versus Hydraulic Loading

The individual activated carbon cylinders may be cleaned by flooding or backwashing. When it becomes necessary to remove the medium, it must be removed from the top of the unit by scooping until enough has been removed to enable the unit to be lifted out of the angle iron support frame. The individual cylinders can then be lifted out separately from the support frame.

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SECTION XI
FLUIDIZED BED DENITRIFICATION UNIT

INTRODUCTION

The fluidized bed denitrification unit consists of a column in which a solid granular material is placed. The wastewater is introduced through a distribution plate at the bottom of the unit. The influent flow has a sufficient velocity to suspend the medium. Chemicals are added to the system to reduce the DO content to near zero and to provide an energy source for the organisms. After a period of about two weeks in this favorable environment, a cream-colored biological growth will develop on the granular material. The microorganisms reduce the influent nitrates to relatively insoluble nitrogen gas which creates two fluid phases to the system: the major phase which is the wastewater in which the medium is suspended, and the minor phase which is the nitrogen gas given off in the reaction (Reference 5).

Denitrification is a two-step process in which nitrate is biologically reduced to nitrogen gas. The equations describing the respiration are shown below.

$$NO_3^- + 0.33\ CH_3OH \rightarrow NO_2^- + 0.33\ CO_2 + 0.66\ H_2O$$

$$NO_2^- + 0.5\ CH_3OH \rightarrow 0.5\ N_2 + 0.5\ CO_2 + 0.5\ H_2O + OH^-$$

$$\text{NET:}\quad NO_3^- + 0.83\ CH_3OH \rightarrow 0.5\ N_2 + 0.83\ CO_2 + 1.17\ H_2O + OH^-$$

It should be noted that one mol of hydroxyl ion of alkalinity is produced for every mol of nitrate reduced to nitrogen gas.

There are several reasons for selecting a fluidized bed instead of a packed bed system: (1) little or no danger of clogging, (2) very small head loss, (3) a greater amount of surface area per unit volume of reactor, and (4) greater simplification of the carrier removal procedure. When the bed

Reference

5. Jeris, J. S., Beer, C., and Mueller, J. A., "High Rate Biological Denitrification Using a Granular Fluidized Bed," *Journal WPCF*, Vol. 46, No. 9, September 1978.

AD-A065 120 NEW MEXICO UNIV ALBUQUERQUE ERIC H WANG CIVIL ENGINE--ETC F/G 6/6
TRANSPORTABLE WASTEWATER ADVANCED REFINEMENT AND DEMONSTRATION --ETC(U)
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particles become fluidized, the entire surface area of the particle becomes available for contact as there is no contact between particles. The significant feature of a packed bed system is the bridging that occurs between granular particles. This biological and physical bridging may cause severe problems with clogging, short-circuiting of flow, and high head loss through the cylinder. As a result, more frequent backwash and lower performance would be anticipated for the unit.

Two critical areas must be in the specification of the flow-through velocity of the system. The upflow velocity must be sufficient to expand the bed and suspend the particles, while leaving adequate void area to prevent bridging. However, the velocity must be sufficient to totally overcome the settling velocity of the medium but not transport the entire column contents to liquify the system and carry the medium out from the unit with the effluent. The biological growth on the medium will continue to increase in size, increasing the depth of the bed and decreasing the density of the particles. Since this condition is dynamic in nature, the depth of the bed and the flow-through velocity must be carefully controlled to insure a minimal loss of the medium. The biologically covered medium should not be allowed to overflow into the sedimentation tank, as it will cause clogging of the sludge collection system.

If the growth of the bacteria is not controlled, the size of the coated medium will continue to increase resulting in decreased efficiency of denitrification within the system. There are several methods employed to regulate the growth of the microorganisms. The most common method employed to regulate the growth of the organisms is to backwash the filter medium periodically. The higher velocity of the backwash water will shear away the excess biological slime. Other methods can be investigated to find a more effective method of controlling the growth of the organisms.

Investigators have found that a satisfactory biological growth can be developed on freshly activated carbon by recycling wastewater to which a high concentration of feed chemicals has been added (Reference 5). The optimum flow-through rate was found to be 8 gal/min/ft^2. Typical values for the initial chemical feed concentrations are shown below.

$NaNO_3$-N	15-45 mg/ℓ
CH_3OH	75-100 mg/ℓ
NH_4CL-N	1-5 mg/ℓ
KH_2PO_4-P	1-3 mg/ℓ
$Na_2HPO_4 \cdot 7H_2O$-P	1-3 mg/ℓ

The startup operation for the fluidized bed denitrification unit will require careful supervision. As the biological growth increases, it may be necessary to remove a portion of the medium to prevent carryover into the sedimentation tank. The growth rate of the microbes should also be closely monitored to determine the optimum chemical feed rates.

DESCRIPTION

The fluidized bed denitrification unit body will be fabricated from a clear acrylic cylinder which has an 8-inch outside diameter and a wall thickness of 0.125 inch. The acrylic cylinder will be in two parts, each 6 feet long. The bottom portion of the cylinder will be secured to an angle iron frame mounted on the trailer. The top portion of the cylinder will be lifted into place prior to operation and removed and stored while not in use or when TWARDS is in transit.

The influent to the unit is first pumped into a mixing chamber where methanol and sodium sulfite are introduced. The mixing is accomplished by a paddle similar in appearance to that used in the flocculator assembly. Provisions have also been included to alter the pH of the influent by adding sodium hydroxide or sulfuric acid to the mixing chamber.

The chemical containers will be fabricated from 6-inch-diameter acrylic tubes and will have a 1/2-inch PVC plate fastened to the bottom of each tube. The top of the tube will be glued to a beveled PVC plate. The top of the cylinder can be sealed by bolting another sheet of 1.2-inch PVC plate through a 1/8-inch neoprene gasket. The effluent from the chemical tanks is pumped from the bottom of the tank through a 1/4-inch nipple. The four chemical containers are located adjacent to the mixing chamber and are supported by an angle iron frame open at the top.

The mixing chamber will be fabricated from a 14-inch (outside diameter) acrylic tube with a wall thickness of 0.125 inch. The mixing chamber is 3 feet high and is sealed at the bottom with the same PVC plate and gasket assembly common to most of the units on the TWARDS trailer (Figure 31). A 1/250-hp motor will be mounted to the top of the cylinder to drive the paddle assembly. The paddle will gently mix the chemicals with the influent. The influent enters the chamber at the bottom and exits through a 1-inch-diameter nipple at the top of the cylinder.

The effluent from the mixing chamber is pumped with adequate head to fluidize the medium in the fluidized bed reaction chamber. A check valve has been provided on the main line between the pump and the fluidized bed reaction chamber. This valve is used to prevent damage to the pump and loss of the wastewater in the reaction chamber should it become necessary to shut down the system for a short period after the biological growth on the medium has developed.

The main body of the fluidized bed reaction chamber is supported by the angle iron frame. The lower end of the cylinder is sealed with the same PVC plate and gasket assembly as used for all of the acrylic units on the TWARDS trailer. This assembly is bolted to a 1/4-inch steel plate and then bolted to the frame. Immediately above the PVC plate is a 1/2- by 3-inch sheet of plexiglass which has been continuously glued around the inside of the acrylic cylinder. The plexiglass plate provides edge support for a 1/2-inch-thick by 14-inch-diameter manifold plate. The manifold plate is perforated with 17-0166-inch-diameter holes. The manifold plate serves to distribute the flow of wastewater into the fluidized bed reaction chamber. A 20- by 40-inch plastic mesh is placed over the manifold plate. A sheet of 1/2- by 1-inch plexiglass is then glued around the inside of the acrylic cylinder to support the manifold plate when the system is in operation. The activated carbon medium will then be placed on top of the manifold plate assembly to a depth of about 6 feet. A 100 percent increase in the depth of the bed may be expected after the biological growth has entirely enveloped the medium particles.

The top PVC plate and gasket assembly is the same as the bottom assembly. The effluent will be pumped out of a 1-inch-diameter nipple at the top center of the column and into the sedimentation tank.

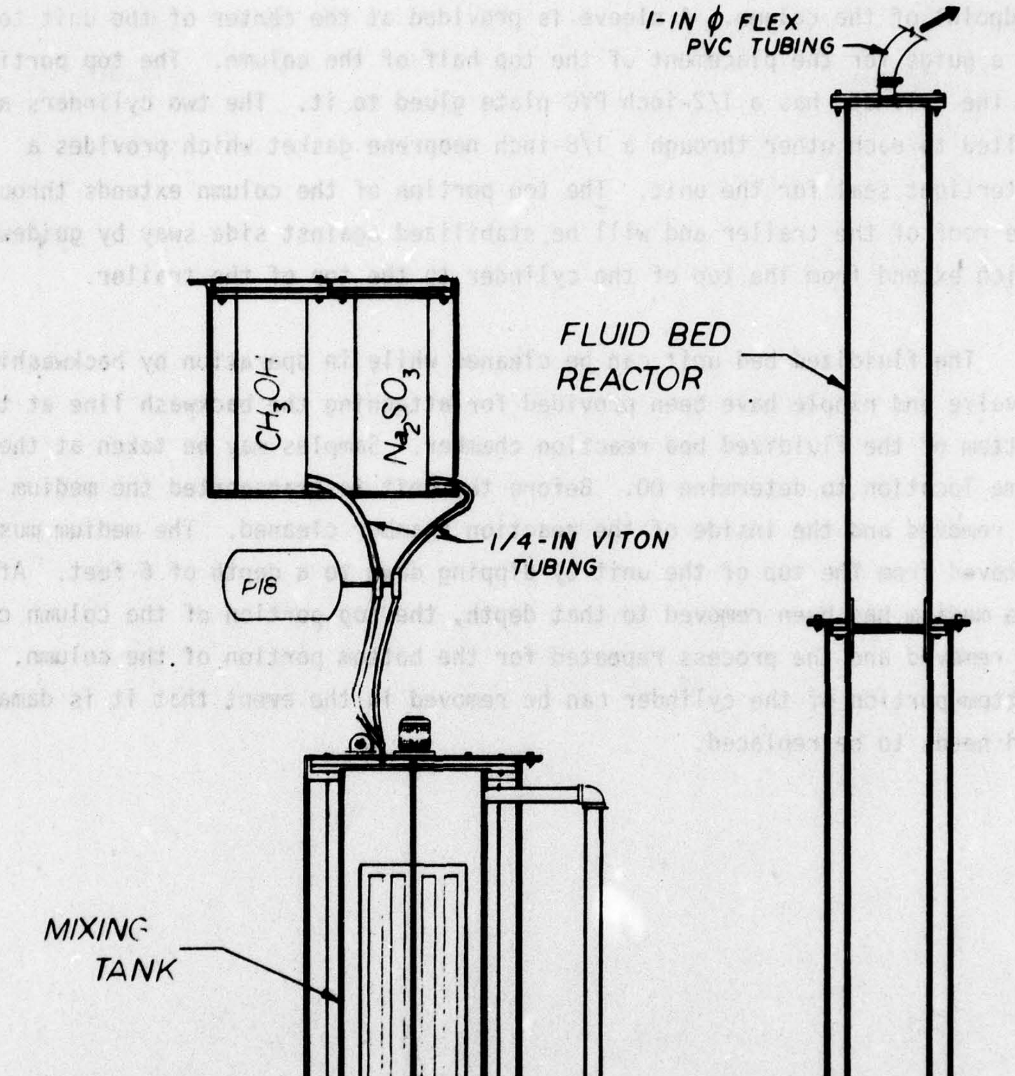

Figure 31. Fluidized Bed Assembly

The frame for the fluidized bed reaction chamber will extend only to the midpoint of the column. A sleeve is provided at the center of the unit to act as a guide for the placement of the top half of the column. The top portion of the cylinder has a 1/2-inch PVC plate glued to it. The two cylinders are bolted to each other through a 1/8-inch neoprene gasket which provides a watertight seal for the unit. The top portion of the column extends through the roof of the trailer and will be stabilized against side sway by guidewires which extend from the top of the cylinder to the top of the trailer.

The fluidized bed unit can be cleaned while in operation by backwashing. A valve and nipple have been provided for attaching the backwash line at the bottom of the fluidized bed reaction chamber. Samples may be taken at the same location to determine DO. Before the unit is transported the medium must be removed and the inside of the reaction chamber cleaned. The medium must be removed from the top of the unit by dipping down to a depth of 6 feet. After the medium has been removed to that depth, the top portion of the column can be removed and the process repeated for the bottom portion of the column. The bottom portion of the cylinder can be removed in the event that it is damaged and needs to be replaced.

SECTION XII
REVERSE OSMOSIS UNIT

INTRODUCTION

Osmosis is the spontaneous passage of a liquid from a dilute form to a concentrated form across a semipermeable membrane. The semipermeable membrane allows water to pass through it but will retain the solids. The transfer continues until the pressure is sufficiently large to prevent transfer. At equilibrium the quantity of water passing in either direction is equal. The pressure (P) at equilibrium is called the *osmotic pressure*. If the pressure on the concentrated solution is greater than the osmotic pressure, the water can be forced to flow in the opposite direction through the semipermeable membrane. The reversed flow through the membrane is defined as *reverse osmosis*.

The osmotic pressure will increase with the concentration of the solution, thus requiring a greater pressure on the concentrated solution to produce reverse osmosis. Pumps are used to supply an adequate pressure to overcome the osmotic pressure. The waterflow rate through the membrane is a function of the driving pressure. The solute flow rate through the membrane depends on the solute concentration of the feedwater.

The USAF purchased the reverse osmosis unit which is mounted on the TWARDS trailer. The unit is the Envirex Model 4189 Reverse Osmosis System (Figure 32). The entire reverse osmosis assembly is mounted on two *W*-flange sections bolted to the structural members beneath the floor of the TWARDS trailer.

The Envirex Model 4189 Reverse Osmosis System handles flow rates up to 7 gal/min. The feedwater is pretreated by filtration in three 5-μm cartridges with throwaway elements. A constant feedwater concentration can be maintained by recycling the brine and feedwater. An automatic temperature controller regulates the flow of hot or cold water into the unit.

The feed and discharge piping system will accept any three reverse osmosis modules. These modules can be tested in series or parallel by simply

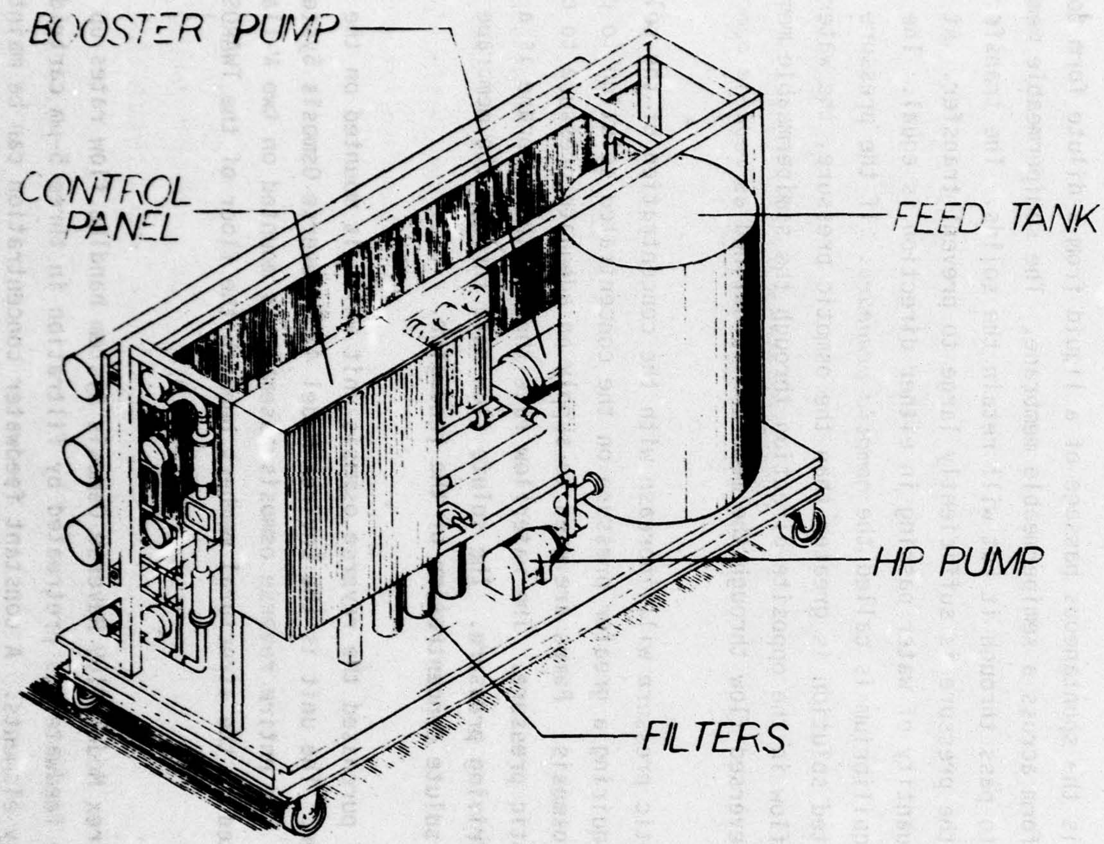

Figure 32. Reverse Osmosis Unit

opening and closing several different valves. The modules which are provided with the unit are the tube, the hollow fine fiber, and the spiral types. An operations and maintainance manual will be provided by Envirex Inc.

The high-pressure pump and the piping system are made of stainless steel and plastic to resist corrosion. The reverse osmosis modules are also protected by an adjustable relief valve and by pressure switches set at the maximum operating pressure for each unit. Trouble lights and an electronic memory system are provided with the unit to show the operator which condition shut down the system: low suction pressure, low feed-tank level, or high feed-pump pressure.

DESCRIPTION OF COMPONENTS

Feedwater Tank System

The feedwater tank is made of polypropylene which will resist deterioration from chemical attack and sunlight. The drawoff and drainage valves are located at the bottom of the tank, and an overflow outlet is provided at the top of the tank. A stainless steel heating coil is located in the tank through which hot or cold water flows to regulate the temperature of the feedwater.

Temperature Controller

A dead-band temperature controller is located inside the control panel. A remote capillary tube is filled with fluid. If the fluid expands or contracts beyond the allowable limits, one of two switches is activated to allow hot or cold water to enter the heating coil.

Booster Pump

The booster pump is made of plastic and stainless steel. The pump is used to maintain a positive pressure on the high-pressure feed pump and to overcome the head loss through the filter cartridges. The pump is controlled by the head loss through the filter cartridges. The pump can be serviced on line and drained from a tee on the side of the pump.

Cartridge Filters

The three cartridge filters are flow rated for 5 gal/min at 100 psi and 100°F and prevent precipitates larger than 5 μm from entering the reverse osmosis modules. No more than two of the cartridges are used at a time.

High-Pressure Feed Pump

The high-pressure feed pump is a corrosion resistant pump made of 315 stainless steel and "Noryel" plastic. The pump is the Goulds model 3933 Series MB-13 Multistage Centrifugal Pump, size 13500. It is driven by a 7-1/2-hp, 3500-r/min motor which runs on 230/460, 3-phase, 60-cycle current.

Pressure Switches

There are two pressure switches provided with the system. The first pressure switch monitors the suction pressure and is factory set to shut down the system if the pressure drops below 6 to 8 lb/in^2. The second pressure switch monitors the discharge pressure and is field set to the discharge pressure for each module.

Reverse Osmosis Modules

The reverse osmosis unit was supplied with the following modules: three DuPont "Permasep" modules, three Fluid Sciences tubular modules, and three Gulf Atomic spiral wound modules.

Flowmeters

The raw feedwater flow and the product water flow from each module are measured by Varea-Meters (variable area flow meters). The meters are read directly by comparison of the level of a floating steel ball with a vertical scale adjacent to it. The Varea-Meters are accurate to 2 percent of full scale.

Piping System

The piping system on the reverse osmosis unit is made of stainless steel and plastic pipe offering a high degree of corrosion resistance. The high-pressure ports at the feed inlets and concentrate outlets are stick-resistant lined high-pressure hoses.

Electrical Control Panel

The electrical control panel is designed in accordance with the National Electrical Code with overload and short circuit protection. The control panel (model 4189) requires grounded 460-480, 3-phase, 60-cycle power, with a minimum 30-amp capacity.

The basic unit provided by the USAF will be modified by removing the wheels attached to the *W*-flange sections. After the four wheels have been removed, the unit will be mounted to the trailer.

OPERATION AND MAINTENANCE

Appendix B presents material from a company-supplied operation and maintenance manual for the Model 4189 reverse osmosis unit.

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SECTION XIII
ULTRAFILTRATION UNIT

The ultrafiltration unit was purchased by the USAF from Romicon, Inc. The unit purchased was an HF1SSS hollowfiber ultrafiltration system (Figure 33). The system utilizes cartridges which contain an inner membrane of skin. The wastewater is pumped through the membrane fibers which retain the large molecules while allowing the small molecules, ions, and water to pass through.

As the filtration process progresses, a thin film of dense organic matter coats the membrane and impedes the flow. The organic matter which coats the membrane must be removed every 24 hours in order to assure that the optimum life of the cartridge is maintained. Prior to transporting the ultrafiltration unit, the cartridges, the permeate tank, and all plumbing must be thoroughly cleaned.

The Romicon Corporation included a booklet on the general operating instructions for the unit. The booklet gives a brief description of the basic components of the unit, lists the specifications to which the unit was fabricated, and includes information on the installation and operation of the unit. Material from this booklet, *Operation Instructions/Romicon Model HF1SSS/HF2SSS/Ultrafiltration Systems*, is presented as Appendix C of this report with permission of Romicon, Inc. The format is that of the original Romicon publication.

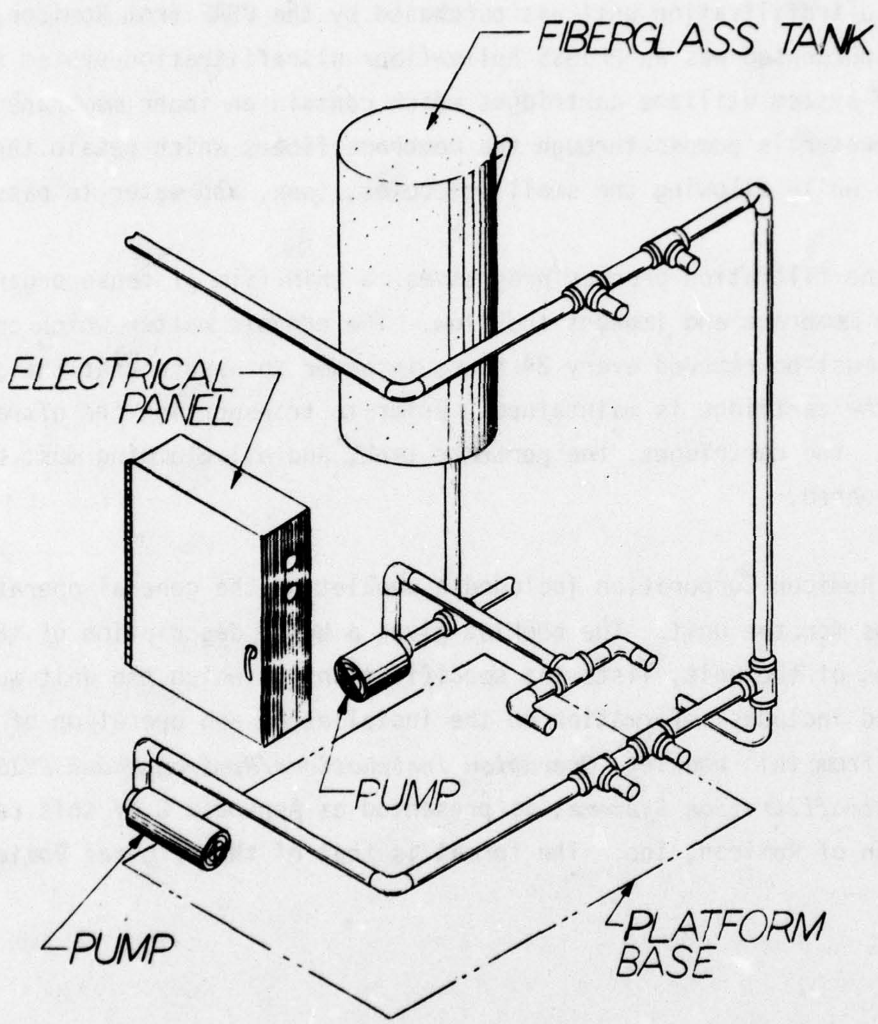


Figure 33. Ultrafiltration Unit

SECTION XIV
DISINFECTION CONTACT CHAMBER

INTRODUCTION

The disinfection contact chamber is a series of compartments which allows for the gradual mixing of chlorine or ozone with the wastewater. The design of the chamber should provide adequate protection against short circuiting. The chlorine or ozone should be added in such a way that complete mixing occurs. This mixing can be accomplished by injecting the chemicals through a small orifice into the influent line, by flash mixing, by bubbling the chemicals into the first compartment through a perforated pipe, or by mixing with hydraulic turbulence for a minimum period of 30 seconds.

The disinfection contact chamber unit should consist of a minimum of six *interconnected compartments*. These compartments are arranged so that the units may be in series or in parallel. Provisions are also included in the design to allow for the bypassing of compartments. A minimum of 80 to 90 percent of the wastewater should be retained in the contact chamber for the specified contact time.

The detention time for the process is typically between 15 and 45 minutes, and compartment size should vary so that the effect of different detention times may be evaluated at the same flow.

The disinfection contact chambers should be constructed from material which is resistant to chemical corrosion and does not allow the passage of sunlight. The material used in fabricating the chambers should also be durable and resist cracking due to variations in the ambient temperature.

DESCRIPTION OF DISINFECTION CONTACT CHAMBER ASSEMBLY

The disinfection contact chamber unit consists of six chambers fabricated from opaque PVC or acrylic pipe. There are two 12-inch-diameter cylinders and four 4-inch-diameter cylinders. The cylinders are all 4 feet in height, and the entire assembly is supported 8 inches above the bed of the trailer by an angle iron frame (Figure 34). Initially, the units will be placed so that the influent will enter the 12-inch-diameter tube from the top. The wastewater will then flow down through the first 12-inch-diameter tube, up a 4-inch-diameter tube, down the next 4-inch-diameter tube, up the second 12-inch-diameter tube, down the next 4-inch-diameter tube, and up the last 4-inch-diameter tube. The cylinders are bolted to the frame in a way permitting them to be removed separately by loosening four bolts per cylinder.

The top of each cylinder will be glued to a 1/2-inch PVC plate machined to fit the outside diameter of the cylinder. A 1/8-inch neoprene gasket will be fitted on top of the plate which has been seated to accept the gasket. Another 1/2-inch PVC plate will be seated to accept the gasket and will be bolted through the gasket to the PVC plate which was glued to the cylinder. The top plate will be machined to accept a 1-inch-diameter nipple glued to it. The same assembly is to be repeated for the bottom of each cylinder.

Flexible pipe secured with band clamps will be used to connect the individual chambers. This will allow an operator to alter the configuration of the unit by simply changing the order in which the compartments are connected. It would be a simple matter to connect all or part of the cylinders in parallel.

The velocity of flow through the small pipes is 3.06 ft/min and the velocity of flow through the large pipes is 0.340 ft/min, at the design flow of 2 gal/min. The detention time of the system can be varied by disconnecting one or more of the chambers from the system. The disinfection contact chamber unit was not designed to accommodate wastes which have not received primary and secondary treatment. If raw domestic wastewater is introduced into the cylinders, there will be a solids buildup in the 12-inch-diameter cylinders. The buildup may require the unit to be periodically shut down for cleaning. However, the performance of the unit should not be adversely affected in this application.

Needle valves have been placed on the 1-inch-diameter flexible lines to bleed off excess buildup of ozone. The needle valves are connected to

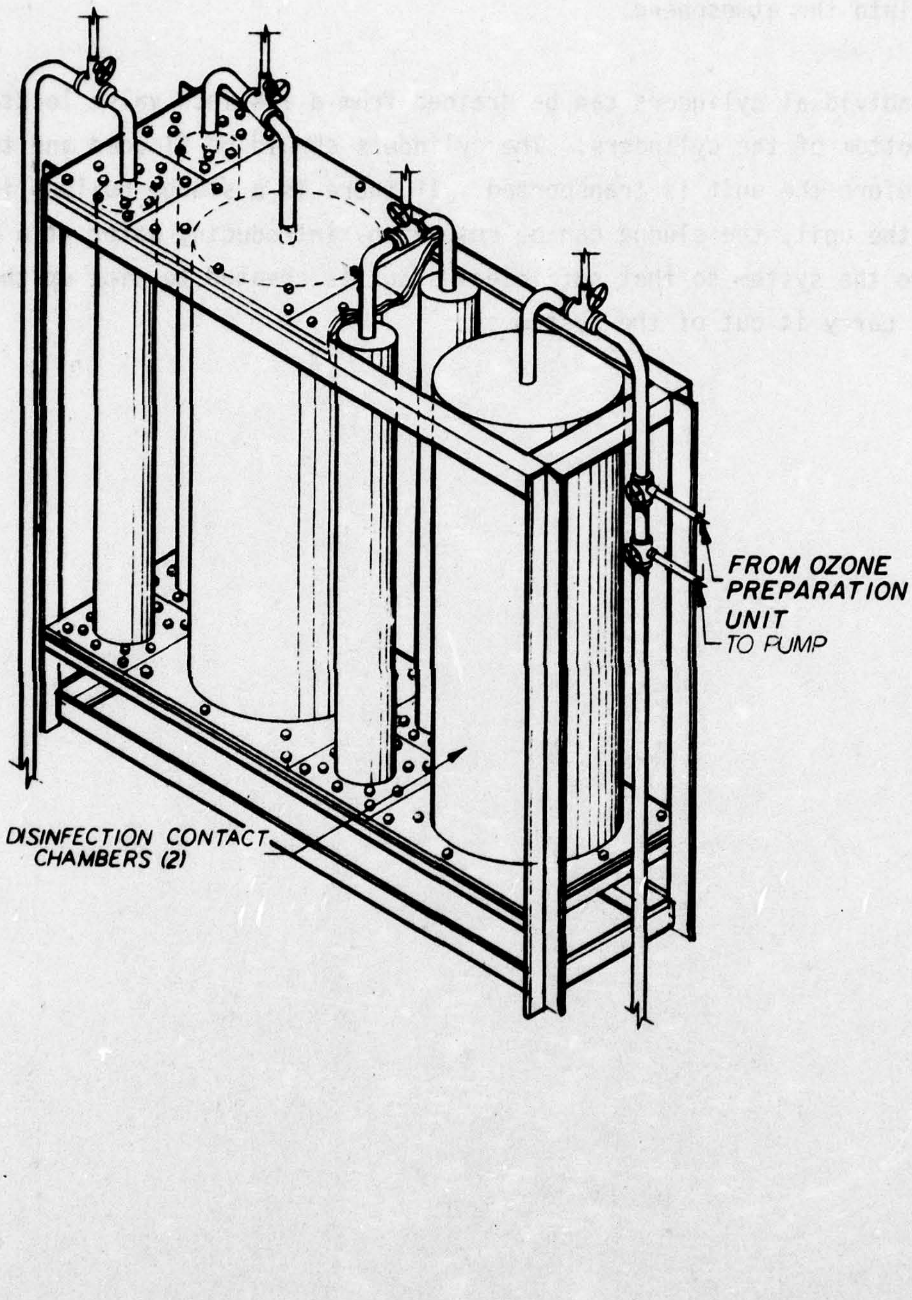


Figure 34. Disinfection Contact Chamber

1/4-inch PVC tubing which will carry the ozone out of the trailer and discharge it into the atmosphere.

The individual cylinders can be drained from a 1/4-inch valve located near the bottom of the cylinders. The cylinders should be flooded and then scrubbed before the unit is transported. If there is a sludge buildup in the bottom of the unit, the sludge can be removed by introducing water at a high velocity to the system so that sufficient scour is created to pick up the sludge and carry it out of the system.

SECTION XV
CHLORINATION

The purpose of chlorination in a wastewater effluent application is to reduce the bacterial count of the effluent, to lower the BOD, and to provide sufficient residual chlorine to kill bacteria which might infect the water in the distribution system. The merits of residual chlorine are being examined at this time, and it has been predicted that ozone treatment of effluent will replace chlorination in both sewage and freshwater treatments (Reference 2).

The chlorine dosage will depend on the type of application, the characteristics of the wastewater, and the effluent standards specified by pollution control agencies. Laboratory chlorination studies should be conducted to determine the optimum chlorine dosages. Under present disinfection policies, the typical determination of the necessary dosage of chlorine is that amount needed to obtain a residual of 0.5 mg/ℓ after 15 minutes of contact time.

Calcium or sodium hypochlorite will be used on the TWARDS trailer as the source of hypochlorite ion since it is much safer to use in this type of an application. If chlorine gas were being used, the chlorination apparatus and chlorine contact chamber would have to be separated from the trailer and accessible only by an outside door. Precautions will also have to be taken to provide adequate ventilation and emergency equipment and operator training.

Calcium hypochlorite is available in either the liquid or the solid form. The calcium hypochlorite is extremely stable in the pellet form and is soluble in water. For these reasons calcium hypochlorite is usually preferred.

Sodium hypochlorite is available in concentrations of 1.5 to 15 percent. The solution decomposes more readily at a high concentration, and the disinfection power of the hypochlorite ion is adversely affected by exposure to light and heat.

The hypochlorite solution will be mixed by hand and placed in a holding tank on the TWARDS trailer. The holding tank is made from an 8-inch-diameter opaque PVC tube. The tube is glued at the bottom to a beveled 1/2-inch PVC plate and is fitted at the top with the same PVC plate gasket assembly used in the disinfection contact chamber. The chamber has an optional airtight seal.

There is a 1/4-inch nipple at the bottom of the chamber from which the effluent is pumped. The effluent chlorine solution will be pumped via a tube to a 1/4- to 1-inch tee with a valve. The small opening at the tee will act as an orifice through which the chlorine will be injected and mixed with the influent wastewater.

SECTION XVI
OZONIZATION

Ozone (O_3) is an unstable gas which occurs naturally in the upper atmosphere. It is created by a high voltage discharge of electricity through air or oxygen. After a lightning storm, it is the ozone which gives the air its characteristic sweet smell. Ozone is one of the strongest oxidizing agents which can react in an aqueous environment.

In order for ozone to be produced commercially, a supply of very dry air must be supplied to an ozone preparation unit. For a typically ozone generating unit, clean air is fed into rotary compressors which produce air up to 300 ft^3/min at 11 psi, which is then cooled to 50°C. The cold air is then circulated through chemical desiccators which dry the air to 30 volumes per million of water or a dew point of -52.5°C. The dry air is subjected to a discharge of up to 20,000 V a.c. in two ozonizers. With these conditions, 3 to 8 kg/h of ozone are produced at concentrations of 10 to 20 mg/ℓ. The effluent from the ozone unit will usually contain one percent ozone. The ozone dosage can be controlled by changing the air flow or the power supply to the ozonizors.

The ozone gas is dispersed into the contact chamber through a 1/4-inch-diameter orifice identical to the one specified for the chlorine injection. Complete mixing of the ozone with the influent should occur as the result of the geometry of the insertion assembly. If operational results indicate that this method of insertion is inadequate, the ozone can be bled into the first chamber through a perforated pipe diffuser.

The ozone unit which will be used on the TWARDS trailer was purchased from PCI Ozone Corp, by the USAF. The ozone generator is Model HC2P-18, and the air preparation unit is Model PS35. These units are supported on the trailer in an angle iron frame as shown in Figure 35. Appendix D provides installation and operating instructions for the Model HC2P-18 ozone generator.

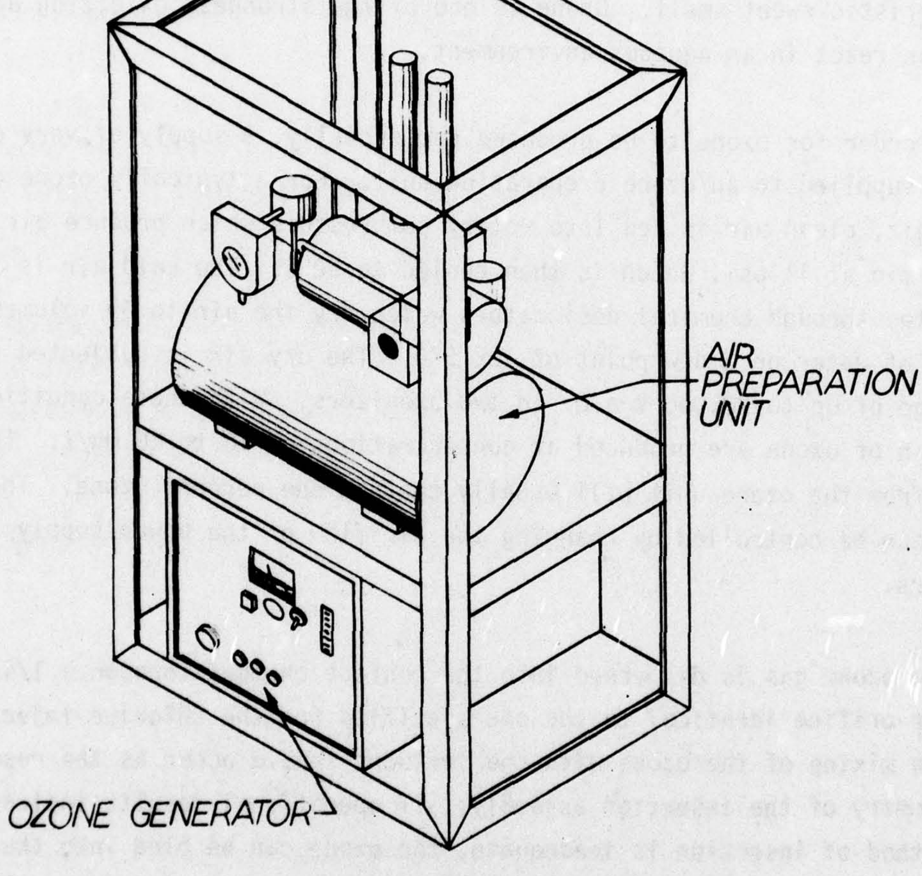


Figure 35. Ozone and Air Preparation Units

SECTION XVII

ULTRAVIOLET DISINFECTION UNIT

The ultraviolet disinfection unit provides a method whereby the bacteria in the wastewater can be killed without use of heat or addition of chemicals. Added chemicals might react adversely with some of the chemicals in the wastewater and produce harmful side products. The disinfection process utilizes shortwave ultraviolet light with a wavelength in the range of 200 to 2950 A.

Shortwave ultraviolet light can be produced commercially by a mercury vapor lamp. The lamp is made of quartz glass which transmits 70 to 90 percent of the shortwave ultraviolet radiation. The lamp emits radiation at 2537 A. The desired ultraviolet radiation is produced by an electric arc which is struck through an inert gas in a sealed glass tube. Heat from the arc causes the vaporization of a small portion of mercury contained in the sealed tube. The electric arc gives off the ultraviolet radiation at the prescribed wavelength.

The degree of microbial destruction is a function of the intensity of the radiation and the time which the micro-organism is exposed to it. The dosage is commonly expressed in $\mu Ws/cm^2$. The turbidity of the wastewater will decrease the efficiency at which the system will operate. In order to compensate for the effects of turbidity, an energy in excess of 30,000 $\mu Ws/cm^2$ is required (Reference 6). It is necessary that the tube-wastewater interface be kept free from debris. This is usually accomplished by baffles placed around the tube to create enough turbulence to keep solids from settling onto the tube.

There are several design parameters which will have an effect on the dosage delivered to the wastewater:

(1) The output: The output of the lamp is 2537 A for a mercury vapor lamp.

Reference

6. Mone, J. G., "Ultraviolet Water Purification," *Pollution Engineering Magazine*, Vol. 5, No. 12, December 1973.

(2) The contact time: The contact time is a function of the length of the tube and is inversely proportional to the linear flow rate.

(3) The diameter of the purification chamber: Water absorbs the ultraviolet radiation at a rate which *varies logarithmically with the distance from the lamp.*

The USAF purchased the ultraviolet disinfection unit to be placed on the TWARDS trailer from the Atlantic Ultraviolet Corporation (Figure 36). The lamp and ultraviolet unit bear the brand name *SANITRON*. The lamp used in the unit is model No. S36T6VZ and is used in ultraviolet unit No. A600. The ultraviolet output is 14.6 W and the rated effective life of the lamp is 7500 hours.

The ultraviolet unit is 38 inches long, 8 inches wide, and 12 inches high; it weighs 25 pounds. It requires 115-V, single-cycle, 60-Hz power. The unit will handle a maximum flow rate of 10 gal/min.

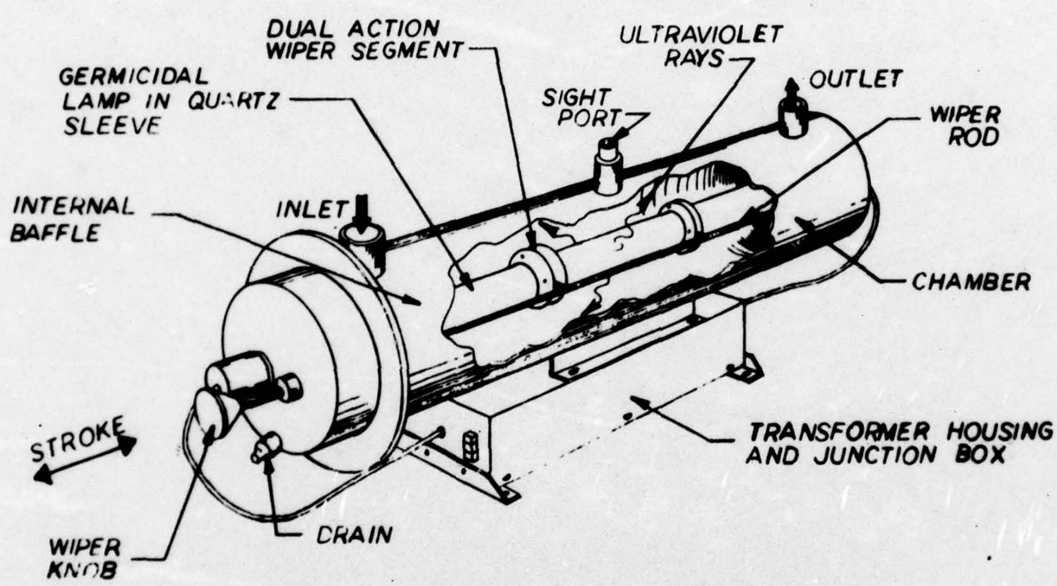


Figure 36. Ultraviolet Disinfection Unit

SECTION XVIII
WORK COMPARTMENT

The work compartment of the TWARDS trailer was designed to accommodate two operators, the data processing equipment, and the electrical control panel. It also provides adequate storage for flasks and other operating equipment as well as a work area for the two operators.

The work compartment will be fabricated by the trailer manufacturer and permanently mounted on the extreme end of the trailer. A collapsible step ladder will be provided and stored under the trailer.

The work compartment is 8 feet wide (the full width of the trailer) and 3 feet long, with an interior height of 8 feet. The heating and air conditioning unit to be provided for the work compartment will maintain an interior air temperature of 21°C for an ambient temperature range from 0°C to 50°C. The exterior paneling will be the same material used in the canopy covering the unit processes. Rigid insulation is to be provided in the exterior walls, ceiling, and floor.

The data processing equipment is mounted at one of the work stations with the support electronics mounted in a rack in the cabinet room above the work station. The work station opposite the data processing station will consist of a desk with adequate book storage both above and below the desk. The printer is located in the cabinet area above the desk. Windows are located above both work areas as shown in Figure 37.

The electrical compartment and the locking cabinet are located on the back wall of the work compartment. Shelves are provided below the locking cabinet. The work compartment also provides storage for the portable instrumentation and all other small portable equipment transported on the TWARDS Trailer.

Lighting for the work compartment consists of an overhead light and two neon lights located at each work station. Electrical outlets have also been

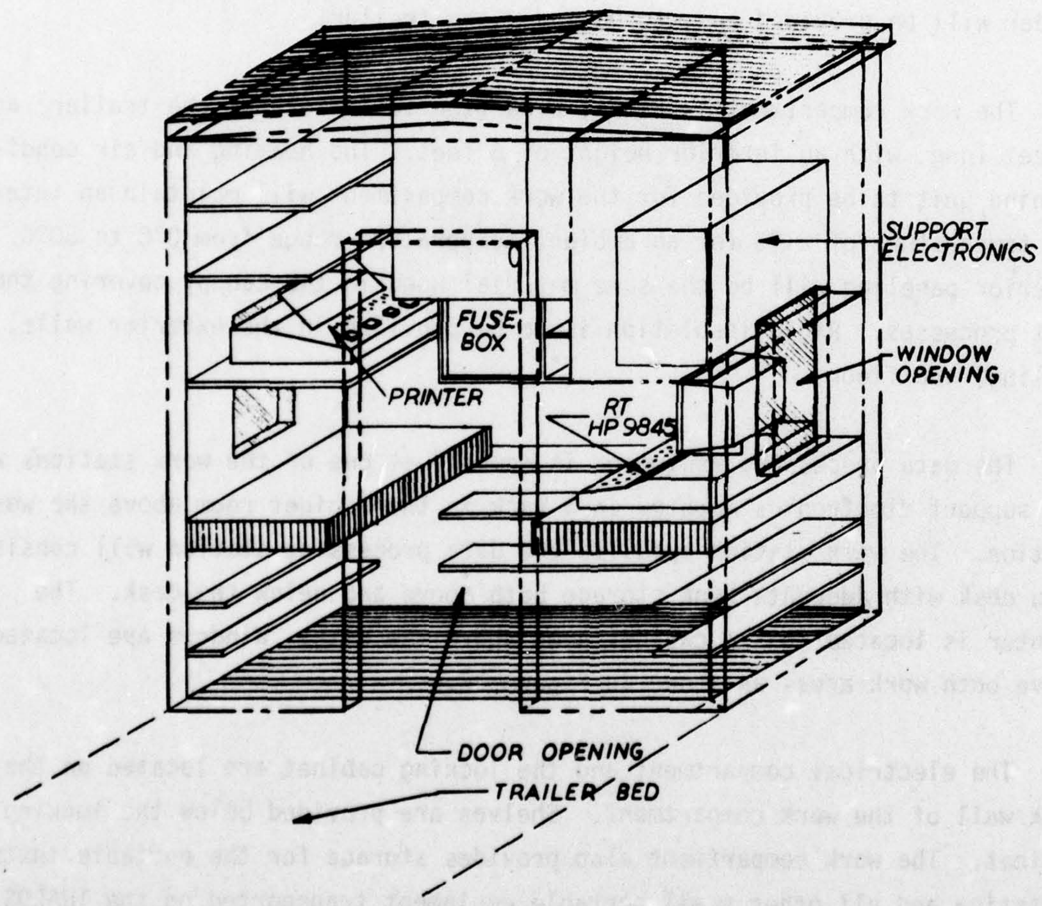


Figure 37. Work Compartment

provided at each work station. Figure 38 illustrates the instrumentation of the work compartment.

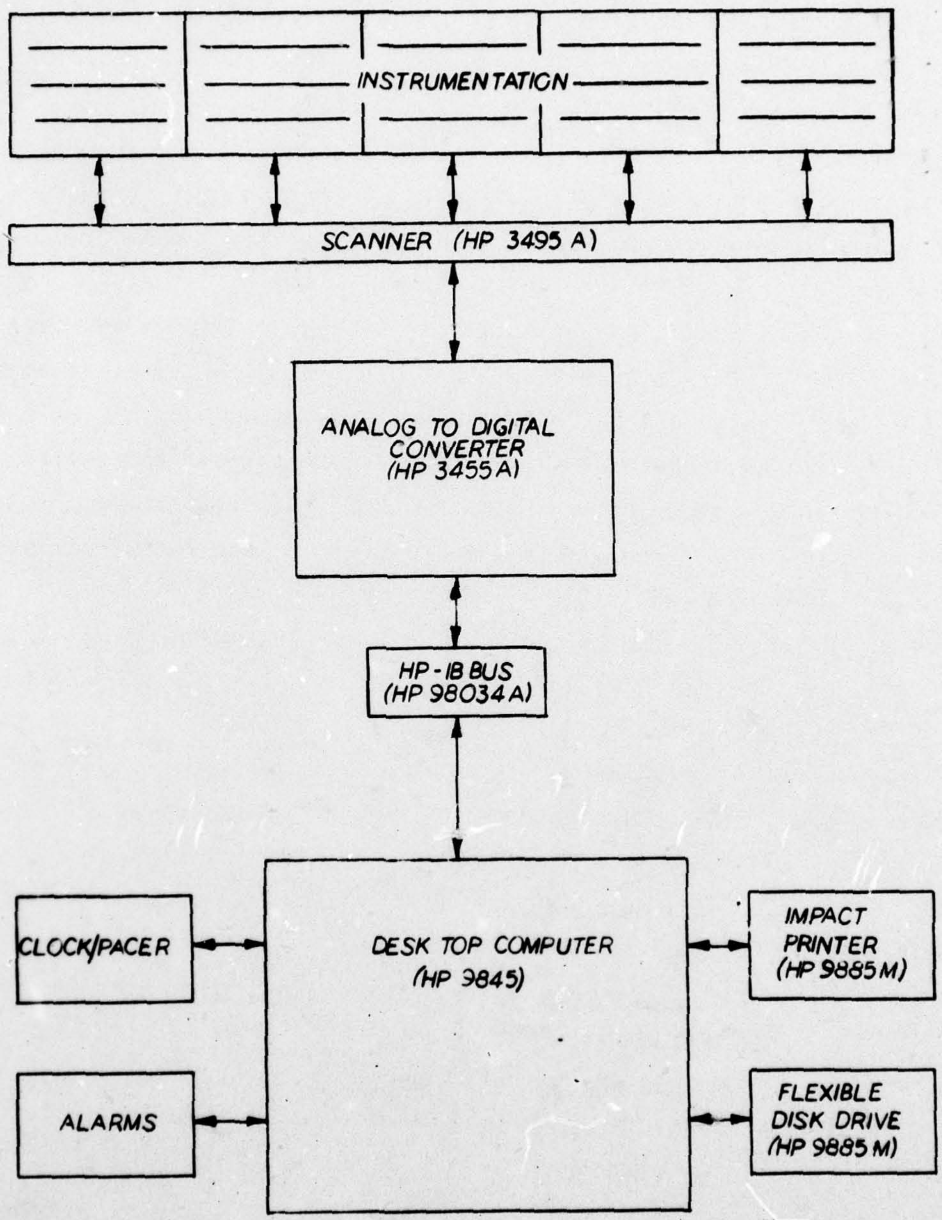


Figure 38. Instrumentation Diagram

SECTION XIX
TWARDS PLUMBING

The effluent from an existing base wastewater treatment facility is pumped onto the TWARDS trailer through the first pump. This pump is portable with a variable flowrate of 0 to 8 gal/min. It provides a head of 20 feet which should be sufficient for most facilities. The wastewater which enters the TWARDS trailer through this first pump will have received primary treatment from the base facility. The primary treatment will have removed the grit, oils, detergents, and approximately 35 percent of the BOD from the wastewater.

The influent line for the system is located on the front end of the TWARDS trailer. The line is on the left side of the trailer when viewed from the front and is located just below the deck. The influent line extends approximately 14 feet along the length of the trailer.

Three main lines leave the influent line to feed the activated sludge, biodisc, and trickling filter units. The system is designed so that two main lines can operate independently and simultaneously on the TWARDS trailer. Two alternate influent lines are provided on the TWARDS trailer to treat wastewater which has received secondary treatment from the base wastewater treatment facility.

The plumbing on the TWARDS trailer is fabricated from 1-inch-diameter standard steel pipe. The main lines are mounted to a bracket bolted to the structural members supporting the floor of the trailer. The design of the mounting brackets and the detailed plumbing layout cannot be provided until the trailer design has been completed. The design of the mounting brackets and the plumbing layout will be submitted to the USAF following the receipt of the design proposal for the TWARDS trailer.

There are two sludge recycle lines on the TWARDS trailer, located between the activated sludge clarifier and the activated sludge unit, as well as between the biodisc and trickling filter clarifier and the biodisc and trickling filter units. All lines are located beneath the bed of the trailer and are fabricated from 1/2-inch-diameter standard steel pipe.

There are 23 pumps located on the TWARDS trailer, three of which are portable pumps used as main influent, backwash water, and cleanup lines. The remaining 20 pumps are remote-control, variable-speed pumps mounted on brackets to the bottom of the structural members of the trailer. Seven tube pumps are used for chemical feed and sludge removal. The remaining six pumps are centrifugal pumps. The specifications for the pumps are given in Table 8.

Tee valves are located before and after each unit on the TWARDS trailer. The purpose of these valves is twofold. First, the units not actively being used in the flow schemes can be used independently of the system operation. Second, the valves and tees can be used to assist in cleanup operations. All of the plumbing should be flushed out with fresh water from the USAF base facility before the TWARDS trailer is transported.

TABLE 8. PUMP SPECIFICATIONS FOR THE TWARDS TRAILER

1. Condition: New

2. Summary:

Type	Flowrate	Head, ft	Quantity	Use
Centrifugal	0-20 gpm	0-20	2	Wastewater
Centrifugal	0-20 gpm	0-10	2	Wastewater
Centrifugal	0-8 gpm	0-20	1	Wastewater
Centrifugal	0-8 gpm	0-10	1	Wastewater
Centrifugal	0-4 gpm	0-20	3	Wastewater
Centrifugal	0-4 gpm	0-10	7	Wastewater
Tube	0-4000 mℓ/m	0-5	4	Sludge
Tube	0-50 mℓ/m	0-5	1	$C\ell_2$
Tube	0-20 mℓ/m	0-5	1	CH_3OH
Tube	0-20 mℓ/m	0-5	1	CH_3OH, Na_2SO_3, and H_2SO_4 or NaOH

3. Electrical Requirements:

- All motors shall be d.c.
- Power supply - 220 VAC, 60 Hz.
- All motors should be variable speed, remote controlled, with 4-20 mA d.c. output, operable in a temperature range of 10-50°C.

Pump Number	rpm's	hp
1-6	3400	1/3
7	100-650	--
8-10	5-100	--

4. Plumbing Requirements:

Centrifugal Pumps: 1-inch inlet and 1-inch outlet

5. Centrifugal pumps should be corrosion resistant.

6. All pumps shall be supplied and serviced by the same manufacturer.

SECTION XX
TWARDS ELECTRICAL

The electrical control panel for the TWARDS trailer is located on the back wall of the work compartment. This panel consists of circuit breakers for the main lines and for each individual unit. The reverse osmosis, ultrafiltration, ozone generation, and ultraviolet units have individual electrical control panels located at the units.

There are three main lines on the TWARDS trailer. One line is a 120-V, AC, 1-phase line which feeds some of the small motors used on the trailer and powers the trailer lighting. The second main line is a 240-V, 3-phase, AC line used to power all pumps, large motors, unit processes, flowmeters, and commercial units. The third main line is a 460-V, 3-phase, AC line used to power the control panel for the reverse osmosis unit (Table 9).

Separate circuits are provided for each unit on the TWARDS trailer. The pumps, flowmeter, motors, and control panels for each unit are also included on the same circuit. This auxillary equipment is included to insure its being shut down if any unit is shut down for maintenance. Fewer circuits are required with this method which cuts down the cost of the system and makes it easier to operate. Waterproof receptacles are provided near every unit on the trailer. Their purpose is to provide power for equipment used in cleanup and maintenance.

An electrical schematic is included as part of the design proposal. The detailed electrical layout and equipment specifications cannot be provided until the design of the TWARDS trailer is completed. Layout and specifications will be submitted to the USAF as part of the construction phase.

[redacted]

TABLE 9. MOTOR SPECIFICATIONS FOR THE TWARDS TRAILER

1.	Condition: New						
2.	Summary:						
	Type	Voltage	Phase	hp	rpm	Shaft Size, in	Quantity
	Impeller	110	Single	1/250	35	1/2	1
	Impeller	220	Three	1/3	350	--	2
	Impeller	220	Three	1/250	35	1/2	1
	Impeller	220	Three	1/50	330	1/4	1
3.	All motors should be d.c.						
4.	All motors should be variable speed, remote controlled, with 4-20 mA d.c. output, operable in a temperature range of 10-50°C.						
5.	All motors should have stainless steel shafts and propellers.						

SECTION XXI
INSTRUMENTATION

The individual unit processes on the TWARDS trailer are monitored and controlled by probes mounted on-line in instrumentation housings. The instrumentation housing is fabricated from a 1-inch-diameter steel pipe, an expansion assembly with a 1-inch-diameter inlet and a 4-inch-diameter outlet, a 6-inch length of 4-inch-diameter steel pipe, a contraction assembly, and another 1-inch-diameter steel pipe. The instrumentation housing is preceded by a valve to enable probes to be removed while the system is in operation.

The individual probes are constructed of a durable chemical-resistant material such as stainless steel or epoxy. The probes are less than 3-1/2 inches long and have pipe fittings. The probes screw into the instrumentation housing at a 60-degree angle from the horizontal. The probes must operate within a temperature range of 0°C to 60°C, withstand pressure of 15 lb/ft^2, have an output of 0- to 1-V DC, and be suitable for taking readings inside pipes. The following probes are included with the TWARDS.

TEMPERATURE PROBES

Five temperature probes are included with the system. They are accurate to ± 0.3°C within the range of 0°C to 60°C.

pH PROBES

Five pH probes are included with the system. The probes are accurate to ± 0.3 pH within the probe range of 0 to 14 pH units.

DISSOLVED OXYGEN

Five dissolved oxygen probes are included with the system. The dissolved oxygen probes are useful in determining if a unit is becoming anaerobic; or in anaerobic units such as the fluidized bed unit, the dissolved oxygen probe is used to determine if the oxygen has been removed. The dissolved oxygen probe has an accuracy of ± 0.3 ppm within a range of 0 to 14 ppm.

CONDUCTIVITY PROBES

The system contains seven conductivity probes used to determine the conductivity of the wastewater. The conductivity of the sample is an indication of the amount of suspended solids present. The conductivity probes are accurate to ± 0.02 μʊ/cm in a range of 0 to 20,000 μʊ/cm.

SPECIFIC ION PROBES

Two specific ion probes are included with the system. The first is a chlorine probe accurate to ± 1 p/m in a range of 0.1 to 500 p/m. The second is an ozone probe which is accurate to 0.2 p/m in a range of 0 to 8 p/m.

The temperature, pH, dissolved oxygen, and conductivity probes have collectively been called the instrumentage package. The locations of the probes are shown in Table 8 and in the plumbing schematic. The probe specifications are listed in Table 10.

In addition to the probes mounted on line, a portable meter is included with the system which interfaces with all of the above-mentioned probes and provides a digitial readout in specified units. One of each of the required probes is provided with the meter.

FLOWMETERS

There are 14 magmeter flowmeters included with the system. The magmeters are unaffected by density changes or the viscosity of the liquid. These magmeter units have replaceable metering tubes and are cleaned on line by an ultrasonic electrode. The specifications for the magmeters are listed in Table 11.

TABLE 10. INSTRUMENTATION SPECIFICATIONS FOR TWARDS PROBES

1. Condition: New

2. Summary:

Probe	Body	Length, in	Probe Range	Accuracy	Quantity
Temperature	Stainless Steel	≤ 3-1/2	0-60°C	± 0.3°C	5
pH	Epoxy	≤ 3-1/2	0-14 pH	± 0.3 pH	5
Dissolved Oxygen	Durable, Chemical Resistant	≤ 3-1/2	0-14 ppm	± 0.3 ppm	5
Conductivity	Durable, Chemical Resistant	≤ 3-1/2	0-20,000 μv/cm	± 0.02 μv/cm	7
Chlorine	Durable, Chemical Resistant	≤ 3-1/2	0.1-500 ppm	± 1 ppm	1
Ozone	Durable, Chemical Resistant	≤ 3-1/2	0-8 ppm	± 0.2 ppm	1

3. All probes must:
   - Include pipe fittings.
   - Operate within a temperature range of 0-60°C.
   - Be suitable for taking readings inside pipes.
   - Withstand pressure of 15 psi.
   - Have an output of 0-1 V d.c.

4. Include a portable meter with the capability of interfacing with the following probes:
   (1) Temperature
   (2) Conductivity
   (3) Dissolved Oxygen
   (4) pH
   (5) Specific Ion (Chlorine, Ozone)

5. All probes and meters shall be supplied and serviced by the same manufacturer.

TABLE 11. INSTRUMENTATION SPECIFICATIONS FOR FLOWMETERS

1.	Condition: New
2.	Type: Magmeter
3.	Design Features: (a) Replaceable Metering Tubes (b) Ultrasonic Electrode Cleaning (c) Unaffected by ± 10°C Voltage and Frequency Variations (d) Unaffected by Density or Viscosity of Liquid
4.	Output: Compatible with the data processing system used on the trailer.
5.	Fluid Types: All Liquids
6.	Accuracy: ± 1% for design flow of 2 gpm.
7.	Type Liner: Teflon
8.	Temperature Limits: 10°C - 50°C
9.	Maximum Pressure: 15 psi
10.	Flowrates: (a) 1 Instrument for 0-20 gpm (b) 13 Instruments for 0-8 gpm
NOTE:	One signal processing unit shall be used to monitor the output of all the 14 flowmeters.

The output of the magmeters is compatible with a signal processor modified to scan all 14 of the magmeters in the system. The function of the signal processor is to count the pulses generated by the magmeters and convert them to a 0- to 1-V DC signal compatible with the data processing equipment. The magmeters are accurate to ± 1 percent of the design flow and can be used to measure all liquids within a temperature range of 10°C to 50°C and a maximum pressure of 15 lb/in^2.

PUMPS

The pumps on the TWARDS trailer are remote controlled and of variable speed. Operating on 240-V, 60-Hz power, they are controlled and monitored by a 4 to 20 mA or analog signal. The types of pumps, pump numbers, and specifications are listed in Table 8.

The subtask statement originally proposed that sludge density meters be included in each bank of the clarifier and that on-line turbidimeters and a TOC analysis be provided for the system (Table 8). These units were not included with the system because an effective, inexpensive unit could not be found.

SECTION XXII
DATA PROCESSING SYSTEM

INTRODUCTION

The data processing system on the TWARDS trailer must be able to sequentially scan all of the probes, flowmeters, and pumps. The system must also be able to control the pumps which are regulated by a 4 to 20 mA current. In addition to providing the capability to sequentially scan the instrumentation, the system must be flexible enough to allow the operator to acquire readings of a given probe, flowmeter, or pump, upon command. The data generated during a given period must be available to be accessed by the user. Data manipulation and evaluation capabilities must also be provided. A description of the required capabilities for the system controller is provided below.

DESKTOP COMPUTER

General Functional Description

The computer is capable of containing in an integrated system all of the basic and optional internal components described below so that it can be transported manually from one location to another as a single unit.

The computer includes a keyboard, internal memory, user memory of at least 62,000 bytes, overlapped processors, built-in tape cartridge for data and program storage, cathode ray tube (CRT) display, output printer, and capability of interfacing simultaneously with at least four external peripheral devices such as XY plotters, external storage memories, and others.

Quality assurance provisions include completely testing samples of the computer according to rigid electrical, mechanical, and environmental specifications.

Active components within the computer are solid state except the cathode ray tube, reflecting state-of-the-art technological advances.

The computation range is from $-9.999\ 999\ 999\ 99 \times 10^{511}$ through -1×10^{-511}, 0, and 1×10^{-511} through $9.999\ 999\ 999\ 99 \times 10^{511}$. The range of values which can be entered, stored, or output is $-9.999\ 999\ 999\ 99 \times 10^{99}$ through -1×10^{-99}, 0, and 1×10^{-99} through $9.999\ 999\ 999\ 99 \times 10^{99}$.

Physical Specifications: Power

The computer is capable of operating on either 110 or 220 V with specified tolerances. Switchable selection of power source voltages is provided. Power line frequency is between 48 and 66 Hz. Power consumption does not exceed 420 VA.

Detailed Functional Description

Keyboard. The computer keyboard includes a block of keys with standard typewriter layout, a block for program control and editing, a block for CRT editing and control, a block of user definable keys, a system command block, and a numeric computation block. A typewriter mode is provided which allows the computer to be used in conjunction with an output device as a typewriter is used, including the standard 128-character ASCII set and tabbing.

Programming language. Language includes capability to handle and manipulate strings of alphanumeric data. Capability is included to edit such strings while a program is running. The user is able to interrupt a program to run a higher priority subprogram. At least five levels of program interrupt priority are provided. Priorities shall be programmable. Capability also is provided to operate using arrays of numerical data, with selection of numerical format using 12-digit integer precision. Tracing capability is provided as a debugging aid, allowing the tracing of the order of statement execution, all variables, or selected variables. A live keyboard feature is provided to allow changing variable or program statements while the program is running or to list the program while it is running.

Cathode Ray Tube (CRT) display. A refresh type cathode ray tube is included in the computer system to enhance programming, editing, and operation, and to minimize required desk space. The image refresh rate is at least

60 Hz to minimize flicker. The CRT display includes an independent area for viewing formatted data and a "prompt" area to display system input instructions.

The amount of data displayable on the CRT is at least 20 lines of 80 characters each. Video highlighting is provided in the forms of inverse, blinking, and underlined display segments.

A cursor and line scrolling capability is included to facilitate data review and program editing. A standard alpha operating mode allows displaying business and scientific data and text. A graphic operating mode allows presentation of graphic information such as plots and pie charts. Graphic displays are transferable to a printed copy using the computer's internal printer.

Internal printer. The computer includes a built-in thermal printer with a line width of at least 80 characters. The print rate may vary depending on the number of characters in a line, but it is at least 300 lines per minute for full 80-character lines. The printer is capable of printing the standard 128 character ASCII set. The printer is further capable of generating characters 150 percent of normal height on command for visual emphasis. Back spacing capability is provided to enable underlining. The printer is also capable of recording dot-for-dot the graphics displayed on the CRT.

Tape cartridge. The computer includes a tape cartridge drive in the mainframe. This cartridge has a program and data storage capacity of at least 200,000 bytes of programs or data. Tape storage operations includes a means of verifying the accuracy of the data. Tape file organization is compatible with that of an external mass storage device to avoid the need for reprogramming when changing records from tape cartridges to the external device. The computer uses the same system commands to operate either the tape cartridge or the external memory. The tape affords at least 2100 mm/sec search speed in either direction and 540 mm/sec read/write speed. Typical high-speed search rate shall be in excess of 2100 mm/sec.

Memory. The computer includes an internal user memory of at least 62,000 bytes and is compatible with external mass storage devices having capacities of up to at least 15 million bytes. The data cartridge file structure and statements are similar to those of the external mass storage devices.

Operational Specifications

Keyboard. The computer keyboard includes a standard typewriter configuration, a numeric computation pad, system operation keys, editing keys, and 16 special function keys with shift to allow up to 32 functions to be defined by the user. The keyboard is designed for convenience. Keys are clearly marked and color coded according to function.

Program protection. A means of protecting programs against accidental erasure is provided. Provisions are included to allow recording backup copies of software programs.

Quality Assurance Testing

The computer passes the following or similar tests which check immunity to extreme environmental conditions.

Non-operating temperature cycle test. The computer should be placed in a temperature test chamber. The temperature should then be reduced from +25°C to -40°C over a 2-hour period. Temperature should be held at -40°C for 3 hours. The temperature can then be increased over a 3-hour period to +75°C and held there for an additional 3 hours. Temperature should then be returned to +25°C over a 2-hour period and allowed to stabilize thermally to room temperature for 1 hour with the computer turned on. The computer should now perform within the specified tolerances and give no indication of failure as a result of this test.

Operating low-temperature test. The computer should be placed in a temperature test chamber and the temperature reduced from +25°C to 0°C for 1 hour with the power off. Then the computer should be turned on and allowed to warm up for 30 minutes. The computer should now perform within all specifications during and after this test, and there should be no indication of failure as a result of this test.

Operating high-temperature test. The computer should be placed in a temperature test chamber and the temperature of the chamber elevated to +55°C. This temperature should be maintained for at least 16 hours. No detrimental effects should be caused by excess heating, and the computer should meet all specifications during and after the heat run.

Humidity test cycle. The computer is required to pass five 24-hour cycles of the +25°C to +40°C to 95 percent RH. At least one reading should be taken at each discrete humidity level during the first eight hours of the humidity cycle. The computer should be required to pass all of its specifications after a 30-minute exposure period to the 95-percent RH part of this humidity cycle.

Vibration test. The computer in its regular enclosure should be secured to the vibration table and then be operated during the vibration test with its principal functions being monitored. A performance check is made before and after vibration. At the completion of the vibration tests, the instrument should display no electrical or mechanical degradation.

(a) Specification. 10 to 55 cycles - to 0.015-inch point-to-point excursions.

(b) Test sequence.

(1) A 0.002 in exploratory excursion.

(2) 15 minutes of cycling (15 1-minute cycles) from 10 to 55 cycles with 0.015 in excursions in each of the three principal directions.

(3) 5 minutes at 0.015 in excursion, at the major resonant point in each of the three principal directions.

(4) If there are no major resonances below 55 cycles, the computer should be vibrated for 5 minutes at 55 cycles at an excursion of 0.015 inches point-to-point.

Shock. The computer should show no degradation in performance after application of a half sine wave shock of 30-g and 11-ms duration. Three shocks should be applied in each of the three axes in which the computer can be supported.

Electromagnetic compatibility. The computer should pass all tests per CISPR publications pertaining to electromagnetic compatibility, as well as tests for radiated and conducted susceptibility.

Front-End Equipment

The required precision for the voltmeter and A/D devices is controlled by the output and required accuracy of the conductivity probes as shown in Table 9. The precision of the A-to-D device must be 1 μv out of 1 V. The input must be floated and guarded to cut down noise problems caused by the extreme environmental conditions in which the system must operate and the long cable lengths between the probes and the A-to-D device.

The system which the CERF suggests to be used is the Hewlett Packard 3052A Automatic Data Acquisition System. A list of the hardware which is included in the system is included in Table 12.

The software which is provided with the system includes (1) complete operating system with controllers for all peripherals; (2) applications packages including graphics, basic statistics, orderstatistics, transformation routines, regression methods, and input/output commands; and (3) data acquisition system library for controlling the A/D and D/A devices. This includes all routines necessary for the control of the devices plus additional application programs and operational verification programs.

The volume of work CERF must do to develop the additional software necessary to make the system operational is greatly reduced because of the number of "canned" programs provided with the system. It is estimated that it will take a moderately skilled programmer approximately four months to write, debug, and document the additional software to be developed at CERF.

TABLE 12. HEWLETT-PACKARD HARDWARE QUOTATION FOR TWARDS DATA PROCESSOR

Item Number	Quantity	Description	Approximate Delivery, weeks	Freight-On-Board Point	Unit Price, dollars	Total, dollars
1	1	3052A Automatic Data Acquisition System	10	Destination	16,781.90	52,481.90
		Option 045 Adds 9845S Controller	26		14,200.00	
		Option 501 Standard Printer			0.00	
		Option 601 US Date Format for 98035A Time Clock			0.00	
		Option 800 Standard Keyboard			0.00	
		Option 003 9 Channel Low Thermal Relay			700.00	
	2	Option 004 20 Channel Low Thermal Relay			700.00	
		Option C10 6940B Multiprogrammer 59500A Interface			2,560.00	
		Option C12 6941B Extender			1,300.00	
	23	Option W41 69370A D/A Current			450.00	
	2	Option W59 69351B Voltage			150.00	
		Option 009 Deletes 3437A			-2,160.00	
		Option 060 60 Hz Line 120 V Single Phase			0.00	
		Option Q85 9885M Flexible Disk			4,450.00	
		Option W92 9885S Flexible Disk/ Drive Slave			2,600.00	
2	1	2631A 180 CPS Printer	16	Destination	3,163.95	3,212.95
		Option 845 For Use With 9845A			50.00	

In a letter dated April 27, 1978, CEEDO proposed an alternate system which utilizes a microcomputer for a system controller. The hardware which would be required for the CEEDO system is listed below:

SBC 80/20A	$ 895.00
SBC 016 (4 required)	3,900.00
SBC 212	4,750.00
SBC 310	655.00
ST-800-32S (3 required)	1,485.00
ST-800-DA8C1 (3 required)	1,485.00
SBC 660	1,350.00
ISC Color CRT	1,925.00
Monitor Software	225.00
RMX/80	1,950.00
128 Character Printer	3,200.00
TOTAL	$21,820.00

The initial hardware cost of the microcomputer system is substantially lower than the hardware cost of this proposed Hewlett-Packard (HP) system. However, it would take approximately 32 man-months to develop the software required to provide the capability of the HP system and would cost approximately 53,000 dollars.

Several important considerations not addressed by the microcomputer system should be carefully evaluated. Whenever possible the component parts should be provided by the same vendor. If a multi-vendor system similar to the microcomputer system were to fail, the unit would remain down for a long period of time until the problem could be isolated and the appropriate service representative contacted. It would also be extremely important to choose companies with numerous, well-located service centers, and proven performance records in well constructed hardware/software.

The use of vendor-supplied software to access A/D and D/A equipment using high level languages such as BASIC or FORTRAN and off-the-shelf integrated hardware can cut the system software costs by a factor of 10. Other features which should be evaluated are system command simplicity, operational verification programs, and vendor-provided systems courses.

SUMMARY

The HP system is extremely versatile, easy to operate, and proven reliable. A minimal amount of time and money would be required to develop software for it. The HP system is installed by HP representatives and is tested through the entire performance range of each unit. Operational verification programs are provided which enable the operator to determine if the system is ready to be used, and where the problem is if the system is not functioning properly.

The system proposed by CEEDO would be tailor made for the TWARDS project and therefore would not have the flexibility of the HP system. The software development requirements would make it very difficult for CERF to complete the project in the allotted time and for the original estimate. CERF, therefore, recommends that the HP system be used for the TWARDS project.

SECTION XXIII
COST ESTIMATES

The cost estimates in this section are preliminary cost estimates only. The estimate for the unit processes (Table 13) does not include money for the purchase or fabrication of a pressurized air floatation unit. The materials cost estimate reflects the cost of all materials used in the fabrication of the unit, plus the cost of the filter media where required.

The instrumentation cost estimate (Table 14) is based on typical costs for the units required. The units will be put out for competitive bid when authorization is received from the USAF to initiate the construction of the TWARDS. Labor costs involved in installing the units and time required for a technician were estimated.

The cost estimate for the data processing equipment (Table 15) is based on an HP system 3052A. The system which will actually be used on the TWARDS will not be determined until the construction phase of the project. The costs involved in software development are based on the HP System, for which a great deal of related software has already been developed. Four months of an engineer's time were allotted to the development of additional software.

The trailer plumbing (Table 16) and electrical (Table 17) cost estimates include the costs for materials used and labor required for installation.

The TWARDS Cost Estimate (Table 18) includes all costs involved in the purchasing of materials, transportation of materials, fabrication, system development, and system testing. The estimated cost of fabrication is approximately 275,000 dollars.

[redacted]

TABLE 13. UNIT PROCESS COST ESTIMATE

Unit Description	Materials, dollars			Man-Hours				
	Steel	Plastic	Misc.	Technician	Plumber	Welder	Laborer	Supervisor
Trickling Filter	1,904	372	175	15	15	80	40	15
Activated Sludge	2,362	690	150	15	15	80	40	15
Bio-Disc Unit	40	50	3,525	10	10	10	15	5
RM & Flocculator	1,200	400	200	15	15	60	40	10
Clarifier	2,350	400	200	30	80	300	100	30
Contact Chamber	476	315	150	15	10	80	10	10
Sand Filter	165	905	600	15	20	60	10	15
Activated Carbon	172	1,584	2,250	30	50	150	25	30
Fluidized Bed	204	945	200	30	30	70	10	10
Ozone Unit	134	0	350	5	5	20	10	5
Misc. Mountings	350	0	100	0	0	150	50	0
Trailer Painting	0	0	1,000	0	0	0	20	0
Total	9,357	5,661	8,900	180	250	1,060	370	145
Use	11,000	7,000	10,000	200	250	1,060	370	250

TABLE 14. INSTRUMENTATION

Item	Model Number	Quantity	Unit Cost, dollars	Cost, dollars
Temperature Probe	703	5	45	225
D.O. Probe	DO 166	5	175	875
Chlorine Probe		1	190	190
Ozone Probe		1	190	190
pH Probe	1085	5	60	300
Conductivity Probe		7	65	455
Model 1500 Multi-Parameter Analyzer	1500	1	500	500
Portable Conductivity Meter	Type 70	1	235	235
Mag-X Flowmeter	10D1418A	14	1,350	18,900
Signal Processor (Mag-X)	50PZ1000	1	1,220	1,220
Remote Control Pumps				
0-20 gpm		4	400	1,600
0-8 gpm		2	400	800
0-4 gpm		10	400	4,000
0-2 gpm		4	600	2,400
0-50 mℓ/m		1	300	300
0-20 mℓ/m		2	300	600
Shipping		Lump	500	500
Total				33,290
10% Increase				3,329
Total (Use)				36,600

TABLE 15. DATA PROCESSING

Unit Description				Cost, dollars	
Option Number	Unit Number	Quantity	Description	Unit	Total
	HP3052A	1	Instrument System	16,000.00	16,000.00
045	HP9845S	1	System Controller	14,200.00	14,200.00
501		1	Standard Printer	N/C	N/C
601	HP98035A	1	U.S. Date Format	N/C	N/C
003		1	Thermocouple Channels	700.00	700.00
004		2	Scanner Channels	700.00	1,400.00
C10	HP6940B/59500A	1	--	2,560.00	2,560.00
C12	HP6941B	1	Extender	1,300.00	1,300.00
W41	HP69370	23	D/A Card	450.00	10,350.00
W59	HP69351B	2	Voltage Card	150.00	300.00
009	HP3437A	1	H.S. Voltmeter	-2,160.00	-2,160.00
060		1	120/208 V, 3-Phase	N/C	N/C
Additions:					
	HP2631A	1	Printer	3,150.00	3,150.00
845	HP9845A (Option for HP2631A)	1		50.00	50.00
			Total		47,850.00
			Less 3%		-1,435.50
			Use		46,500.00

TABLE 16. TRAILER PLUMBING

Item	Quantity	Unit Price, dollars	Cost, dollars
Valves, 1-inch Ind.	50	18	900
Elbows, 1-inch	60	2	120
"T", 1-inch	90	2	180
Check Valve, 1-inch	1	50	50
Needle Valve, 1-inch	3	15	45
Pipe, 1-inch Standard	300 ft	1.5 lb/ft @ 0.60	180
Pipe, 1/2-inch Standard	175 ft	1.5 lb/ft @ 0.40	70
Labor	400 hours	15/hour	6,000
Instrumentation Housing	10	25	250
Total			7,795
10% Increase			780
Total (Use)			8,575

TABLE 17. ELECTRICAL

Item	Quantity	Unit Cost, dollars	Total, dollars
Wire, 220-V	500 ft	76.00/1000 ft	38.00
Wire, 110-V	450 ft	76.00/1000 ft	34.20
Plugs, 220-V	18	2.60 each	46.80
Plugs, 110-V	17	2.60 each	44.20
Outlet Boxes, Weatherproof	31	2.50 each	77.50
Outlet Boxes, Standard	2	0.60 each	1.20
Total			241.90
Use			250.00
Labor	160 hours	15.00/hour	2,400.00

TABLE 18. TWARDS COST ESTIMATE

Description	Cost, dollars
Trailer	50,000
Trailer Delivery	4,000
Unit Process Fabrication and Mounting	119,391
Instrumentation	38,000
Data Processing Equipment	46,500
Plumbing	9,000
Electrical	2,750
Motors	1,250
Total	270,891

SECTION XXIV
OBJECTIVES, IMPLEMENTATION, SUMMARY, AND CONCLUSIONS

OBJECTIVES

The main objective of the development stage of the project is to fabricate the TWARDS trailer and unit processes. An operator's manual, maintenance manual, technical report, and complete set of as-built drawings will be completed describing in detail all phases of the project.

During the design phase of the project, the feasibility of building the TWARDS trailer was addressed. It was determined that TWARDS would be necessary to analyze the effluent from existing base wastewater treatment facilities effectively and to determine the most cost-effective method for upgrading the existing facilities or constructing new ones which meet future government standards.

IMPLEMENTATION

The implementation of the main objectives of the development phase of the project are listed in the following paragraphs.

Fabrication of TWARDS Trailer

The manufacturer who submitted the low bid for the construction of the trailer (Calumet Coach Company) will be contacted and arrangements made to begin the design of the trailer. Within 30 days after the contract is awarded, the manufacturer will submit detailed plans and specifications for the fabrication of the trailer. A two-week period will be allotted to CERF to check plans and specifications. The completed trailer will be delivered to CERF in Albuquerque, New Mexico on or before November 30, 1978.

Unit Processes

The unit processes will be fabricated and installed on the trailer. All of the materials required for the fabrication of the TWARDS will be ordered by CERF no later than June 30, 1978. Upon receipt of the materials, the following unit processes are to be fabricated at CERF: biodisc modifications, activated sludge unit, trickling filter unit, clarifier unit, rapid mix and flocculator unit, sand filter units, activated carbon units, fluidized bed unit, frame for ozone preparation unit, and the disinfection contact chamber. These units will be completed no later than November 30, 1978. The ultrafiltration unit, ozone and air preparation units, ultraviolet unit, and the reverse osmosis unit will be delivered to CERF as soon as the development phase begins. The work compartment is to be fabricated by the trailer manufacturer and delivered with the trailer. The unit processes will be mounted on the trailer and plumbed, and the trailer and unit processes will be wired, before January 31, 1979.

Data Processing Equipment

The data processing equipment will be selected, purchased, and delivered before November 30, 1978.

Layout Drawings and Specifications

Detailed layout drawings and specifications for the plumbing and electrical systems are to be completed and submitted to the USAF before November 30, 1978.

Instrumentation Equipment

The instrumentation equipment--which includes all probes, pumps, and flowmeters--will be put out to bid, purchased, and delivered no later than November 30, 1978.

Installation of Instrumentation and Data Processing Equipment

The instrumentation and data processing equipment will be installed in the trailer by January 31, 1979.

Testing

The unit processes, plumbing, and chemical feed systems are to be leak-tested for a period of 120 continuous hours prior to delivery. The sludge collection assemblies, pumps, and devices will be tested, with domestic wastewater sludge. Two performance tests are to be conducted on all probes, pumps, flowmeters, motors, and the data processing equipment. The instrumentation will be tested through its entire performance range. All tests are to be completed, and written approval of the completed system received, before March 31, 1979.

TECHNICAL REQUIREMENTS OF IMPLEMENTATION

In support of this effort, the following technical information will be generated.

Software

The software for the data processing and acquisition system will be written, tested, and submitted to the USAF for approval.

Drawings

As-built drawings will be submitted to the USAF to show changes which were made in the fabrication of the unit processes, trailer, and support equipment.

Operator's Manual

An operator's manual will be written which gives detailed information on the start-up, operation, shut-down, and clean-up procedures for all unit processes, instrumentation, data processing equipment, and support equipment.

Maintenance Manual

A maintenance manual will be provided with the system which includes detailed isometric projections of the unit processes and trailer. The manual will give detailed troubleshooting information, information on preventative maintenance, and a list of suppliers of all purchased equipment.

Technical Manual

A technical report will be submitted to the Air Force before May 15, 1979. The technical report will include a detailed written account of the fabrication and testing of the TWARDS.

SUMMARY

The staff of CERF is of the opinion that the TWARDS trailer should be fabricated according to the design information and schedule submitted to the USAF. The CERF staff thinks that there is a well-defined need for TWARDS and that the system will effectively evaluate the effluent of existing wastewater treatment facilities. The information which is generated by the TWARDS will be extremely valuable because the system is large enough to model the existing facilities accurately. Money will be saved in the design of new, upgraded facilities because all of the design parameters will be well defined.

APPENDIX A
DESIGN CALCULATIONS

Activated Sludge Unit (Reference 2)
Hydraulic Retention Time Design

HRT = 8 h
Q = 2 gal/min

$\forall = (2 \text{ gal/min})(60 \text{ min/h})(8 \text{ h})(1 \text{ ft}^3/7.5 \text{ gal})$
$\forall = 128 \text{ ft}^3$

f = Freeboard = 0.65 ft
d = sidewater depth
D = d + f
w = width $\quad 1.5\ d \leq w \leq 2\ d$

$\forall = LWd - 2L(0.5 \text{ ft})^2 = 128 \text{ ft}^3$
$w = 1.5\ d$
$\forall = 6.93 \text{ ft } (1.5)(d^2) - 2(6.93 \text{ ft})(0.25 \text{ ft}^2) = 128 \text{ ft}^3$

d = 3.56 ft
D = 4.50 ft
w = 5.33 ft
L = 6.93 ft

Air Requirements:

$Q_{AIR} = (2 \text{ gal/min})(60 \text{ min/h})(3 \text{ ft}^3/\text{gal}) = 360 \text{ ft}^3 \text{ air/h}$

Activated Sludge Design Check

u = food-to-microorganism ratio
u = 0.2 to 0.5 lb BOD_5/lb MLVSS-day (0.2 is conservative)
θ_c = mean cell resistance time (6 to 15 days)

θ_c = 10 days

k_d = microorganism-decay coefficient, time^{-1}

k_d = 0.10/day

Y = growth-yield coefficient, mass of microorganisms/mass of substrate utilized

Y = 0.65 lb cells/lb BOD_5 utilized

E = efficiency of waste stabilization expressed in percentage form

S_o = mass concentration of influent waste

S = mass concentration of influent waste not biologically degraded appearing in the effluent

Q = volumetric flowrate

Q = 2 gal/min

X = concentration of microorganisms (MLVSS), mass/volume

X = 3500 mg/ℓ

BOD Loading = 35#BOD/1000 ft^3

BOD_5 in effluent = 20 mg/ℓ

Return sludge concentration = 12,500 mg/ℓ of suspended solids

= 10,000 mg/ℓ volatile suspended solids

Mixed-liquor volatile suspended solids (MLVSS) = 3,500 mg/ℓ = 0.80 total MLSS

T = 20° C

BOD_5 = 250 mg/ℓ

35% removal of BOD_5 by primary treatment

Solution:

1. Estimated Overall Efficiency

$$E = 100 \frac{S_o - S}{S_o}$$

$$E = \frac{250 \text{ mg/ℓ} - 20 \text{ mg/ℓ}}{250 \text{ mg/ℓ}} (100) = 92\%$$

2. Reactor Volume

S = 6 mg/ℓ Soluble BOD_5

$$x¥ = \frac{YQ\theta_c(S_o - S)}{1 + kd\theta_c}$$

$3500\ mg/\ell\ \mathcal{V} =$

$$\frac{(0.65\ \text{lb cells/lb BOD}_5)(2\ \text{gal/min})(1440\ \text{min/day})(10\ \text{day})(250\ mg/\ell - 6)}{1 + (0.10/\text{day})(10\ \text{day})}$$

$\mathcal{V} = 652.53$ gal

$\mathcal{V} = (652.53\ \text{gal})(\text{ft}^3/7.5\ \text{gal})$

$\mathcal{V} = 87.00\ \text{ft}^3$

3. **Sludge Production Rate**

$$dX/dt = \frac{X\mathcal{V}}{\theta_c} = \frac{(3500\ mg/\ell)(87.00\ \text{ft}^3)(7.5\ \text{gal/ft}^3)(\text{mgal}/10^6\ \text{gal})(8.34\ \text{lb/gal})}{10\ \text{days}}$$

$dX/dt = 1.90$ lb VSS/day

$$\text{Sludge Production Rate} = \frac{1.90\ \text{lb VSS/day}}{0.80\ \text{Total MLSS}} = 2.38\ \text{lb SS/day}$$

4. **Sludge Wasting Rate from Recycle Line**

$$Q'_w \cong \frac{\mathcal{V}X}{\theta_c X_r} = \frac{(87.00\ \text{ft}^3)(3500\ mg/\ell)}{(10\ \text{days})(10{,}000\ mg/\ell)} = 3.05\ \text{ft}^3/\text{day}$$

5. **Recirculation Ratio**

VSS = 3500 mg/ℓ   Return VSS = 10,000 mg/ℓ

$3500(Q + Qr) = 10{,}000\ Qr$

$$\frac{Qr}{Q} = 0.54$$

6. **Required Hydraulic Retention Time**

$$\text{HRT} = \frac{\mathcal{V}}{Q} = \frac{87.00\ \text{ft}^3}{(2\ \text{gal/min})(60\ \text{min/h})(\text{ft}^3/7.5\ \text{gal})} = 5.44\ \text{h}$$

7. **Compute Oxygen Requirements**

$$\text{lb } O_2/\text{day} = (dF/dt)_L - 1.42\ (dX/dt)$$

$$= \frac{(250\ mg/\ell - 6\ mg/\ell)(8.34\ \text{lb/gal})(0.00288\ \text{mgal/day})}{0.68\ mg/\ell}$$

$- 1.42(1.90\ \text{lb VSS/day})$

$= 5.92\ \text{lb } O_2/\text{day}$

8. Check U Ratio and Volumetric Loading

$$U = \frac{dF/dt}{X} = \frac{(250\ \text{mg}/\ell - 6\ \text{mg}/\ell)(8.34\ \text{lb/gal})(0.00288\ \text{mgal/day})}{(3500\ \text{mg}/\ell)(8.34\ \text{lb/gal})(87.00\ \text{ft}^3)(7.5\ \text{gal/ft}^3)(\text{mgal}/10^6\ \text{gal})}$$

$U = 0.308$ lb BOD_5/lb MLVSS-day $\quad 0.2 < U < 0.5 \therefore$ OK

$$\text{Loading} = \frac{(250\ \text{mg}/\ell)(8.34\ \text{lb/gal})(0.00288\ \text{mgal/day})(1000)}{(87.00\ \text{ft}^3)(7.5\ \text{gal/ft}^3)}$$

$$= \frac{9.20\ \text{lb}\ BOD_5\ \text{removed}}{1000\ \text{ft}^3}$$

Trickling Filter Unit (References 2 and 3)

Q = volumetric flowrate

Q = 2 gal/min

$BOD_L = 250$ mg/ℓ

R = 4 = recirculation ratio

L = applied BOD_L which is removable (not over $0.90\ L_0$ where L_0 is equal to the applied BOD_L)

L_D = removable portion of BOD_L remaining at depth D

E_1 = fractional efficiency of BOD removal for process, including recirculation and sedimentation

W = BOD loading to filter, lb/day

V = volume of filter media, acre-ft

F = recirculation factor

U = unit organic loading on filter, in pounds of BOD per acre-ft

Total BOD = (250 mg/ℓ)(8.34 lb/gal)(0.00288 mgal/day) = 6.005 lb BOD/day

Assume: 35% BOD_L removed by primary treatment

Effluent $BOD_5 \leq 30$ mg/ℓ

$BOD_5 = 0.7\ BOD_L$

$L = 0.9\ L_0$

1. BOD_L of the Effluent

$$BOD_L = \frac{30}{0.7}\ \text{mg}/\ell = 43\ \text{mg}/\ell$$

2. BOD that is not removable

$$BOD = 250(1 - .35)(0.1) = 1L$$

3. Compute L_D and L

$$L_D = 43 - 16 = 27 \text{ mg}/\ell$$
$$L = 250(1 - .35)(.9) = 146 \text{ mg}/\ell$$

4. Required Filter Depth D

$$L_D/L = \frac{27 \text{ mg}/\ell}{146 \text{ mg}/\ell} = 0.185$$

$$0.185 = 10^{-0.15D}$$
$$5.41 = 10^{0.15D}$$
$$D = \frac{1.097}{0.175} = 4.9 \text{ ft}$$

Filter Design:

$BOD_{max} = 40$ lb BOD/1000 ft³-day

Let D = 6.00 ft

$$\text{¥} = \frac{\text{TOTAL BOD}}{BOD_{max}}$$

$$\text{¥} = \frac{6.005 \text{ lb BOD/day}}{40 \text{ lb BOD/1000 ft}^3\text{-day}} = 150.12 \text{ ft}^3$$

$$A = \frac{\text{¥}}{D} = 25.02 \text{ ft}^2$$

Use: D = 6.00 ft + 0.50 ft Freeboard
Length = 7.00 ft
Width = 3.57 ft
D = 6.50 ft

Efficiency:

35% BOD_L removed by primary treatment

$$F = \frac{1 + R}{(1 + R/10)^2} \qquad F = 2.551$$

$$w = 6.005 \text{ lb BOD/day}(1 - 0.35) = 3.90(\text{lb BOD/day})$$

$$u = \frac{w}{VF}$$

$$u = \frac{(3.90 \text{ lb BOD/day})(43{,}560 \text{ ft}^2\text{/acre})}{(150.12 \text{ ft}^3)(2.551)}$$

$$u = 443.6 \text{ lb BOD/acre-ft/day}$$

$$E_1 = \frac{100}{1 + 0.0085\sqrt{u}}$$

$$E_1 = \frac{100}{1 + 0.0085\sqrt{443.6 \text{ lb BOD/acre-ft/day}}}$$

$$E_1 = 84.82\%$$

$$BOD_e = 250 \text{ mg}/\ell(1 - 0.35)(1 - 0.8482) = 24.67 \text{ mg}/\ell$$

$$\% \text{ Removal} = \frac{250 \text{ mg}/\ell - 24.67 \text{ mg}/\ell}{250 \text{ mg}/\ell}(100\%) = 90.1\%$$

Clarifier Bank (Reference 2)

$Q = 2$ gal/min — W = width

$V < 100$ ft/h — L = length

$3W \leq L \leq 5W$ for Q_{opt} — D = total depth

$Q_{opt} = 2$ gal/min — d = liquid depth

$Q_{min} = 0.5$ gal/min

$Q_{max} = 3.5$ gal/min

A = required surface area

Maximum Loading = 700 gal/day/ft^2

For Q_{max}:

$$A = \frac{(3.5 \text{ gal/min})(1440 \text{ min/day})}{700 \text{ gal/day/ft}^2}$$

$$A = 7.20 \text{ ft}^2$$

if $W = 1.03$ ft — W = width

$L = 7.00 \text{ ft} = L_T$ — L = length

For Q_{opt}:

$$A = \frac{(2 \text{ gal/min})(1440 \text{ min/day})}{700 \text{ gal/day/ft}^2}$$

$$A = 4.11 \text{ ft}^2$$

$$\text{if } W = 1.03 \text{ ft}$$

$$L = 4.00 \text{ ft} = L_1 + L_2$$

$$3W \leq L \leq 5W \quad \therefore \text{ OK}$$

For Q_{min}:

$$A = \frac{(0.5 \text{ gal/min})(1440 \text{ min/day})}{700 \text{ gal/day/ft}^2}$$

$$A = 1.03 \text{ ft}^2$$

$$\text{if } W = 1.03 \text{ ft}$$

$$L_1 = 1.00 \text{ ft}$$

Depth:

$$\forall = (3.5 \text{ gal/min})(60 \text{ min/h})(\text{ft}^3/7.5 \text{ gal})(1.5 \text{ h})$$

$$\forall = 42 \text{ ft}^3$$

$$d = \frac{\forall}{A}$$

$$d = \frac{42 \text{ ft}^3}{7.2 \text{ ft}^2} = 5.833 \text{ ft; Freeboard} = 0.50 \text{ ft}$$

Use: $d = 5.833$ ft

$D = 5.833 \text{ ft} + 0.50 \text{ ft} = 6.33 \text{ ft}$ D = depth

$W = 1.03 \text{ ft } w_1 = w_2 = w_3 = w_4$ W = width

$$V = \frac{Q}{A}$$

$$V = \frac{(2 \text{ gal/min})(\text{ft}^3/7.5 \text{ gal})(60 \text{ min/h})}{4.11 \text{ ft}^2}$$

$$V = 3.89 \text{ ft/h} < 100 \quad \therefore \underline{\text{OK}}$$

Rapid Mix and Flocculator Unit (References 2 and 3)

Q = volumetric flowrate = 2 gal/min

HRT = Hydraulic Retention Time

Rapid Mix:

$HRT = 1\ min$

$W = 1.00\ ft$

$$A = \frac{(1\ min)(2\ gal/min)(ft^3/7.5\ gal)}{1.00\ ft}$$

$$A = 0.267\ ft^2$$

Use: $L_{RM} = 0.75\ ft$

$d_{RM} = 0.36\ ft$

$D_{RM} = 0.75\ ft$

$W_{RM} = 1.00\ ft$

Flocculator:

$$V = \frac{Q}{A}$$

$$V = \frac{(2\ gal/min)(ft^3/7.5\ gal)}{(1.5\ ft)(1.5\ ft)} = 0.119\ ft/min$$

$L = 5.00\ ft$

$$HRT = \frac{L}{V}$$

$$HRT = \frac{5.00\ ft}{0.119\ ft/min} = 42.2\ min > 15;\ < 60\ \therefore\ OK$$

Use: $L = 5.00\ ft$

$w = 1.50\ ft$

$d = 1.50\ ft$

$D = 2.00\ ft$

See Figure 25.

Design of Flocculator Paddles

See Figure 24.

For: $Q = 2$ gal/min

$\forall = 11.25\ ft^3$

HRT = 42.2 min

C_D = Drag Coefficient for Rectangular Paddles = 1.8

$v_p = 0.5$ ft/s to 2 ft/s $\quad v = 0.75\ v_p$

$G = \sqrt{P/\mu V} = 75\ s^{-1}$ $\quad P = \mu G^2 V$

$T = 60°F$

$\mu = 2.359\ lb\text{-}s/ft^2 \times 10^{-5}$

$\rho = 1.938\ lb\text{-}s/ft^4$

$P = (75\ s^{-1})^2(2.359 \times 10^{-5}\ lb\text{-}s/ft^2)(11.25\ ft^3) = 1.493$ ft-lb/s

$P = 2.714 \times 10^{-3}$ hp

$$A = \frac{2P}{C_D \rho v^3}$$

$$A_{max} = \frac{2(1.493)}{1.8(1.938)[0.75(0.5)]^3} = 16.232\ ft^2$$

$$A_{min}^{\,v_p=2} = \frac{2(1.493)}{1.8(1.938)[0.75(2)]^3} = 0.254\ ft^2$$

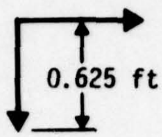
$$A_{ave} \text{ where } v_p = 1.0 = \frac{2(1.493)}{1.8(1.938)(0.75)^3} = \underline{2.029\ ft^2} \qquad A_{req} = 0.676\ ft^2$$

If $D_{max} = 1.25$ ft $\quad d = 1.417$ ft $\quad A_p = 1.771\ ft^2$

$A_{holes} = 1.771 - 0.676 = 1.10\ ft^2 = (6d)(1.333) \Rightarrow d = 0.14$ ft

Use d = 1-11/16 in

Design of Flocculator Motor



$v_{p_2} = 2$ ft/s

$v_{p_1} = 1$ ft/s

$C = \pi d = 2(0.625)\pi = 3.927$ ft

$$\boxed{w_2 = \frac{2 \text{ ft/s}}{3.927 \text{ ft}} \ \frac{60 \text{ s}}{\text{min}} = 30.56 \text{ r/min}}$$

$$\boxed{w_1 = 15.28 \text{ r/min}}$$

$$p = 2.714 \times 10^{-3} \text{ hp} = \frac{1}{368.5}$$

$\boxed{\text{Use a 1/250 hp Motor}}$ ⟵

Design of Impellar Motor

Given: $Q = 2$ gal/min

$\forall = (0.36)(0.75)(1.00) = 0.270 \text{ ft}^3$

HRT = 1.00 min

C_D = Drag Coefficient for Rectangular Paddles = 1.8

$D_{in} = 6$ in

$G = \sqrt{P/\mu\forall}$

$T = 60° F$

$\mu = 2.359 \text{ lb-s/ft}^2 \times 10^{-5} = 7.59 \times 10^{-4}$ lb-mass/s-ft

$\rho = 1.928 \text{ lb-s}^2/\text{ft}^4 = 62.353 \text{ lb-mass/ft}^3$

$k = 6.30$

$n = r/s = 30$ r/s

$g_e = 32.2 \text{ ft-lbm/s}^2\text{-lbf}$

Design of Impellar Motor (Concluded)

N_R = Reynolds Number $\geq$ 10,000

Use N_R = 50,000

$$\eta = \frac{N_R\ \mu}{D_{in}^2 \rho} = 5.478 \text{ r/s}$$

$$= 328.65 \text{ r/min}$$

$$P = \frac{k}{g_c} \rho n^3 D^5$$

$$p = \frac{6.30}{32.174} (62.353)(5.478)^3 (0.33)^5 / 550$$

P = 0.0143 hp = 1/70 hp : Use $\boxed{1/50 \text{ hp}}$

$$P_{use} = \left(\frac{1}{50} \text{ hp}\right)\left(\frac{550 \text{ ft-lb/s}}{\text{hp}}\right) = 11.00 \text{ ft-lb/s}$$

$$A = \frac{2P}{C_D \rho v^3}$$

$$v_p = (5.478/\text{s})(\pi)(0.33 \text{ ft}) = 5.70 \text{ ft/s}$$

$$v = 0.75\ v_p = 4.26 \text{ ft/s}$$

$$A = \frac{2P}{C_D \rho v^3} = 0.034 \text{ ft}^2 = 4.90 \text{ in}^2$$

$$A_p' = \frac{4.802}{6} = 0.82 \text{ in}^2$$

where A_p' = area of single vertical bar

See Figure 23.

Fluidized Bed Unit Design Calculations (Reference 5)

See Figure 31.

Flowrate = 2 gal/min (Optimum)

Length = 12 ft - 3 in - 9 in = 11.00 ft

Detention Time = 10.5 min

Volume Required = (2 gal/min)(10.5 min) = 21.0 gal = 2.80 ft^3

Area = 2.80 ft^3/11.00 ft = 0.255 ft^2

$$\text{Diameter Required} = \left(\frac{4(0.255)}{\pi}\right)^{1/2} = 0.569 \text{ ft} = 6.83 \text{ in}$$

Use: 8 in O.D. Clear Acrylic Pipe

t = 0.125 in

I.D. = 7.75 in

Area = $\pi(7.75/12)^2/4 = 0.328$ ft^2

Volume = 0.328(11.00) = 3.603 ft^3

Detention Time = Vol/(2 gal/min)(ft^3/7.5 gal) = 13.51 min

Hydraulic Flux = 2 gal/min/0.328 ft^2 = 6.105 gal/min/ft^2

CH_3OH Requirements:

75 mg/ℓ = 75 ppm

$$(2 \text{ gal/min})\left(\frac{8.33 \text{ lb}}{\text{gal}}\right)\left(\frac{454{,}000 \text{ mg}}{\text{lb}}\right) = (2 \text{ gal/min})(3.785\ \ell/\text{gal}) = 7.6\ \ell/\text{min}$$

Q = 7.6 ℓ/min

= 0.82 ℓ/day CH_3OH

$$Q = \left(\frac{1000 \text{ m}\ell}{\text{day}}\right)\left(\frac{1 \text{ day}}{24 \times 60}\right) = \frac{0.7 \text{ m}\ell}{\text{min}}$$

Mixing Motor Design:

$P = \mu G^2 \forall$

$\mu = 2.35 \times 10^{-5}$ lb-s/ft^2

$G = 75\ s^{-1}$

$\forall = 2.67\ ft^3$

P = (0.353 ft-lb/s)(1 hp / 550 ft-lb/s) = 1/1558 hp)

Use: P = 1/250 hp

Fluidized Bed Unit Design Calculations (Concluded)

$$\text{Area of Paddle Required} = \frac{2(1/250)(550)}{C_D \rho v^3}$$

$C_D = 1.8$ (Coefficient of Drag for Rectangular Paddles)

$\rho = 1.938\ \text{lb-s}^2/\text{ft}^4$

$v_p = 1.5\ \text{ft/s}$

$v = (0.75)v_p$

Area $= 0.886\ \text{ft}^2 = 127.6\ \text{in}^2$

$3d(22) + 9.5(1) = 63.8$

$d = 0.82$ in

$N = v_p/\pi D$

D = diameter of impellar = 10 in

N = 34.4 r/min

Use: N = 35 r/min

Holding Tank Design:

Volume = (2 gal/min)(10 min)(ft^3/7.5 gal) = 2.67 ft^3

Detention Time = 10 min

Diameter Required = 14 in O.D. = 13.5 in I.D.

Area = 0.994 ft^2

Depth = Vol/Area = 2.69 ft

Height = 3.00 ft

Chemical Container Design:

Volume = (2 gal)(ft^3/7.5 gal) = 0.267 ft^3

Diameter = 6 in O.D. = 5.75 in I.D.

Area = 0.180 ft^2

Depth = 0.267/0.180 = 1.50 ft

Height = 2.0 ft

Sand Filter Unit

d_{60} = diameter of sand grains = 0.736 mm

γ_w = specific weight of water = 62.4 lb/ft^3

G_I = specific gravity of sand grains = 2.65

T = temperature range = 10°C to 50°C

μ_{3D} = viscosity = 0.8004

1. V_{mf} = Minimum Fluid Flux = $\dfrac{0.00381\, d_{60}^{1.82}[\gamma_f(\gamma_3 - \gamma_f)]^{0.94}}{\mu^{0.88}}$

   V_{mf} = 10.02 gal/min/ft^2

2. R_{emf} = Minimum Fluid Reynolds Number = $\dfrac{\rho_f(d_{50}\%)V_{mf}}{\mu}$

   R_{emf} = 6.26 g < 10 ∴ OK

3. R_{e_0} = Initial Reynolds Number = 8.45 $R_{e_{mf}}$ = 8.45(6.26) = 52.90

   n = Exponent of Expansion Equation = $(4.45 + 18\, d_{60}/D_t)R_{e_0}^{-0.1}$ = 3.01

4. Minimum Fluid

   Use $E_{nominal}$ = 0.45

   $V_{mf} = R(O_{mf})^n$

   R = 110.84 gal/min/ft^2

5. V_{mf} = 20 gal/min/ft^2 Expansion

   $V = RE^n$

   E = Void Ratio of Expanded Bed = 0.566

Sand Filter Unit (Concluded)

6. Expanded Media Height

   $L_o(1 - E_o) = L_e(1 - E)$

   $(18 \text{ in})(1 - 0.45) = L_e(1 - 0.566)$

   E_o = initial void ratio

   L_e = 22.82 inches

7. Filtration Rate = 2 gal/min/ft^2

   $$A = \frac{2 \text{ gal/min}}{2 \text{ gal/min/ft}^2} = 1.00 \text{ ft}^2$$

   ϕ = 1.128 ft

   Use ϕ = 14 in = 1.17 ft

   F.R. = 2 gal/min / 1.069 ft^2 = 1.871 gal/min/ft^2 < 10 $\therefore$ OK

8. Sand

   0.45 mm $\leq d_{10}$ < 0.50 mm

   1.50 $\leq$ U.C. $\leq$ 1.60

   95% < 1.0 mm

   100% < 2.0 mm

   U.C. = 60%/10% Size (Uniformity Coefficient)

See Figure 26.

Disinfection Contact Chamber (Reference 2)

$Q = 2$ gal/min

HRT = 15 to 45 min

Application Rate = 15 mg/ℓ

ϕ = diameter of pipes

Small Pipes

$\phi = 4$ in

$A = \pi r^2$

$$A = \frac{(2\text{ in})^2\pi}{144\text{ in}^2/\text{ft}^2} = 0.0873\text{ ft}^2$$

$$V_s = \frac{Q}{A} = \frac{(2\text{ gal/min})(\text{ft}^3/7.5\text{ gal})}{0.0873\text{ ft}^2}$$

$V_s = 3.06$ ft/min

Large Pipes

$\phi = 12$ in

$A = \pi r^2$

$$A = \frac{(6\text{ in})^2\pi}{144\text{ in}^2/\text{ft}^2} = 0.7854\text{ ft}^2$$

$$V_L = \frac{Q}{A} = \frac{(2\text{ gal/min})(\text{ft}^3/7.5\text{ gal})}{0.7854\text{ ft}^2}$$

$V_L = 0.340$ ft/min

Hydraulic Retention Time

$$2\left(\frac{X}{3.06\text{ ft/min}} + \frac{Y}{0.340\text{ ft/min}}\right) = 30\text{ min}$$

$X = 2Y$ — Y = Total Length 12-inch ϕ Pipe

$Y = 4.173$ ft — X = Total Length 4-inch ϕ Pipe

Use L = 4.00 ft (per "bank")

HRT = 28.8 min $\therefore$ OK

Chlorine Required

$$R_{APP} = (15\ mg/\ell)(g/1000\ mg)(kg/1000\ g)(2.2046\ lb/kg)(3.7854\ \ell/gal)$$

$$R_{APP} = 1.2518 \times 10^{-4}\ lb/gal$$

$$Q = (2\ gal/min)(R_{APP})(60\ min/h)(24\ h/day) = 0.361\ lb/day$$

Activated Carbon Columns Design Calculations (Reference 7)

Type: Upflow

Flowrate = 2 gal/min

Hydraulic Loading = 5.1 gal/min/ft^2

Contact Time = 30 min

Area = 2 gal/min / 5.1 gal/min/ft^2 = 0.392 ft^2

Volume = (2 gal/min)(30 min)(ft^3/7.5 gal) = 8.00 ft^3

$$\phi = \left(\frac{4(0.392\ ft^2)}{\pi}\right)^{1/2} = 0.707\ ft = 8.48\ in$$

Use: 8.75 in ϕ Clear Acrylic Tubes
t = 0.125 in
I.D. = 8.50 in

Area = 0.394 ft^2

Volume = 8.00 ft^3

Height = 8.00/4(0.394) = 5.075 ft

Use: 4 Tubes, Height = 6 ft, 0 in

See Figure 28.

Reference

7. *Process Design Manual for Carbon Adsorption*, Environmental Protection Agency, Technology Transfer, Program Number 17020 GNR, October 1971.

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APPENDIX B

MODEL 4189 - REVERSE OSMOSIS UNIT

OPERATION AND MAINTENANCE MANUAL[1]

Footnote

1. Envirex, Inc., Environmental Sciences Division, P.O. Box 2022, Milwaukee, Wisconsin 53201.

I. Envirex Model 4189 Reverse Osmosis System

The Envirex Model 4189 Reverse Osmosis (RO) System is designed, built, and tested to treat up to 7 gpm of feedwater. The feedwater is pretreated by filtration in three 5 micron cartridge filters with throw away elements. The brine and product water may be recycled back to the feedwater tank to maintain a constant feedwater concentration. A temperature controller maintains the feedwater temperature between an adjustable dead band by controlling the flow of hot or cold water through a cooling coil located within the feedwater tank.

Any group of three different types of RO modules may be easily connected into the feed and discharge piping system for comparison studies. A given set of modules may be tested in either series of parallel operation by opening and closing the appropriate valves. More specific information on each type of module, spiral wound, tube type, or hollow fine fiber type, can be found in the appendix of this manual.[1]

The high pressure feed pump and piping system are built of stainless steel and plastic materials of construction to resist corrosion. Further protection of the RO modules is offered by an adjustable relief valve and pressure switches, which are to be set at the maximum recommended pressure for the modules being tested. An electronic memory system and set of trouble lights show the operator which operating condition shuts down the system: excessively high feed pump pressure, low suction pressure, or low feed tank level.

The Envirex Model 4189 RO system is designed for continuous duty. The finest components available were selected to allow its use as a reliable test bed for experimenting with various feedwaters and various modules.

Footnote

1. Throughout this operations manual, reference is made to an appendix to the manual that contains specification sheets for the various elements making up the reverse osmosit unit. The appendix to the manual is not included in this report because much of the material it contains is unreproducible. It will, however, be included in the TWARDS equipment listing.

II. Description of Components

For ease in following the ensuing discussion, please refer to the process flow sheet, photographs, assembly drawing, and electrical schematic in the appendix of this manual. Read this manual in its entirety before attempting to start the RO system.

A. Feed Water Tank System

The feedwater tank is provided in black polypropylene to resist attack from a wide variety of chemicals and damage from sunlight. Fittings were provided at the tank bottom for drainage, level monitoring, and drawoff. A fitting near the tank top serves as an overflow outlet. The tank is fitted with a stainless steel cooling/heating coil through which cold or hot water flows. The zone at the tank bottom serves to collect sediment.

B. Temperature Controller

Located on the side of the control panel is a dead band temperature controller. When the fluid in the remote capillary tube bulb expands or contracts due to water temperature change, a bellows arrangement in the controller opens or closes the contacts of two switches. One switch operates a cold water solenoid valve and the other a hot water solenoid valve. The flow of either hot or cold water through the cooling coil maintains the tank temperature within the set range (dead band).

C. Booster Pump

The all plastic and stainless steel booster pump is used to maintain a positive pressure on the high pressure feed pump, while overcoming the head loss through the cartridge filters. This pump is controlled solely by the head loss through the cartridge filters. A valve on the suction pipe and the three cartridge filter inlet valves can be closed to service this pump. A plug in the side of a tee at the pump discharge can be removed for draining the pump.

D. Cartridge Filters

The (3) cartridge filters provide final protection against solids or precipitates larger than 5 microns from entering the RO modules. Each filter is flow rated for 5 gpm at 100 psi and 100°F. Only two filters should be in operation at one time, with the third filter on standby to be rotated into use when one of the others becomes clogged.

E. High Pressure Feed Pump

The feed pump provided on this RO system is the Goulds Model 3933 Series MB 13 Multistage Centrifugal Pump, size 13500. It has a 7-1/2 hp, 3500 rpm motor which runs on 230/460, 3-phase, 60-cycle current. A mechanical seal is provided, thus eliminating lubrication and adjustment common to packings. This pump is constructed of 316 stainless steel and "Noryel" plastic for corrosion resistance.

F. Pressure Switches

Pressure switches sense the feed pump suction pressure and discharge pressure. The suction pressure switch is factory set to shut down the RO system and turn on an indicator light if the pressure gets below 6-8 psi. The feed pump discharge pressure switch should be set to shut down the RO system and turn on an indicator light when the discharge pressure exceeds 400 psi for the DuPont modules, 600 psi for the Gulf Atomic modules, and 600 psi for the Fluid Sciences modules. These two switches are located on the right side of the control panel and are of the static "O" ring type. Pressure acts on a small diaphragm held in place by an "O" ring in the switch stem.

A diaphragm actuated mercury switch mounted above the feed tank monitors the fluid level in the tank. If the water level gets below a predetermined point, the switch shuts down the RO system and turns on an indicator light on the panel.

G. Reverse Osmosis Modules

The Envirex Model 4189 RO system is equipped with three DuPont "Permasep" modules, three Fluid Sciences tubular modules, and three Gulf Atomic spiral wound modules. All modules have been adapted to use the 37° flared connector at all ports. These modules are all mounted on the RO system frame for convenience in handling and shipping. They can be removed easily for replacement, examination, or maintenance, should it be required. More specific information about each type of module can be found in the appendix of this manual.

H. Flowmeters

The raw feed water flow into module No. 1 is measured by a direct reading Varea-Meter (variable area of flow meter). Increased flow pushes a metal "float" higher in a tube of increasing cross sectional area. The float magnetically moves a level attached to the pointer which indicates the float position, and thus the quantity of flow. The read out is in gpm, and accuracy is 2% of full scale.

The product water (permeate) from each module is measured by direct reading varea meters. These meters are simple, clear plastic units read by the position of a steel ball relative to a fixed vertical scale. Read out is in gpm and accuracy is 2% of full scale.

I. Piping System

The piping system is made entirely of stainless steel and plastic for good corrosion resistance. PVC ball valves allow the operator to take individual cartridge filters out of line for replacement. Stainless steel ball valves are used to change the flow of feedwater to the modules from parallel flow to series. Needle valves are also used for this purpose, besides used to control the flow of feedwater to each module when operating in parallel. An adjustable relief valve prevents the modules from being over pressurized. It must be set to bypass excessive flow back to the recirculation tank. A stainless steel ball valve is used to throttle the flow from the feed pump to minimize the flow through the relief valve, thus decreasing power consumption and wear on the relief valve seat.

All high pressure ports (feed inlets and concentrate outlets) are fed by teflon lined high pressure hoses with female 37° swivel fittings. The modules all have male 37° fittings. Any set of modules can be connected to the piping system by removing the storage caps and screwing the hoses to the module fittings. The storage caps should be kept in place on the unused modules to prevent drying out. Plastic tubing is used to carry product water to the flowmeters and back to the recirculation tank. Rubber discs in the product water outlet tube nuts serve as storage caps and should be saved for storage or shipping.

J. Electrical Control Panel

The Model 4189 control panel requires grounded 460-480 volt, 3 phase, 60 Hz power, with at least 30 amp capacity. The panel has been designed and built according to the National Electrical Code, with overload and short circuit protection.

Each motor is provided with a fused automatic/manual reset starter which will cause a system shutdown in case of a motor overload. The short wait necessary while allowing the motor starter heaters to cool serves as the indication that the motors were overloaded. The system will start immediately if other safeguards cause a shutdown.

A system of relays and pressure switches allows the appropriate trouble light to remain on in event of an automatic shutdown, thus indicating the cause of the shutdown. To restart the system, the operator must manually restart the system and correct the cause for shutdown. If not corrected, the system will continue to stop after switching to "automatic." If the cause for shut down is excessive feed pressure, the operator must also press the reset button before attempting to restart the system.

III. Start Up Procedure

A. Mounting

The entire Model 4189 RO system is mounted on an aluminum base with castered wheels for easy handling and portability. It can be wheeled into place and connected to the utilities.

B. Connections

1. Wire the control panel with a source of 460-480 volt, 3 phase, 60 Hz power of at least 30 amp capacity.
2. Pipe the hot and cold water sources into the appropriate solenoid valve, as marked.
3. Connect a hose or pipe to the cooling coil discharge, overflow discharge, and tank drain, as required, and extend these hoses or pipes to a drain.

C. Preparations

1. Fill the feed tank with water and adjust the pH with acid as required for the type of modules being put into service. If the system is being run for the first time after shipment, the modules should be flushed according to the instructions for each type of module in the appendix [to this manual] to remove shipping preservatives.
2. Connect the appropriate hoses to the desired modules, being careful to connect the feed hose to the feed inlet, the concentrate hose to the concentrate outlet, and the product water tube to the product water outlet. These hoses and tubes are marked and the modules are numbered 1, 2, 3 from top to bottom. Feed and concentrate hoses are marked at the end where they join into the hard pipe manifold.
3. Open or close the appropriate valves to allow parallel flow to the modules. Use the following table of valve positons and drawing No. FG-4189-C-1 in the appendix to set the valves:

Valve No.	Valve Position	Valve Type
1	Open	Needle
2	Closed	Ball
3	Open	Ball
4	Open	Needle
5	Closed	Ball
6	Open	Ball
7	Open	Needle

Open the inlet and outlet ball valves of any two cartridge filters and close the inlet and outlet valves of the third filter.

4. Set the pressure switches. Refer to the module specifications in the appendix [to this manual] to find the proper feed pump discharge pressure. The high pressure switch can be adjusted by removing the cover and turning the adjustment nut up or down to decrease or increase the desired set point. A numbered scale within the switch serves as an approximate guide. See the appendix [to this manual] for more instructions on pressure switches.

   The low pressure switch can be set in the same manner, except that the set point should be 6-8 psi.

   The tank level switch is actuated by the column of compressed air trapped above the liquid in the external tube connected to the feed tank bottom. Make sure that the tube does not leak, or is not removed; otherwise the feed tank will have to be emptied to trap a new column of air above the liquid in the tube. This switch is adjusted by removing the cover and increasing or decreasing spring tension with a screw driver. Two screws must be adjusted; the high level (spring tension) and the range or low level (magnet position). Scales in this switch give the approximate settings. Adjust the switch to open the circuit when the tank water level falls below the desired level. The minimum dead band of this switch is 7 inches. This switch should be as level as possible to work well.

5. Set the high and low temperature limits on the temperature controller. Pull open the case and set the high temperature limit by turning the high temperature adjustment knob until the red pointer is positioned as desired. Slide the low temperature indicator (yellow clip-on pointer) to the desired low temperature

limit. See the appendix [to this manual] for more detailed instructions on the temperature controller.

6. With the main ball valve throttle open, start the booster pump to purge the high pressure feed pump, the modules, and piping of air. Observe the concentrate return tubes and product flowmeters to determine when all lines are purged of air.
7. With the main ball valve throttle closed, jog the high pressure feed pump to determine its rotation. Interchange any two of the three feeder wires at the terminal strip in the panel if the rotation is not clockwise as viewed from the motor end of the pump. See the warning labels on the pump and the instruction booklet in the appendix [to this manual].

DO NOT RUN THE PUMP WITHOUT WATER OR SERIOUS DAMAGE TO THE PUMP COULD OCCUR.

D. Starting the RO System

1. Start the booster pump if it is not already running, by moving the switch to "Manual Start" position.
2. Close the main throttling ball valve. DO NOT START THE HIGH PRESSURE FEED PUMP UNLESS THE MAIN THROTTLE BALL VALVE IS CLOSED. SUDDEN VARIATIONS OF PRESSURE COULD DAMAGE THE RO MODULES. Start the high pressure feed pump by moving the start switch to "Manual Start" position.
3. Slowly open the main valve to the full open position.
4. Adjust the three needle type throttle valves (valve numbers 1, 4, and 7 with black plastic knobs) until the desired concentrate pressure is reached.
5. Adjust the pressure relief valve until the feed pressure is 600 psi for the spiral wound and tubular modules, or 400 psi for the hollow fine fiber modules. Loosen the lock nut on the relief valve adjustment screw and turn the adjustment screw with a socket head wrench (Allen wrench) clockwise to increase or counter-clockwise to decrease the feed pressure. Lock the screw with the locknut when the discharge pressure is adjusted as desired.

6. Slowly close the ball valve until the feed pressure just begins to drop. By so doing, noise, chatter, flow fluctuation, relief valve wear, and power consumption will be minimized.
7. Quickly flip the pump switches from "Manual Start" to "Automatic Run" position. Slowly moving the switches will allow the motor starters to drop out long enough for pressure to drop below the low pressure switch set point, thus shutting down the system. System "Bounce" can also occur, a condition during which the starters bounce on and off, thus causing sudden pressure surges which are damaging to the modules.

   Note: If this is the first time the unit is to be run since shipment, flush the shipping preservative out of the modules. Direct the concentrate return tubes (from the feed tank) into a sewer or disposal vessel, and refill the feed tank with water while the system is running. See the module instructions [in the appendix to this manual] for the time period.

   Another method is to recycle the water through the modules, drain the tank, refill the tank and continue recycling water through the modules. Repeat this process until the number of gallons of flush water used in the first method above have been pumped through the system.

   The system is now in operation, and comparitive tests of the modules may be taken. Water samples may be taken directly from the return tubes at the feed water tank. If the operator wishes to change operating pressures, readjustment of the valves will be necessary. It may take some "fine tuning" adjustment between the concentrate throttle valves and the main throttle valve before the desired operating pressures are obtained.

E. Restarting the RO System

1. See Section D above and carry out steps 1, 2, 3, 6, and 7.
2. **If excessive feed pressure stops the system, press the high pressure switch reset button, before proceeding with the above steps.**

F. Operation with the Modules in Series

The previous discussion was for parallel operation of the RO system. To operate the system in series, follow these steps.

1. With the system shut down, open or close the valves according to this table:

Valve No.	Valve Position
1	Closed
2	Open
3	Closed
4	Closed
5	Open
6	Closed
7	Open

2. Perform all of the operations outlined earlier up to Section D as required.
3. Refer to Section D as previously discussed, and carry out steps 1, 2, and 3. Close valve No. 7 slowly until the desired module No. 3 concentrate pressure is reached. Continue to carry out steps 5, 6, and 7 as in Section D.

G. Determining Flow

1. See the module specifications, graphs, tables, and sample calculations in the appendix [to this manual] for theoretical flows at various pressures and temperatures. Perform the necessary calculations to determine the pressure settings for the desired flows.
2. For parallel flow, the product water flows are directly as indicated on the three product flowmeters. If the feed pressures are all equal, the feed flows can all be assumed to be equal to that read on the feed flowmeter of module No. 1. The concentrate flow is found by subtracting the product flow from the feed flow.
3. For series flow, the entire feed flow enters the No. 1 module flowmeter and is read directly. The feed flow to each successive module is the concentrate of the previous module and is found indirectly by subtracting the previous module's product water flow from its feed flow (measured or calculated).

IV. Operating the RO System

A. Check the feed water temperature. If the coolant is not cold enough, overheating could occur even if coolant is flowing through the cooling coil. Shut down the RO system if the feedwater temperature gets above the values recommended in the module specifications [appendix to this manual].

B. Check the pH. Readjust as necessary to maintain the desired range (see appendix [to this manual]).

C. Check the feed and concentrate pressures. If they vary from the desired values, adjust as required. If the feed and concentrate pressures vary by more than 50 psi, flush the modules.

D. Check the pressure drop and feed pump suction pressure. If the drop is 10 psi or more, or the suction pressure is near or below 8 psi, cycle in a reserve cartridge filter and replace the clogged cartridge filter elements. See the appendix [to this manual] for replacement procedures.

E. Check the flow from the relief valve. If there is considerable flow, close the main ball valve slightly until the feed pressure just begins to drop.

F. Check the feed tank water level. Insufficient feed volume will not derive the full cooling benefit from the cooling coils. Add enough feed water to keep the cooling coil submerged.

G. Periodically test the product water for total dissolved solids (TDS). If TDS is abnormally high, the problem may be too high a conversion rate, too low a feed pressure, fouling, or module damage. Readjust operating conditions or flush the modules. If neither action rectifies poor module productivity, consult Envirex Inc.

H. When adding water to the feed tank, be sure that the chlorine and other chemicals detrimental to the modules in the water are below the concentrations allowed as listed in the module specifications [appendix to this manual].

I. If the high pressure switch is tripped by feed pressure exceeding the switch setting, the high pressure reset switch must be pressed to allow restarting of the system. Check the switch setting, or valve positions if tripping persists.

V. Precautions

A. Never operate the unit without filter elements in the cartridge filters. To allow continuous operation, only two filters should be on line at one time. The third clean filter is to be "rotated" into operation as the other filters blind.

B. Never operate with closed concentrate throttling valves. This causes 100% conversion and rapid membrane fouling.

C. Keep the feed pressure at the recommended values.

D. Do not exceed the recommended temperatures.

E. Maintain lubrication of the feed pump as required by the instructions in the appendix [to this manual].

F. Keep permeators wet during shutdown. Do not allow siphoning or drainage during shutdown. For extended periods of shutdown, see the special shutdown instructions in this manual.

G. Do not allow the feed-concentrate pressure difference to exceed the module manufacturers specified values. Cleaning is more difficult, if possible at all.

H. Do not disconnect or bypass the pressure switches when in continuous operation.

I. Do not run the RO system at feed pressures higher than recommended. Always maintain the proper relief valve adjustment.

J. Make sure cartridge filter cartridges are properly installed to prevent unfiltered water from reaching the modules.

VI. Shut Down, Shipping, and Storage Procedure

A. Short Term Shutdown

1. Turn off the RO feed pump and the booster pump.
2. Turn off the power.
3. Close all valves to trap the water in the system to keep the membranes wet.

B. Long Term Shutdown (For Storage or Shipping)

1. If the unit will not be used for 2 or more days, a 1% formaldehyde solution should be recirculated through the modules to prevent biological growth. DO NOT USE CHLORINE OR QUATERNARY AMMONIUM type sanitizing agents ("ZEPHIRAN").
2. If the unit is in danger of freezing during shipment or storage, an 18% by weight glycerine solution with 1% formaldehyde should be recirculated through the system to prevent freeze damage down to a temperature of 0°F (-18°C).
3. Use the feed water tank and booster pump to feed the RO pump through the cartridge filters. Recycle the product water and brine back to the tank. Readjust pressure switches or disconnect them if necessary to maintain continuous operation.
4. Operate the RO system at 300-400 psig at low conversion rates for at least 2 hours. Provide cooling coils in the tank to PREVENT THE TEMPERATURE FROM RISING OVER 90°F.
5. Turn off the system and close all valves and plug all outlets to prevent the leakage and loss of preservative.
6. Use the above procedure before removing a module from service to preserve it for storage or shipping.
7. Drain the feedwater tank by opening the bottom drain valve.

VII. Flushing Procedure

A. The high pressure feed pump can be used for flushing the RO modules if the feed pressure is reduced to 150-250 psi. Feed the detergent solution in the same manner as formaldehyde and glycerine (see Section VI, Shutdown Procedure). Use the feed tank for the detergents recommended in the Technical Bulletins [appendix to this manual] for the modules.

B. Start the pumps, and flush at the recommended rates for the recommended times (see appendix [to this manual]).

C. Drain the detergent solution. Flush with clean water and drain. Fill with the fresh water to be used in the tests and continue operations.

VIII. Trouble Shooting Guide

If the RO system shuts down, refer to this trouble shooting guide before restarting the system.

The causes of the various alarm conditions and corrective action are as follows:

Problem	Probable Cause
A. High Permeator Pressure	1. Pressure relieve valve (PRV) is set too high or inoperative. Readjust to lower pressure or disassemble and clean.
	2. While the contrary can be true, the PRV is not intended to mask overpressure due to possible plugged feed lines or valve orifice ports. Step by step inspection of the high pressure plumbing from the reject flow control valve is required to locate the pluggage.

Problem	Probable Cause
B. Low Concentrate Pressure	1. Fouling of the membranes by hydrated metal oxides will increase ΔP rapidly within 24 hours. Slower ΔP buildup may be due to colloids, calcium precipitates, or bacterial slimes. See appendix [to this manual] (Modules) for the cleaning reagents and Section VII for flushing procedures.
	2. At excessive feed flows, module internal headloss could account for a greater ΔP. Adjust the main control valve and concentrate valves to minimize internal headloss.
C. Low Pump Suction Pressure	1. Insufficient feed pressure to high pressure pump. Open cartridge filter inlet and outlet valves on "fresh" cartridge. Isolate and replace the plugged filter cartridge.
	2. If cartridge filter elements are "new," check for sufficient feed volume to booster pump and/or air leaks in suction piping.
D. Decreasing Product Flow	1. Productivity of membranes decreases with time due to a variety of factors, a natural characteristic of all RO systems.
	2. A decline in product flow outside these guidelines may be attributed to the following: a. Fouling by calcium precipitated (e.g., $CaCO_3$, $CaSO_4$, $CaPO_4$). b. Water or wastewater with a high osmotic pressure (high feed TDS). Flush the system.

To start the system after an alarm condition, push the alarm reset button and follow the start-up sequence detailed earlier (i.e., start booster pump, wait for low pressure build-up and any entrapped air to purge, start RO feed pump). If proper corrective action has not been taken, an alarm condition will once again shut down the booster pump and RO feed pump. A re-check of the system and troubleshooting guide may then be necessary.

A false alarm condition can exist if an overload or short circuit occurs. See section on Electrical Control, for identifying procedure (Section II, Item J).

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APPENDIX C

OPERATING INSTRUCTIONS FOR ROMICON MODEL HF1SSS/HF2SSS ULTRAFILTRATION SYSTEMS[1]

Footnote

1. Romicon, Inc., 100 Cummings Park, Woburn, Massachusetts 01801.

1.0 DESCRIPTION

1.1 GENERAL

The Romicon HF1SSS/HF2SSS (Figure C-1) is a complete, self-contained, sanitary cartridge ultrafiltration system for the ultrafiltration of aqueous solutions. The system consists of a process circulation pump, a backflush pump, a hollow fiber ultrafiltration cartridge(s), a permeate tank, and appropriate valving and pressure and temperature gauges. The system is mounted on a structural steel frame with sanitary legs. All pressure control valves, drain valves, pressure gauges, thermometer, and pump control switches are mounted for easy access on the frame of the unit. An electrical control box on the unit contains two motor starters, fuse blocks and electrical relays. All process piping is sanitary stainless steel. The unit is designed to operate in conjunction with a process tank supplied by the customer.

1.2 PROCESS SYSTEM

The process system consists of a circulation pump, a strainer, ultrafiltration cartridge(s), 2 pressure control valves, pressure gauges, a thermostat, a thermometer, and 2 process drain valves.

1.2.1 Process Circulation Pump

A Ladish centrifugal pump is used to circulate the process stream through the hollow fiber ultrafiltration cartridge. The pump is driven by a totally enclosed fan-cooled 1-horsepower 3600 rpm motor. The pump is controlled by a pull-to-start, push-to-stop button, with a built-in amber pilot lamp.

1.2.2 Strainer

A Ladish sanitary strainer with a 100-mesh (104 μ) screen is provided at the circulation pump outlet to eliminate large particles from the solution.

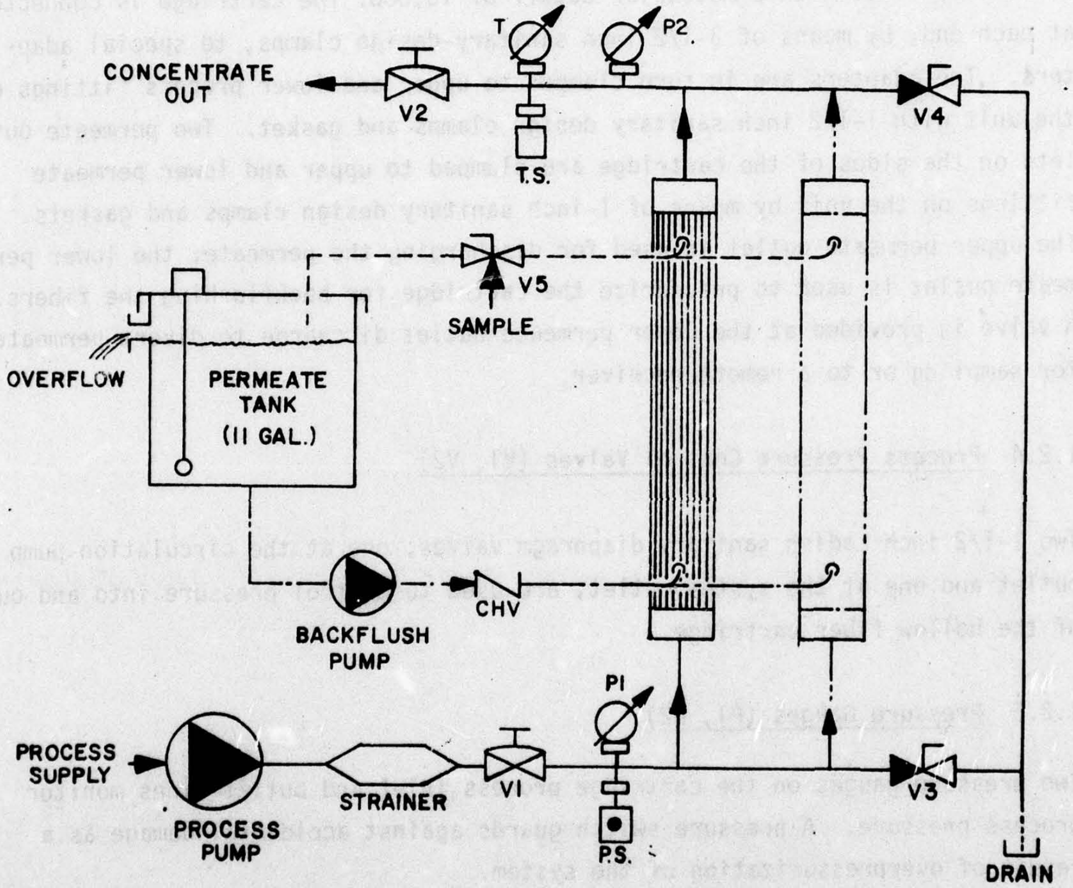

Figure C-1. HF1SSS/HF2SSS Flow Schematic

1.2.3 Ultrafiltration Cartridge

A Romicon hollow fiber ultrafiltration cartridge is used to concentrate the solution. Two types of cartridges are available; one has 30 square feet of membrane area with a molecular cutoff of 50,000, the other has 25 square feet of membrane area with a molecular cutoff of 10,000. The cartridge is connected at each end, by means of 3-1/2 inch sanitary-design clamps, to special adapters. The adapters are in turn clamped to upper and lower process fittings on the unit with 1-1/2 inch sanitary design clamps and gasket. Two permeate outlets on the sides of the cartridge are clamped to upper and lower permeate fittings on the unit by means of 1-inch sanitary design clamps and gaskets. The upper permeate outlet is used for discharging the permeate; the lower permeate outlet is used to pressurize the cartridge for backflushing the fibers. A valve is provided at the upper permeate outlet discharge to divert permeate for sampling or to a remote receiver.

1.2.4 Process Pressure Control Valves (V1, V2)

Two 1-1/2 inch Ladish sanitary diaphragm valves, one at the circulation pump outlet and one at the system outlet, are used to control pressure into and out of the hollow fiber cartridge.

1.2.5 Pressure Gauges (P1, P2)

Two pressure gauges on the cartridge process inlet and outlet lines monitor process pressure. A pressure switch guards against accidental damage as a result of overpressurization of the system.

1.2.6 Thermometer

A thermometer is provided on the process stream outlet line to monitor operating temperature. An operating temperature of 120°F maximum should be observed.

1.2.7 Thermostat

A safety thermostat is provided on the process stream outlet to shut down the system at 120°F.

1.3 BACKFLUSH SYSTEM

The backflush system consists of a pump, a permeate tank, a pressure control valve, and attendant piping.

1.3.1 Backflush Pump

A miniature, close-coupled, all plastic centrifugal pump is used to pump clean ultrafiltrate, or permeate, from the permeate tank back into the cartridge for cleaning. The pump is driven by a 1/5-horsepower universal motor. An electrical interlock prevents the backwash pump from operating simultaneously with the process circulation pump. The pump is controlled by a pull-to-start, push-to-stop button with a built-in blue pilot lamp on the front panel.

1.3.2 Permeate Tank

An 11-gallon Polyethelyne tank mounted on the base of the unit stores permeate for backflushing the cartridges. The permeate outlet on the bottom of the tank is connected to the backflush pump. The permeate outlet on the side of the tank is a one inch female pipe thread for connecting to the customer's drain or process line. A level control switch consisting of a stainless steel float and magnetic switch is immersed in the tank. The switch is set to the minimum practical volume allowable before the pump runs dry. At that point, the switch shuts down the pump.

1.3.3 Permeate Sampling Valve (V5)

A 3-way PVC valve is provided at the permeate inlet to the tank. This valve is used for diversion of the permeate for sampling or to a remote reservoir.

2.0 SPECIFICATIONS

Cartridge type............................HF30-20-XM50... HF22-20-PM10
Membrane area.............................30 square ft... 22 square ft
Circulation rate..........................15 to 20 gpm... 4 to 6 gpm
Nominal molecular cutoff.................. 50,000 mw...... 10,000 mw

Operating pressure..	25 psi maximum
Operating temperature..	120°F maximum
Circulation pump...	Ladish C114-4
Circulation pump motor..	1 hp 3600 rpm, TEFC
Backflush pump..	Eastern P7
Backflush pump motor..	1/5 hp 6000 rpm
Wetted materials...	Stainless steel, CPVC
Dimensions..	46 inches high
	37 inches wide
	36 inches deep
Electrical requirements..	230 V / 30/60 Hz, 6.4 A
	460 V / 30/60 Hz, 3.2 A
Overload heaters for circulation pump motor starter.....	230 V: GE#CR123C3.26A
	460 V: GE#CR123C1.63A

3.0 PRINCIPLES OF OPERATION

3.1 ULTRAFILTRATION

The Romicon HF1SSS/HF2SSS hollow fiber ultrafiltration system is designed to be used as a pilot plant or small production plant for a wide range of ultrafiltration processes. An aqueous solution is pumped through a cartridge containing hollow fibers. The inner membrane skin of the fibers rejects large molecules while allowing smaller molecules, ionic species, and water to pass freely. The solution becomes progressively more dewatered as it moves through the fibers and returns to the source.

3.2 BACKFLUSHING

After dewatering most organic materials, a film of high molecular weight material will coat the inside of the fibers, forming secondary membrane which will impede the permeate flux. This film must be removed between runs or every 24 hours, whichever is shorter, if optimum life of the hollow fiber cartridge is

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TRANSPORTABLE WASTEWATER ADVANCED REFINEMENT AND DEMONSTRATION --ETC(U)
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to be maintained. After each run, the permeate retained in the permeate tank is pumped into the shell of the cartridge. The pressure of the permeate outside the fibers will loosen any foreign material inside the fiber lumens and drive it out through both ends of the cartridge.

4.0 PREPARATION FOR OPERATION

4.1 INSTALLATION

a. Locate the HF1SSS/HF2SSS unit near a drain. Connect the drain line on the right hand side of the unit to a drain.

b. Connect the pump inlet to a source of process fluid, usually a tank of at least 10-gallon capacity.

NOTE

If the run will be long or the tank is small, a plate-type heat exchanger may be required to insure that the process fluid temperature does not exceed 120°F.

c. Connect the process outlet, high on the left-hand side of the unit, to a pipe or hose returning to the process fluid tank.

d. Connect the permeate outlet either to drain or to another tank, depending on whether or not the permeate is to be retained for additional processing.

e. Bring in a 230 or 460 volt, 3 phase, 60 Hz power line to the electrical enclosure on the back of the unit. In the main fuse block, install fuses appropriate to the voltage used. Connect the transformer jumpers in accordance with the wiring diagram. Install correct heaters for the motor in the motor starter.

f. Wire the motor connections in the motor terminal box for appropriate voltage, following the printed instructions on the motor.

g. Jog (start and stop quickly) the circulation pump motor to see if it is turning in the proper direction (clockwise when viewed from the back of the motor). If the direction is incorrect, reverse any two of the three wires between the motor starter and the motor.

h. Repeat the procedure for the backflush pump.

4.2 PREPARATION FOR OPERATION

a. Remove the cartridge(s) from its packing.

b. Connect the two end adapters to the cartridge(s) using the 3-inch sanitary gaskets and special Marman clamps.

NOTE

Orient the cartridge permeate ports 90° from the adapter ports before tightening clamps.

c. Attach the cartridge with its adapters to the flanged process fittings on the right-hand side of the unit using two 1-1/2 inch gaskets and two 2 inch sanitary clamps. Attach the permeate outlets on the cartridge to the permeate fittings on the unit with two 1 inch gaskets and two 1-1/2 inch sanitary clamps.

d. Charge the customer-supplied tank with process solution.

e. Open all valves between the tank and the circulation pump inlet and between the process outlet and the tank.

f. Turn on the main electrical disconnect switch to supply power to the system.

5.0 OPERATION

(Refer to Figure C-1)

5.1 SETTING THE VALVES

a. Close drain valves V3, V4 and turn the permeate outlet valve V5 towards permeate tank.

b. Close input pressure valve V1 and open back pressure valve V2.

5.2 ULTRAFILTRATION OF PROCESS SOLUTIONS

a. Pull out CIRCULATION PUMP button.

b. Slowly open input pressure valve V1 until a pressure of 20 psi is attained on the adjacent pressure gauge (P1).

c. Slowly close back pressure valve V2 until a pressure of 8 to 10 psi is attained on the adjacent gauge (P2).

d. Readjust the input pressure control valve V1 until the input pressure is stabilized at 25 psi maximum and the back pressure stabilized at 10 psi.

NOTE

The system will now continue unattended. Be sure to observe the pressure gauges at 10 to 15 minute intervals to insure that the pressure has not changed due to the inevitable change in viscosity of the process stream. Check the thermometer from time to time to insure that the maximum temperature of 120°F is not exceeded. If the temperature is rising, install a heat exchanger in the process tank or in line with the process fluid stream.

5.3 SHUTDOWN

a. Open the back pressure valve V2 fully.

b. Close down the inlet pressure valve V1 until the pressure indicated is less than 10 psi.

c. Press the CIRCULATION PUMP button.

d. Drain the concentrate outlet line.

e. Open the inlet pressure valve V1.

f. Connect the drain outlet of the system to a suitable vessel and open drain valves V3 and V4 to remove remaining process fluid.

5.4 BACKFLUSHING AND STORAGE BETWEEN RUNS

NOTE

Backflushing must be done after each run or every 24 hours, whichever is less, to insure long-term flux stability.

a. Open drain valves V3 and V4.
b. Reconnect drain port to drain.
c. Close permeate shutoff valve V5.
d. Close inlet pressure valve V1 and back pressure valve V2.
e. Pull out BACKFLUSH PUMP button.

NOTE

The backflush cycle will now run unattended until the contents of the permeate tank have been depleted. The film of material accumulated inside the fibers will loosen and be carried out through both ends of the cartridge(s) and into the drain.

NOTE

The cartridge sleeve will remain full of clean permeate, preventing the fibers from drying out. In this mode, the system and cartridge(s) can remain for several days.

5.5 LONG-TERM STORAGE

CAUTION

If the system and cartridge(s) are to be left unattended for a week or more, it is necessary to prevent bacterial growth in the cartridge(s).

This may be accomplished by adding a bacteriastat concentrate to the permeate in the tank <u>before</u> backwashing, or by a second backwashing cycle with a diluted bacteriastat solution.

5.5.1 Adding Bacteriastat Concentrate

a. Start backwashing as in Section 5.4 and allow to run for about fifteen seconds to lower the permeate level in the tank. Stop the backwash pump.

b. Using a small funnel, pour 8 g of sodium azide or 3.2 g of Neogermitol into the permeate tank.

c. Start the backwashing cycle as in Section 5.4

5.5.2 Running a Second Backwash Cycle with Bacteriastat Solution

a. Start the normal backwash cycle as in Section 5.4 and allow the cycle to run to completion.

b. Pour at least three gallons of a 25% solution of ethanol or a 5% solution of formalin into the permeate tank.

c. Start the second backwashing cycle as in Section 5.4.

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APPENDIX D
INSTALLATION AND OPERATING INSTRUCTIONS
FOR OZONE GENERATOR, MODEL HC2P-18[1]

Footnote

1. PCI Ozone Corp., One Fairfield Crescent, West Caldwell, New Jersey 07006.

OZONE GENERATOR, MODEL HC2P-18

Description:

The ozone generator is a Model HC2P-18 Ozone Generator which has a capacity of 18 grams/hour of ozone from air.

Instrument Panel:

Main switch, pilot light, ozone output control (voltage control), volt meter, pressure gauge, pressure regulator, flow meter, flow control.

Dimensions:

Model HC2P-18: 16 inches high x 26-1/2 inches deep x 19 inches wide.

Electrical Supply:

115 volts, 60 cycle, 1 phase.

Air Supply:

Compressed filtered oil free air at a pressure up to 100 psig is to be delivered at a flow of 60 SCFH. The dew point of the air is -40°F or better. The pressure regulator of the ozone generator reduces the inlet air pressure to 0-15 psig.

Cooling:

Air cooled.

Capacity:

The ozone capacity is determined using dry, -40°F dew point, oil-free, filtered air. The capacity of the Model HC2P-18 Ozone Generator is 18 grams/hour.

Operation:

The ozone generator is supplied with fine controls to permit the control of ozone concentration in the range of 0-1% as well as the control of air flow and pressure. They are designed for use in laboratory and pilot plant studies.

INSTALLATION

Ozone Generator:

The Ozone Generator should be located in a dry and clean area, not subject to water sprays. The Ozone Generator has HIGH VOLTAGE, approximately 7,000 VAC RMS inside; thus caution should be exercised locating it. The atmosphere should be clean and not contain a large amount of dust. It should be free of corrosive gases and oily organic chemical vapors which can cause corrosion in internal components of the ozone generator. Failure to keep the ozone generator in the proper environment will increase the chances of its malfunctioning.

Air supply should be connected to gas inlet on back panel of ozone generator marked "AIR", "OXYGEN". Fitting is 3/8-inch tube. Use copper tubing or other tubing that can withstand pressures to 100 psig. Ozone outlet on the back panel is marked "OZONE". The fitting is also 3/8-inch tube. Use aluminum, stainless steel or PVC tubing. Do not use copper or brass tubing.

A plug for the electrical connection for the ozone generator is supplied with the unit. It should be plugged into 110-120 volts, 60 cycle, 5 amp circuit. The recommended fuse is 5 amps.

OPERATION

Start Up:

1. Turn on dry (-40°F dew point), oil-free and particle-free air supply.
2. Set air flow to about 60 SCFH through the ozone generator by using the

pressure regulator and the flow regulator valve on the flow meter. The back pressure read on the pressure gauge is dependent on the air flow rate through the system and the pressure drop through the piping after the ozone generator.

3. Turn ozone output switch located on front panel to extreme counter-clockwise position.
4. Turn "ON-OFF" switch to "ON" position.
5. Select ozone output with ozone output switch located on front panel.

Turn Off:

1. Turn ozone output switch to extreme counter-clockwise position.
2. Put "ON-OFF" switch to "OFF" position.
3. Wait 10 minutes to let air purge ozone generator.
4. Turn off air supply.

Air or Oxygen Supply:

Dry air, having a dew point of -40°F or lower, should be used exclusively. The use of wet air (dew point -20°F or higher) will damage the equipment and void the guarantee. The dry air supply should have a pressure of 10-100 psig. Be sure that tubing between air supply and ozone generator is properly rated.

Maintenance:

If the ozone generator is placed in a reasonably clean environment and the proper air supply is used, the ozone generator should be practically maintenance free.

1. Keep records of maintenance and hours of operation.
2. Clean ozone generator cells every 6-12 months of 24-hour operation or as needed. Frequency of cleaning depends on the quality of the air passing through the ozone generator.

   [Instructions for disassembly and cleaning of ozone generating cells are available in CERF project files.]

HC2P OZONE CELL DISASSEMBLY AND CLEANING INSTRUCTIONS

1. Turn off all power to ozone generator. Pull out plug to ozone generator.
2. Loosen brass 1/4-20 hex nut on high voltage terminal on cell head. (Caution - Hold bottom stud firmly so it will not turn; this procedure will prevent the breaking of wires inside the stud.)
3. Loosen 2 slotted 10-32 screws.
4. Loosen 1/4-20 hex head bolts.
5. Gently slide PVC head assembly horizontally until cell head is free of cell body.
6. Check cell head for excessive build up of dirt, moisture or oil and for pitting of ceramic, which will cause failure of cell from electrical arcing.
7. Clean cells in mild detergent solution or in organic solvent (alcohol). The ceramic plates and head assembly *must be absolutely* dry before reassembly. (If cells were excessively dirty it will be necessary to clean the metal cell body.)
8. To clean the cell body, loosen Swagelok nuts on cell bodies to be removed.
9. Remove connecting tubing.
10. Remove 4 corner 1/4-20 stainless steel hex nuts.
11. Lift cell body vertically off vertical studs.
12. Remove balance (nine) 1/4-20 stainless steel hex nuts from cell body and open cell body exposing center electrode.
13. Remove O-ring material from grooves.
14. Clean thoroughly all surfaces including grooves with mild detergent solution or alcohol. (Before reassembly, make sure all components of cell are thoroughly dry.)
15. Replace O-ring material. O-ring material can be obtained by contacting PCI Ozone Corporation.
16. Reassemble cells by reversing steps of disassembly (steps 1-14).

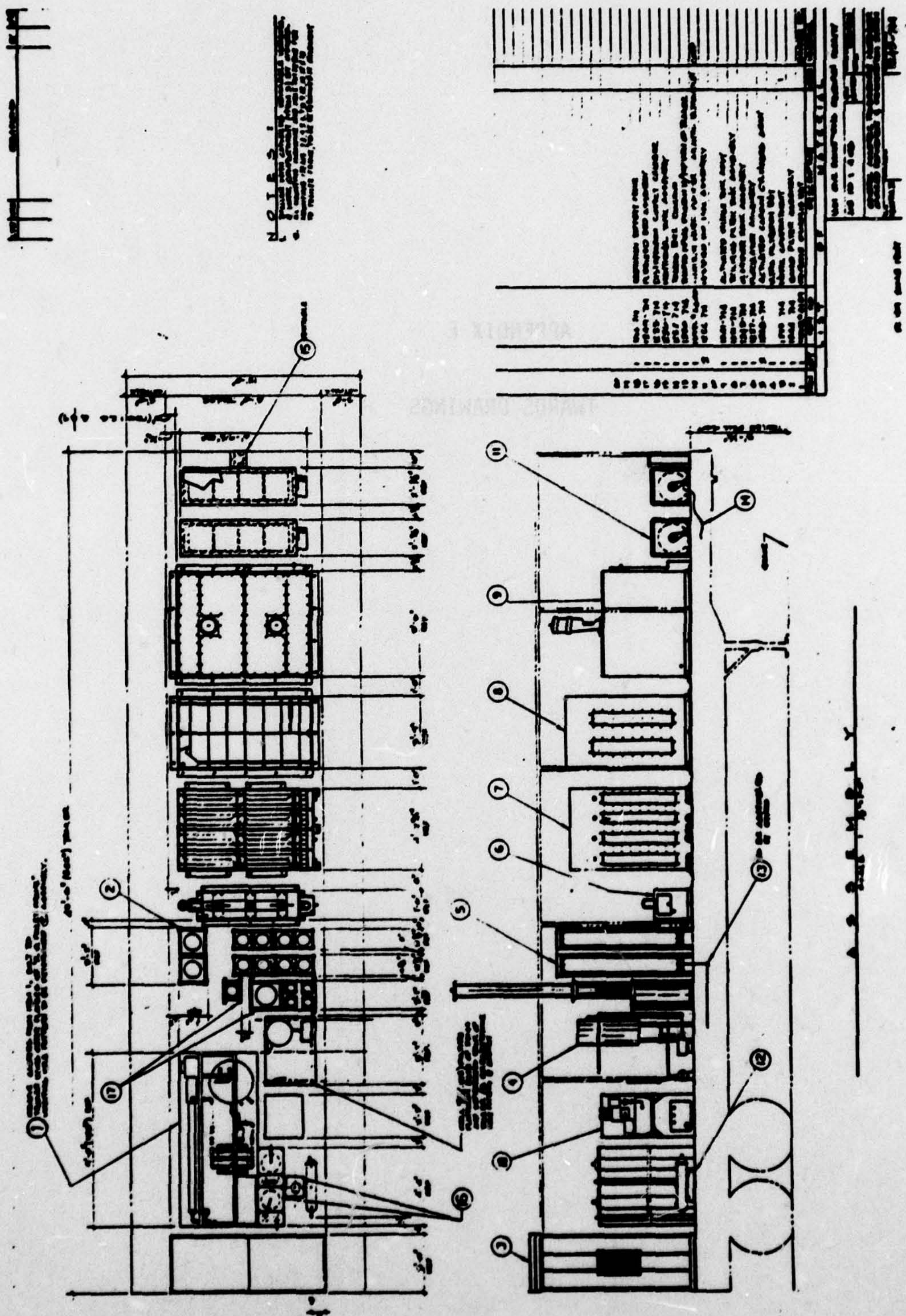
PRESSURE CHECKING OZONE GENERATOR

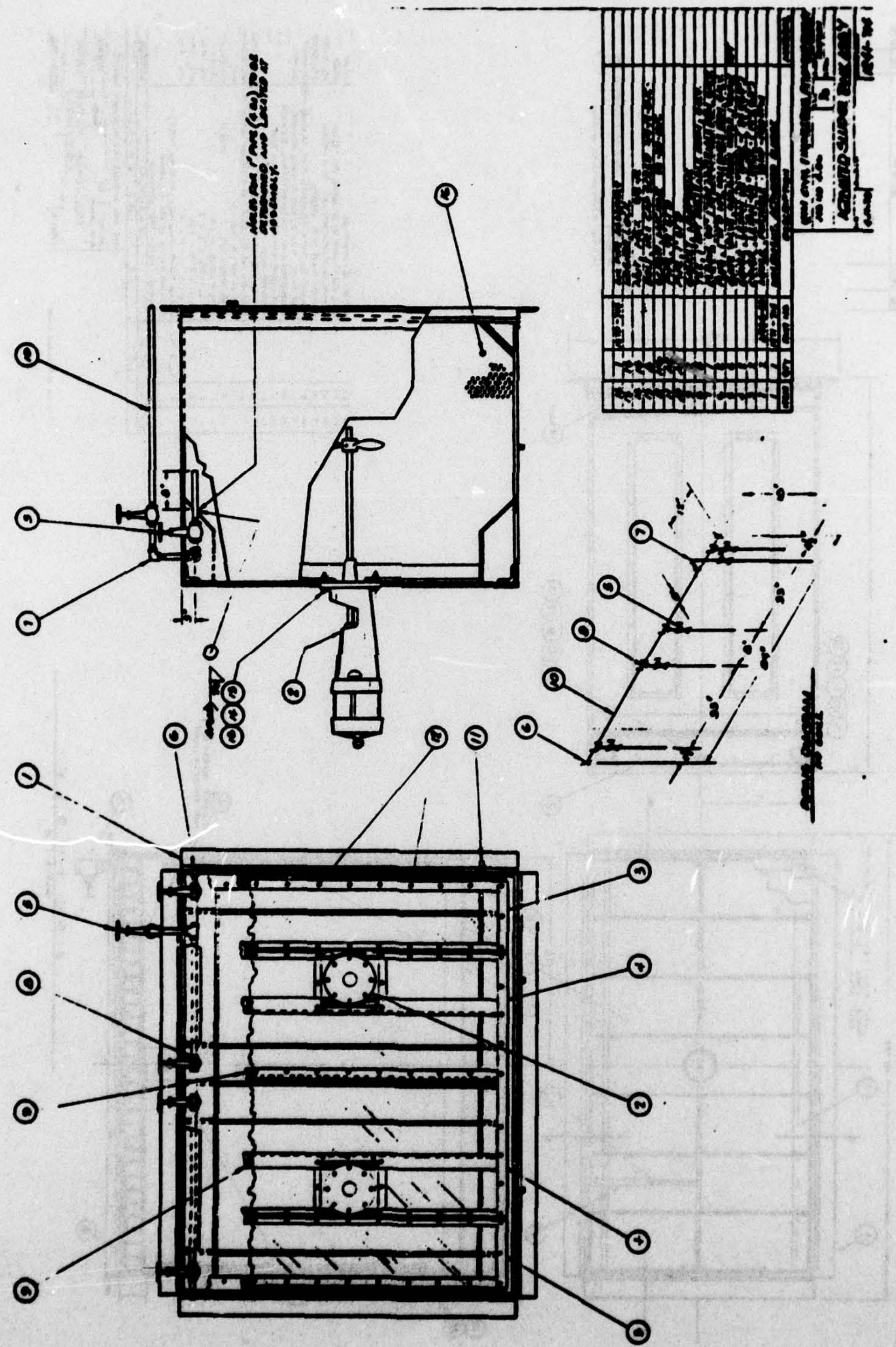
After cells are reassembled, ozone generator should be checked for air leaks before unit is turned on.

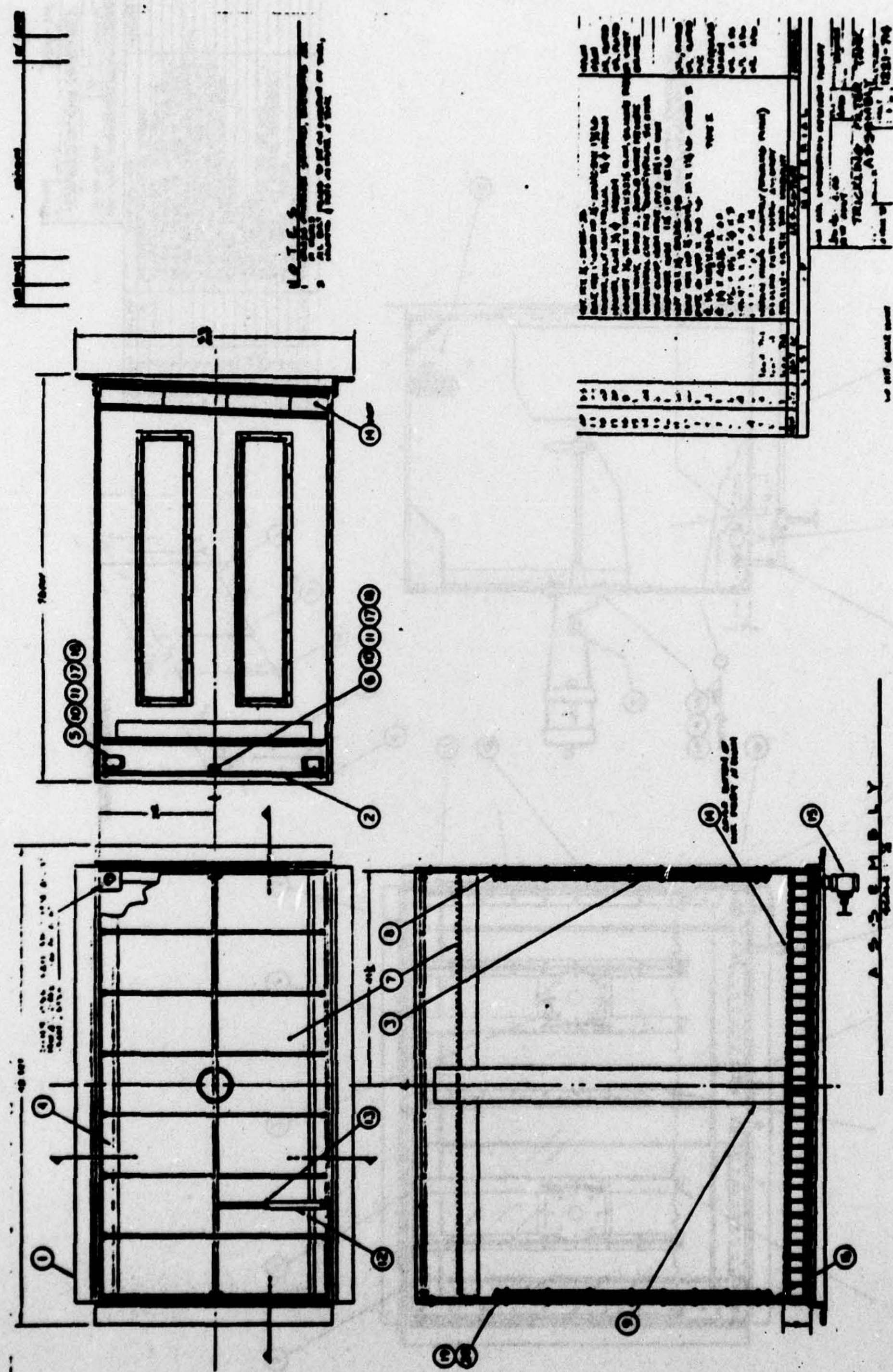
1. Make sure ozone generator power is disconnected.
2. Close ozone discharge line and turn on air preparation unit.
3. Set air pressure to 15 psig using pressure regulator on instrument panel of ozone generator.
4. Shut off air flow by closing air flow control at the bottom of flow meter on instrument panel of ozone generator. Turn off air preparation unit.
5. Wait 20 minutes. If pressure decrease is less than 1/2 psi, the system does not have any leaks. If pressure decrease is greater than 1/2 psi, there are leaks in the system.
6. Open air flow control on instrument panel of ozone generator. Turn on air preparation unit.
7. Set pressure to 15 psig with pressure regulator and check all fittings and around cell head and cell body with leak detector solution (soap-water solution).
8. Bubbles will form around leak. Tighten necessary fittings.
9. Repeat steps 2-5 to determine if system still has leaks.
10. IMPORTANT! Make sure ozone generator is completely dry before unit is turned on.

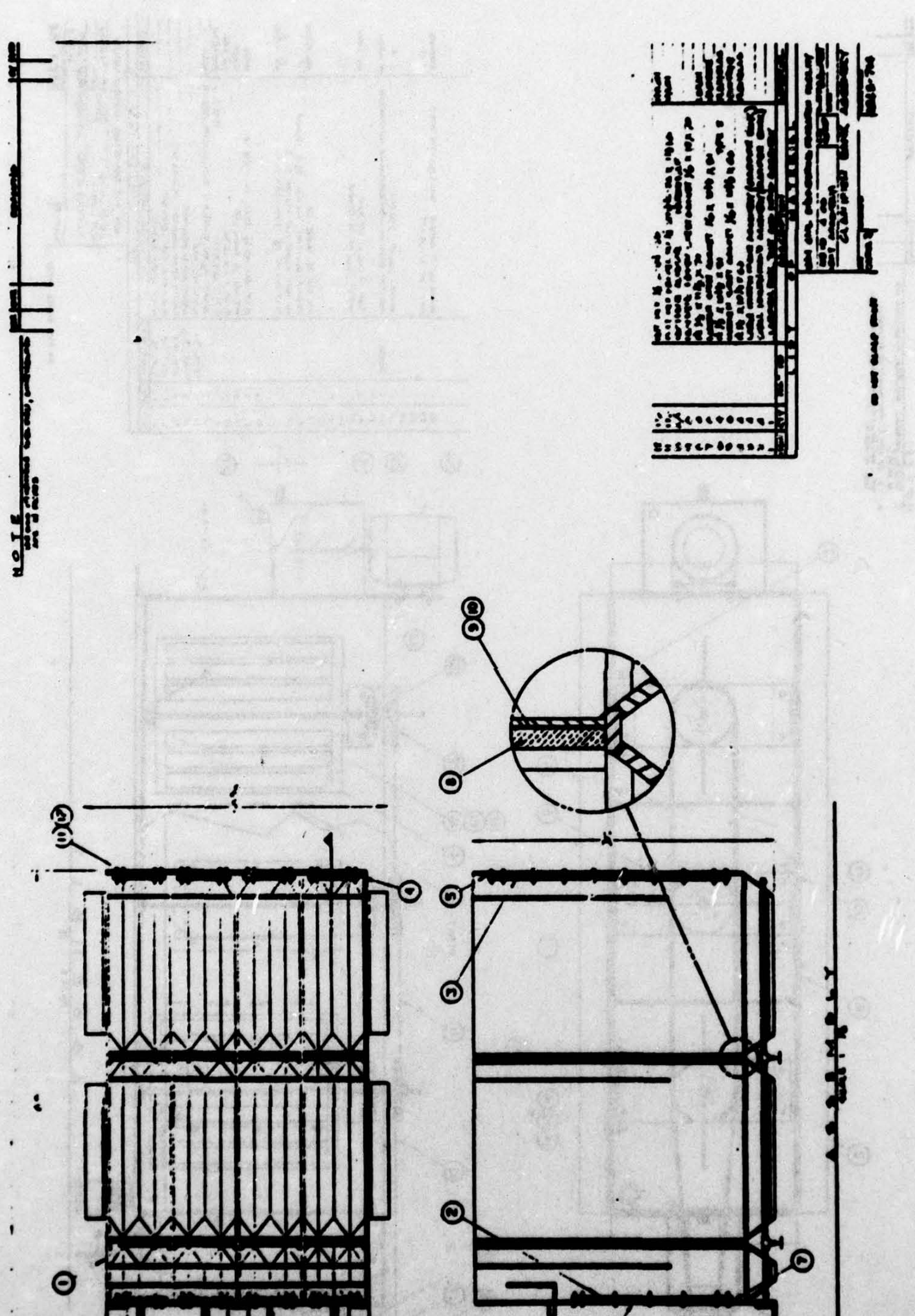
APPENDIX E

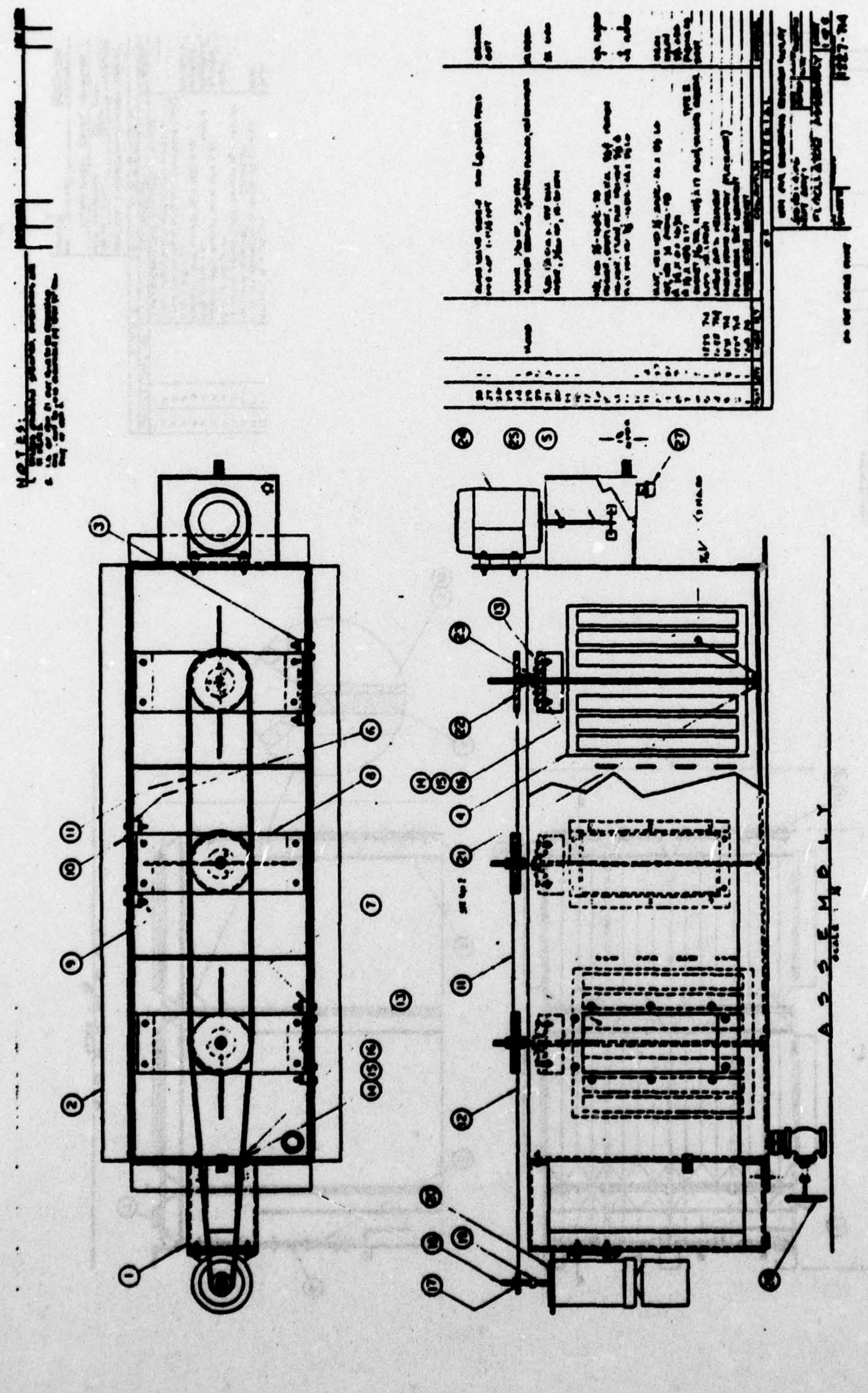
TWARDS DRAWINGS







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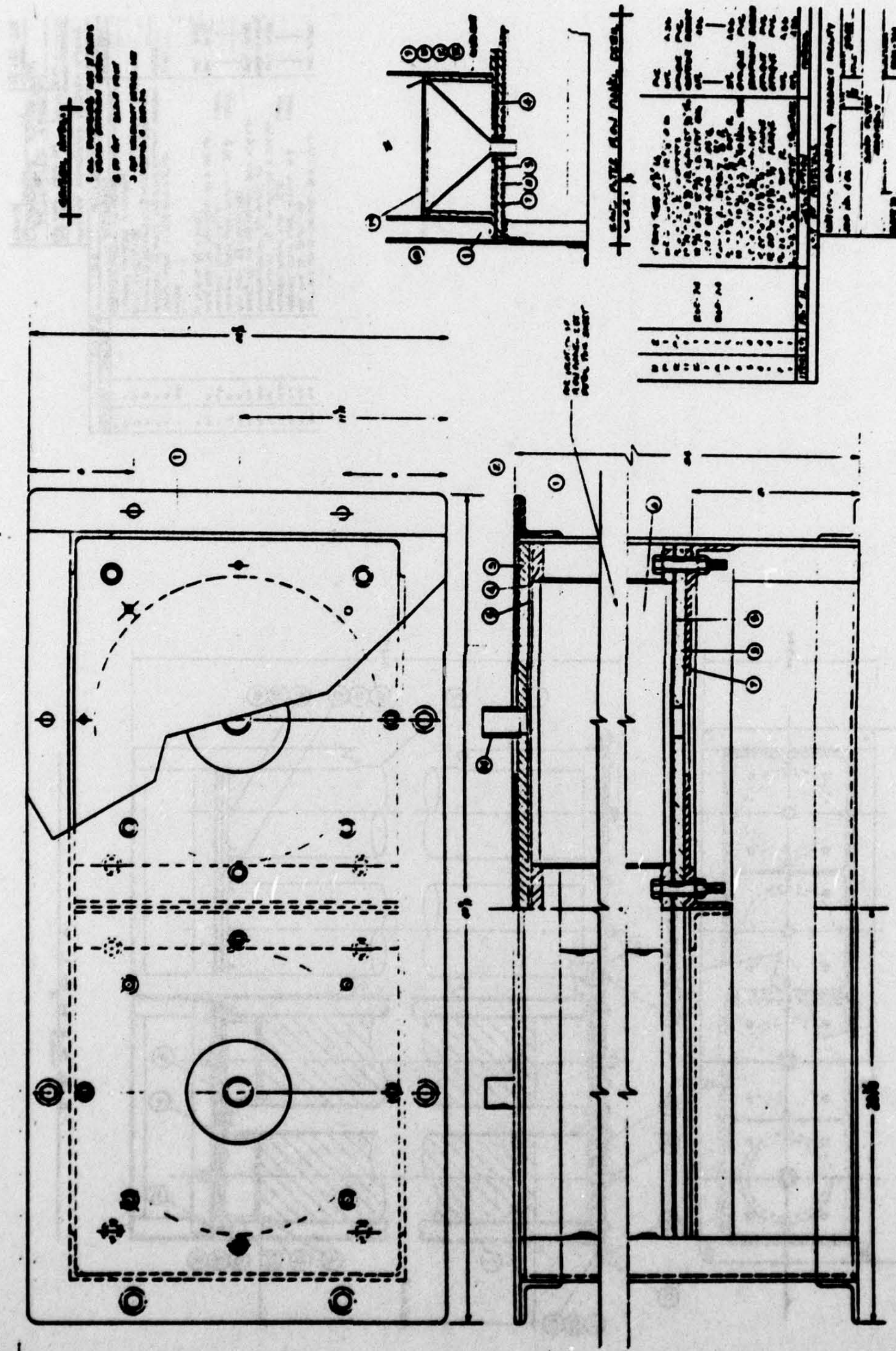

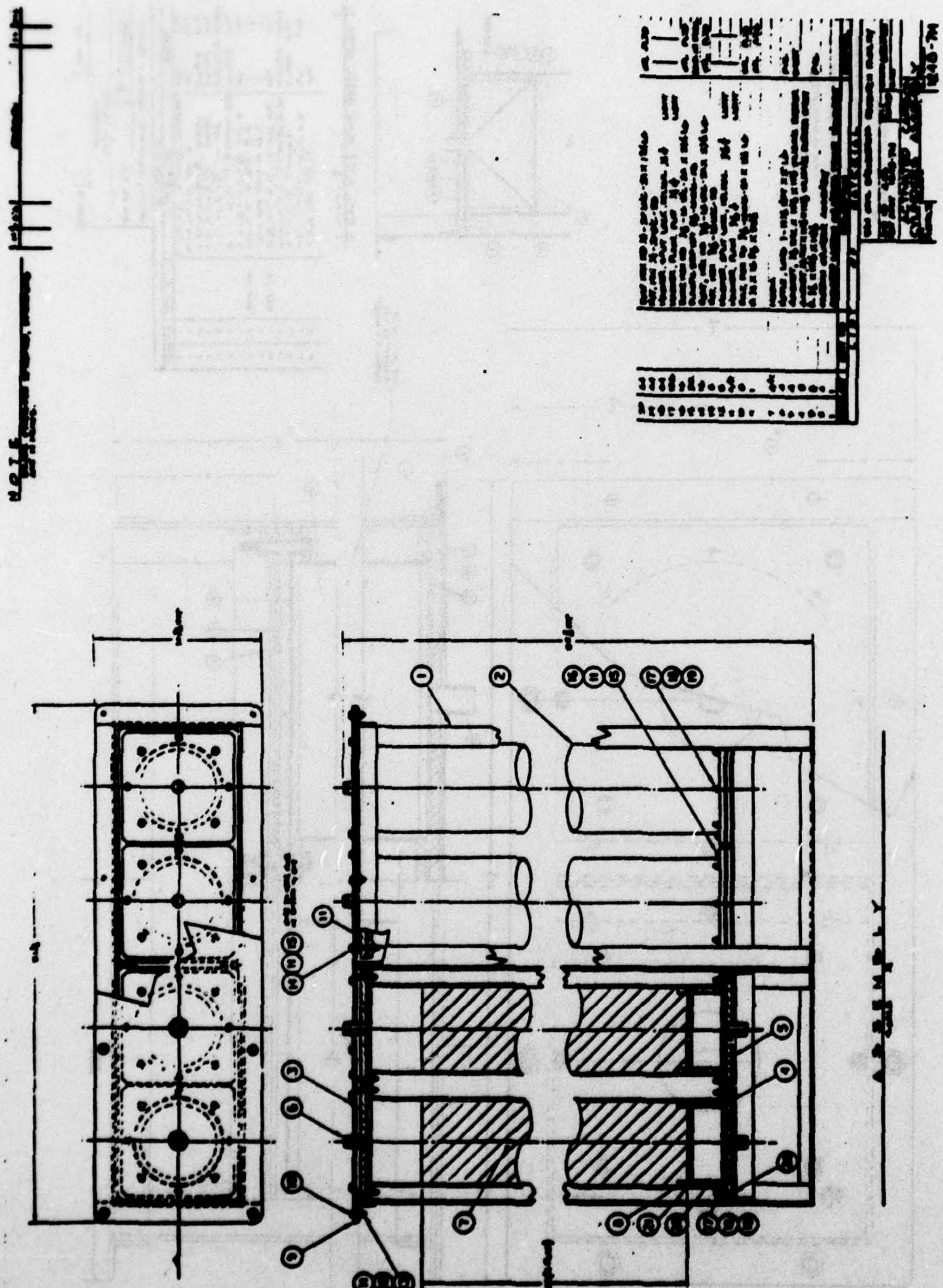

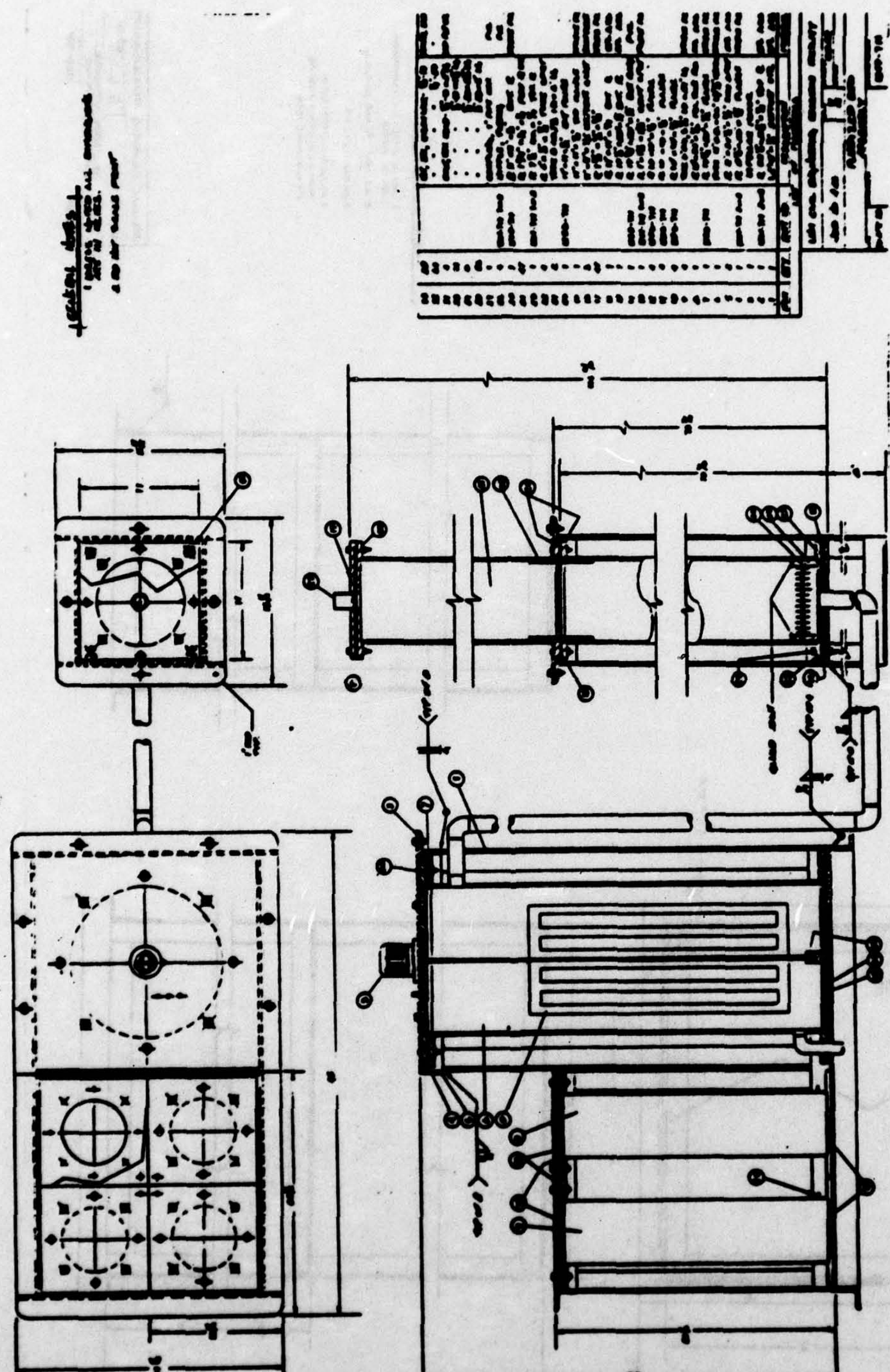

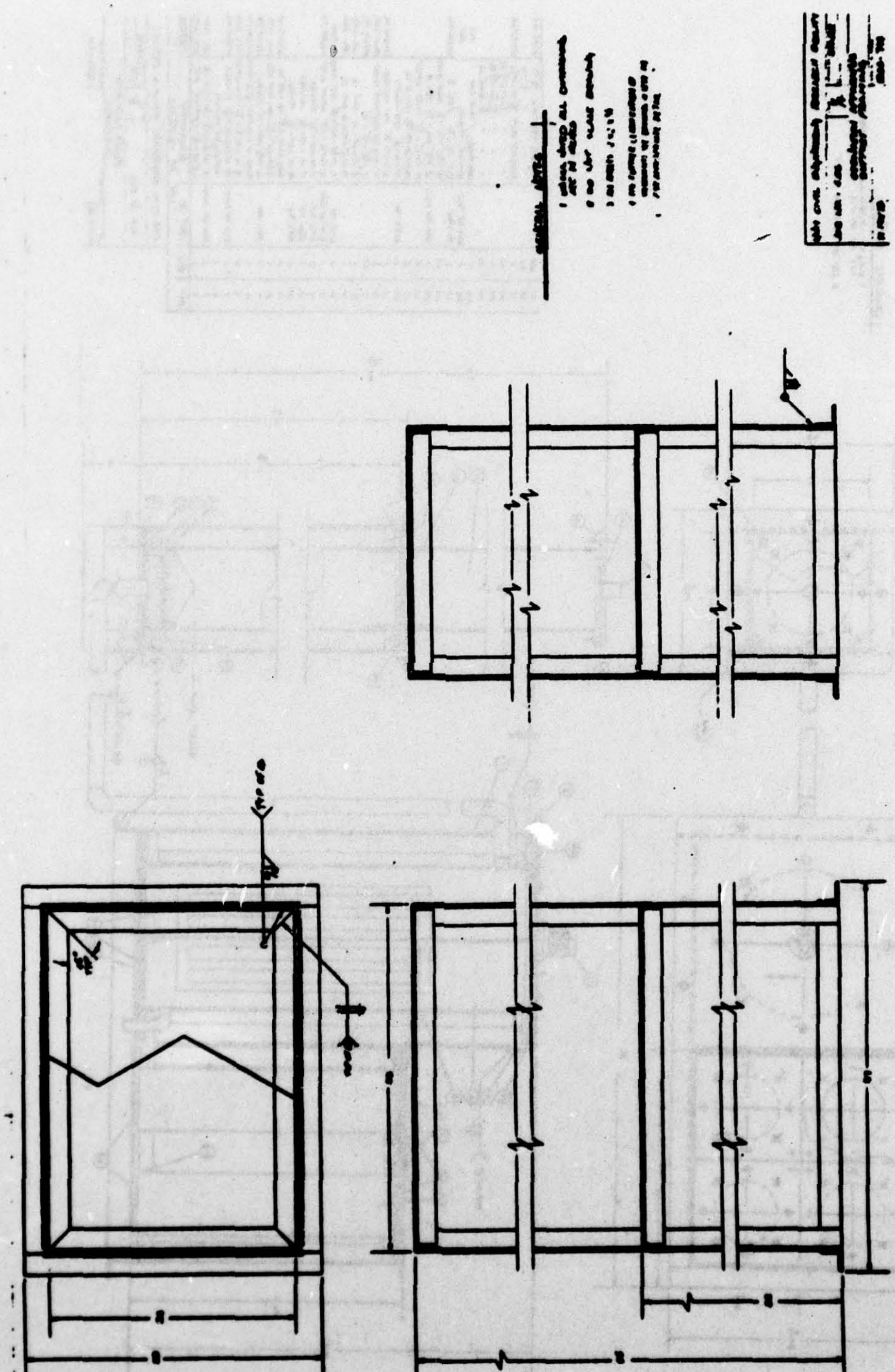

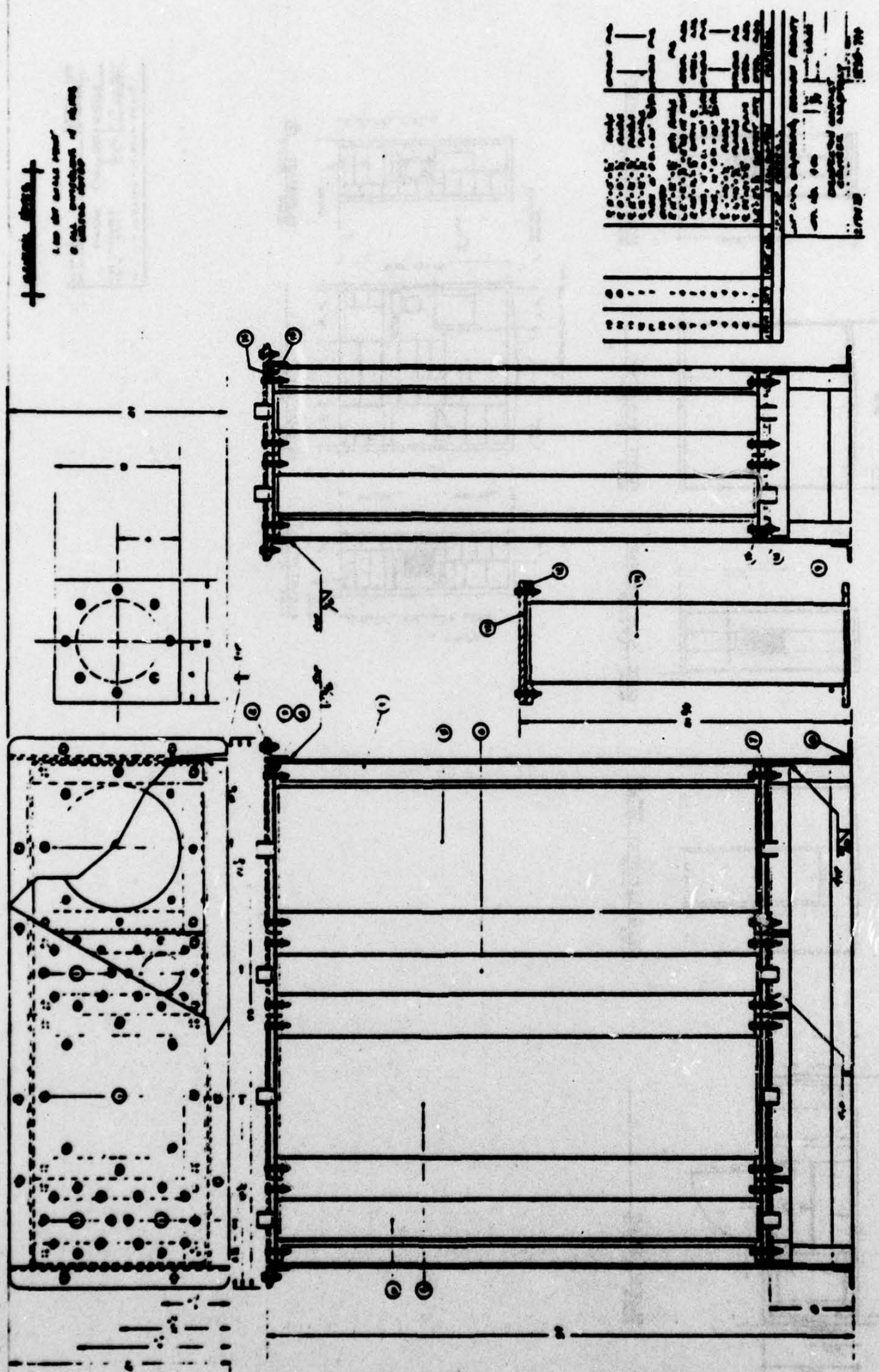

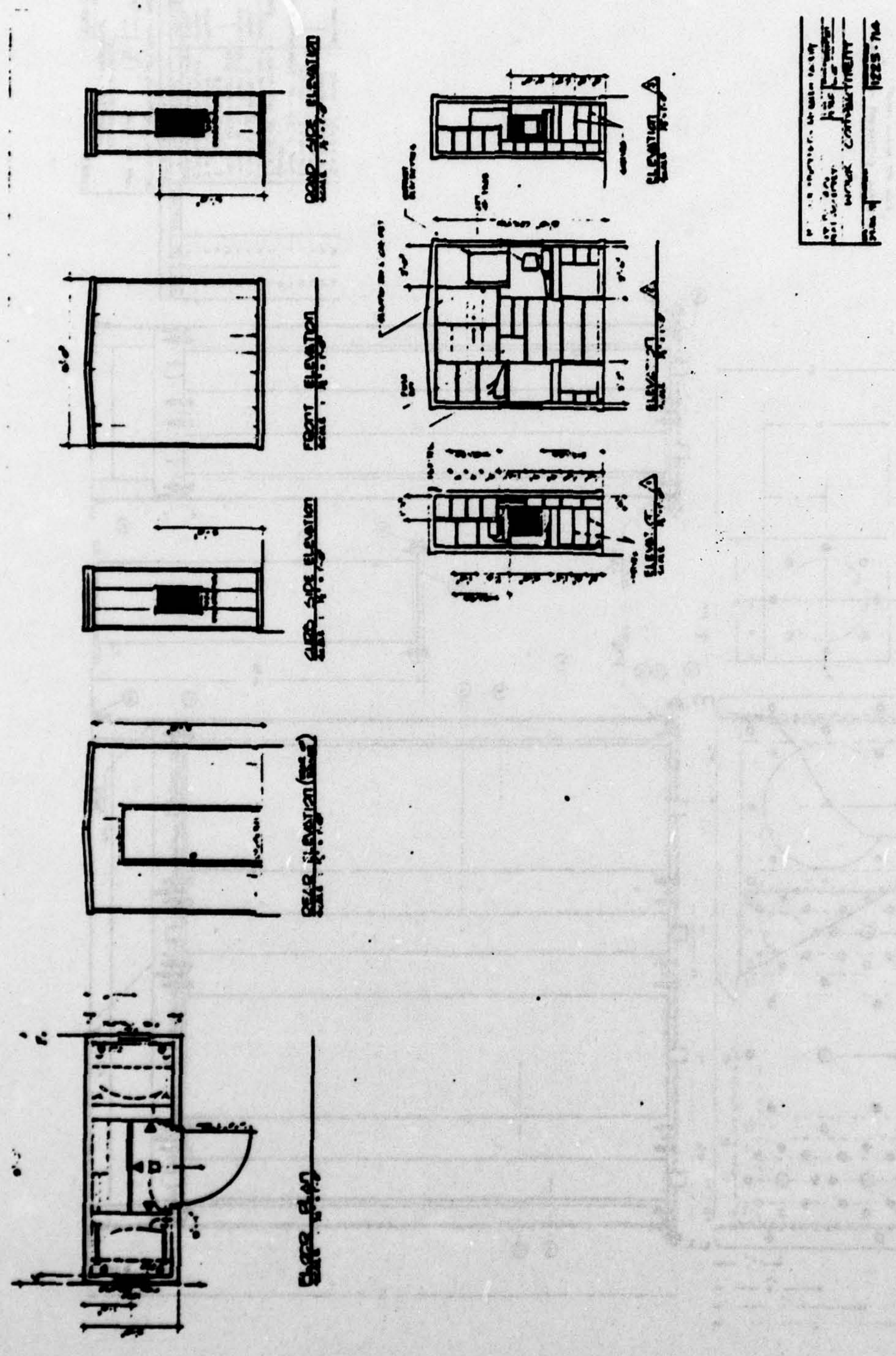

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