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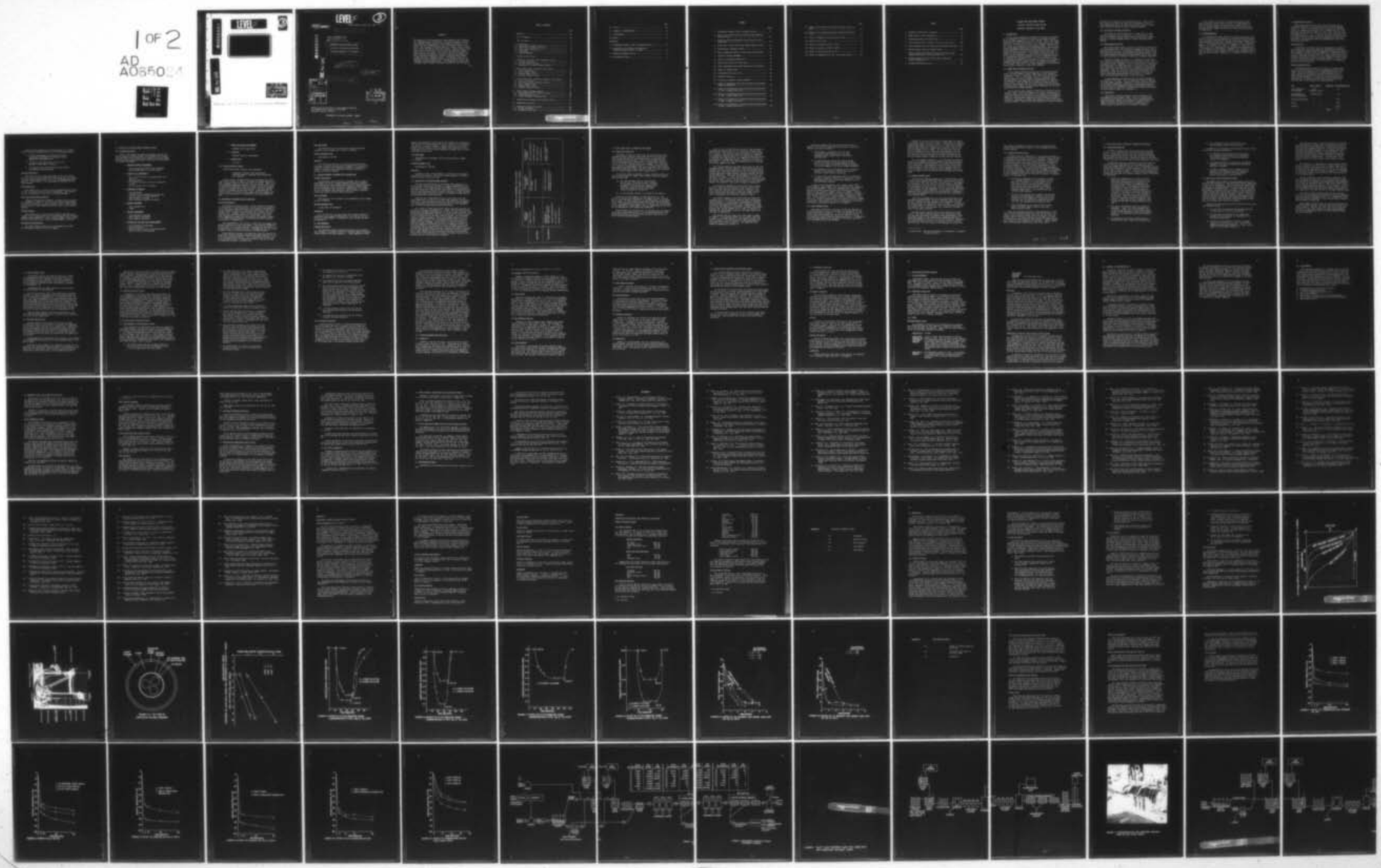

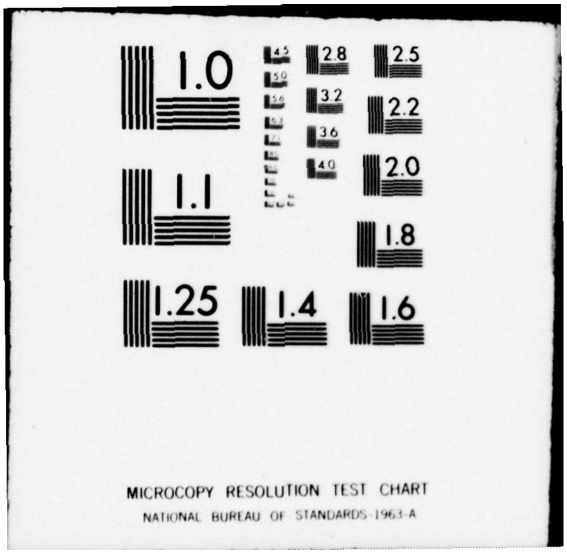

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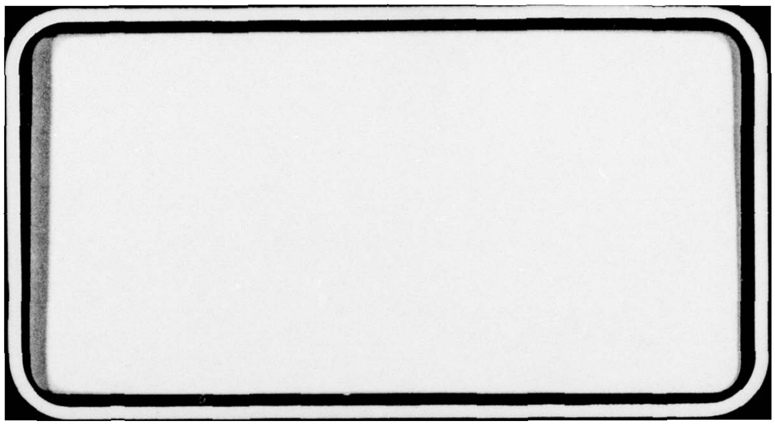

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ABSTRACT

The design of an air-transportable Environmental Service Module, an integrated water purification, solid waste disposal, and sewage treatment system complete with consumer facilities, is outlined with cost estimations for small 100-200 man groups in the North. The treatment processes produce a compact sterile residue which can be disposed of relatively easily. Eighty percent of the water used in the facility is recycled from the waste streams to potable quality for reuse, thus greatly reducing the demand for water from the environment. Test data from a scaled-down pilot plant operating on municipal sewage is presented which demonstrates the basic treatment process. Preliminary selection of equipment has been completed, and conceptual module layouts for full-scale system are also shown. A bibliography on Arctic water treatment, waste disposal, and related topics is also included.

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RESEARCH AND DEVELOPMENT TOWARDS
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1. Introduction

On the whole inadequate attention has been given to meeting water purification, solid waste disposal, and sewage treatment needs for small communities in Arctic regions. While functioning and modern facilities have been built in cold regions, the common practice of treating each of these three problems separately has led to the use of expensive and redundant systems. On the whole, the systems employed have been transplanted from southern environments to northern climes with only minor modifications. In particular the effects of cold stress impose severe constraints on methods of waste disposal. If the fragile ecology of these regions is to be protected for present and future generations, and if the hazardous health conditions in Arctic communities are to be alleviated at reasonable cost, it will be necessary to take an integrated approach to the problems of potable water production, adequate sanitation of human excreta, and disposal of garbage. At the present time there is no single combined facility available which offers a solution to these three problems.

1.1 Human Waste Disposal Practices

Of the numerous methods employed for the disposal of human waste, the most common in small communities is the dumping of excrement in plastic "honey-bags" onto terrain not far from the habitations. This is a hazardous practice. Although the excrement freezes in winter, extensive documentation has shown that pathogenic micro-organisms can remain viable for long periods of time. Thus the dump sites become the prime sources of disease in warm weather when the solids thaw, and cause pollution of ground waters, lakes, rivers, and ice formations, all of which may be used for drinking purposes.

Other forms of waste disposal suffer from a variety of shortcomings. Septic tanks and cesspools can be kept operating if certain conditions can be maintained, but in general such systems are expensive, require close control and are unsuitable for permafrost areas, or are potentially dangerous sources of ground and water pollution. Disposal of contents from chemical toilets still poses a health problem. Outdoor privys are impractical because of heating problems and the nature of the permafrosted soil. Flush systems like those in the South are practical and economical only for large communities which can afford the utilador system of heated pipes place above ground to avoid permafrost problems.

1.2 Solid Waste Disposal Properties

Solid waste is usually disposed of in dump sites in loose form or in discarded oil barrels where it may be burned. For esthetic and health reasons, this method of disposal is undesirable as it creates problems similar to those from human waste dumping.

1.3 Water Supply Practices

The primary water sources available in the Arctic suitable for producing potable water are fresh-water streams and lakes, and the melting of snow and ice. More advanced techniques include the desalinization of sea water, and regeneration from wastewater: however these methods in general have been applied only in very large or unique operations in southern climates or in manned spacecraft.

For winter supplies of water ice is usually cut from fresh water lakes in the Fall when the ice is about 30 cm thick. The ice is stored and used throughout the winter by melting it, usually in improvised equipment employing steam or some form of heat derived from combustion. Snow gathering does not usually provide enough mass unless snow barricades are used to promote drifting and accumulation. Lakes can serve as a continuous water supply only if they do not freeze to the bottom, which rules out most of the shallow lakes and ponds prevalent in the Arctic. In summer, water can be obtained from lakes, ponds, and rivers.

Of more importance than the qauntity of water available is the quality of the water. The low temperature tends to lengthen the decay times of organic refuse and to allow a buildup of harmful pathogenic organisms. Consequently ground water supplies, lakes, and rivers in permafrost regions are frequently polluted by runoff from the dump sites described above, and they are often bacteriologically unsafe for consumption.

1.4 Objectives

This report outlines the research and development of an Environmental Service Module (ESM): that is, an integrated facility for the production of potable water regenerated from human wastewater, and for the treatment of human and solid waste, to be used in remote locations by small groups of 100-200 people in mobile units or permanent settlements.

Other objectives are that the ESM should employ as much water recycling as practically possible, be transportable in Hercules C-130 aircraft, contain complete consumer facilities such as toilets, showers and laundry areas, and produce an innocuous, sterile, compact residue which could easily and safely be disposed of.

1.5 Acknowledgements

In developing the final design for the ESM presented in this report, a portion of the information presented here has been modified and correlated from three reports written by the Ontario Research Foundation (ORF) under commission from DCIEM. These reports are: 1) "Conceptual Design of an Environmental Service Module", BROWN, C.K., CADOTTE, A.P., SETO, P., SMITH, D.K., Report # 75-01, July 29, 1975; 2) "Final Report--The research and Development of an Environmental Service Module", CADOTTE, A.P., Proposal P-2114/G, Jan. 27, 1976; 3) "Final Report--ESM Pilot Plant Wastewater Treatment System Evaluation", CADOTTE, A.P., Proposal P-2192/G, Feb. 27, 1978.

2. Design Specifications

Where applicable the specifications listed below were established with the aid of literature found in the Bibliography, section 12. There is a large variation in some of the published values for consumption and output rates, compositions, etc., depending on factors such as population type, size, location, unique environmental effects, etc. In particular, data for northern regions was either very scarce or was for specific military or native settlements. Hence it was occasionally necessary to make extrapolations or interpolations from the published data to set the design specifications.

Population Size

A population of 100 was used as a design figure. However it was realized that since most commercial equipment available for water treatment purposes would be designed for larger installations, the population size that could be handled by any minimally sized facility might well be larger than 100. Hence, when necessary and possible, consideration was given to servicing populations as high as 200 without major system or equipment changes. The exact capabilities of the facility will not be known until the commercial equipment has been selected.

Water Consumption Rates

The following specifications were based to a large degree on data obtained from the Alaska Village Demonstration Project (AVDP), and on an examination of the methods and devices currently available for reducing household consumption rates. These devices are explained in more detail in section 8. The AVDP has goals similar to our own, with the major differences being that it is primarily involved with native populations, and that water is not recycled to potable quality.

Use	Type of Water	Quantity - Litres/Capita-Day
Food Preparation and drinking	From Freshwater Source	7.6
Dishwashing and other Kitchen use	Recycled Water	7.6
Bathing and Washing	" "	10.6
Toilet	" "	10.6
Laundry	" "	10.6
	TOTAL	47.

Water for food preparation and drinking was to be treated from an external freshwater source for the following reasons:

1) To avoid psychological problems with certain populations concerning the drinking of water regenerated from human waste,
2) To prevent long term buildup of trace contaminants which might be harmful.
3) To replenish water lost from the system through the dumping of refuse streams.

Sanitary Waste Rate

This total is 10.6 Litres/Capita-Day (L/c-d) and consists of water from the toilets mixed with human solid and liquid waste. The total solid weight in this flow is .075 Kilograms/Capita-Day (kg/c-d). (See section 6.1 for adjustment of this rate in the final design).

Solid Waste Rate

This design rate is 1 kg/c-d with an average moisture content of 30%, and a heat content of 3000 calories/gram. (See section 6.1 for an adjustment of this rate in the final design).

Fresh and Recycled Water Quality

Canadian Drinking Water Standards, the main portion of which are reproduced in table I. were used to set quality requirements. For specific purposes other than drinking, the U.S. Public Health Service Limits of Water Impurities shown in table 2 were used for guidance.

Transportability

For transport in a C-130 Hercules aircraft, the ESM was to be made up of a minimum number of sub-modules having the following maximum outside dimensions: width, 2.79 m; height, 2.59 m; length, 11.89 m; Each module was to have a maximum weight of 4500 kg.

Wastewater Characteristics

The values shown in table 3 were calculated for the ESM. They are based on municipal sanitary wastes.

3. Selection of Optimal Waste Treatment Process

3.1 Process Objectives

Since it was planned to design and evaluate several different treatment process systems, the following list of desirable ESM objectives was drawn up with which each of the systems could be scored, thus facilitating a choice of the best system for further development.

1. EXPECTED PROCESS PERFORMANCE
   - produce recycled potable water from waste
   - have minimum impact on the environment

2. STABILITY OF PERFORMANCE
   - able to work on salt or brackish water, ice, snow etc.
   - high reliability
   - be sensitive to shock loads and variations in feed
   - able to operate in all climates

3. OPERATION OF PROCESS
   - low maintenance
   - physically safe (possibility of fire, explosion, escape of toxic materials)
   - safe disposal of garbage
   - easy to operate (operator attention)

4. PROCESS EQUIPMENT
   - easy to manufacture
   - rugged

5. PROCESS DEVELOPMENT
   - uses available technology
   - short time to development
   - many potential suppliers

6. SUITABILITY FOR ARMY AND CIVILIAN NEEDS
   - air and ground transportable
   - ease of scale-up
   - suited to both military and civilian needs
   - ease of start-up and shut-down

7. ENERGY AND POWER REQUIREMENTS

- minimum total energy input

8. LOGISTICS

- minimal logistics requirements

9. CAPITAL COST

- low cost

3.2 Process Design Concepts

Three broad process concepts were considered:

- biological treatment with incineration
- physical-chemical treatment with incineration
- wet oxidation

Various process configurations were investigated for each of these three concepts in order to determine an optimum design for each, keeping in mind the objectives set out earlier. Each of the final processes developed produced a sterile residue which could be handled and disposed of relatively easily, and also renovated the water to potable quality for recycling. The three optimum designs so developed are described below. Considering the conceptual nature of the work at this stage, the size, weights, and costs in particular must be considered as first approximations only.

A: Biological Treatment with Incineration

Process Description

This process includes grinding, aerobic biological treatment in the presence of activated carbon, clarification, multimedia filtration and ozone oxidation/disinfection followed by distillation of the effluent by thin film evaporation with a device such as a Hickman still. Garbage, surplus sludge and concentrate liquid from the still would be treated in an incinerator. The waste water biological treatment unit selected for the design is based on the CABOS (Carbon absorption bio-oxidation system) developed at the ORF for shipboard use.

The disadvantage of this process is that both the Hickman still and the incinerator require development. The principle behind the Hickman still is well understood and a prototype has been built, but no such device is currently marketed. Approximately one year of development would be required to produce a reliable machine.

The incinerator presents a problem since there are none on the market that are both corrosion resistant and small enough to fit into an air-transportable module. It is foreseen that at least one year of moderate effort of development would be required in order to design and construct a suitable unit.

Size and Weight

Two sub-modules would be required to house the process equipment, with a weight in the order of 5,000 kg.

Process Equipment Cost

Approximately $40,000.

Logistics

26 L per day of fuel oil is required to operate the incinerator, and 200 Kilowatt-Hours/Day (kwh/day) of electricity, is needed to operate the remaining equipment. 0.5 kg/day of carbon is required, and the process produced 38 kg/day of a sterile, dry ash for disposal.

B. Physical-Chemical Treatment with Incineration

Process Description

The processes selected include screening, lime treatment, multi-media filtration, possibly ammonia stripping, activated carbon absorption, ozone oxidation/disinfection, demineralization, by reverse osmosis and incineration of garbage surplus sludges and the concentrate from the reverse osmosis step. The incineration is the same as that employed in the biological treatment concept and suffers from the same limitations.

Size and Weight

This process could be housed in 1½ sub-modules, with a weight of about 6,000 kg.

Process Equipment Cost

In the order of $65,000.00

Loagistics

26 L of fuel oil, 2.6 kg of lime, and 1.2 kg of carbon are required per day along with 300 kwh/day of electricity for operation of the equipment. 38 kg/day of a dry, sterile ash must be disposed of.

C. Wet Oxidation

Process Description

The processes selected comprise maceration, wet-oxidation, lime treatment, multimedia filtration, possibly ammonia stripping, reverse osmosis, and ozone oxidation. A high temperature, high pressure wet-oxidation reactor essentially replaces the incinerator used in the two previous processes, as the products of wet-oxidation are similar to those of burning. However, the use of this device permits a great saving in size and weight (from 4,000 kg, 28 sq. m to 500 kg, 2.8 sq. m)--an 8-fold reduction in weight, and a 10-fold reduction in floor area.

Size and Weight

Approximately ½ sub-module would be required with a weight of 2,000 kg.

Process Equipment Cost

Approximately $120,000.

Logistics

8 kg/day of lime, and 350 kwh/day of electricity is required to support this process. The sterile residue consists of 78 kg of solids in 54 kg of water per day.

3.3 Evaluation of Process Design Concepts

The three process designs outlined above were compared in relation to the objectives in section 3.1 using a weighting and scoring technique. The biological,physical-chemical, and wet-oxidation processes scored 64%, 78%, and 86% respectively of a maximum possible score for an idealized "perfect" system. The chart on page 10 shows the more important differences between Environmental Service Modules incorporating these three processes.

Costs are not a significant factor in this chart since the study showed that the costs of the additional equipment sub-modules required for the biological and physical-chemical processes negated to a large degree any significant savings that the lower equipment cost of those processes would otherwise have had.

As a result of these evaluations, the wet-oxidation process was selected for further development for the ESM. The processes were examined more thoroughly and developed to the point where equipment could be specified and laboratory and/or pilot plant tests could be carried out for verification of the more important stages. The redesigned process is shown in figure 1, along with design objectives for the chemical oxygen demand (COD) and suspended solids (SS) at various stages within the process. A description of this preliminary design and of each treatment process within, is given in appendix A. The only significant difference between the redesigned process and the process used in the evaluation is that the former substituted flocculation for multimedia filtration, omitted the ammonia stripping portion, and combined ultraviolet (UV) radiation with the ozonation step. These changes are only refinements and minor modifications, and would not have significantly altered the superior rating of this process over the other processes considered.

COMPARISON OF ENVIRONMENTAL SERVICE MODULES INCORPORATING VARIOUS TREATMENT PROCESSES

	BIOLOGICAL TREATMENT	PHYSICAL-CHEMICAL TREATMENT	WET-OXIDATION TREATMENT
ADVANTAGES	- simple process - low power requirement	- many potential suppliers of equipment - proven system	- high transportability - maximum flexibility - high reliability - low maintenance
DISADVANTAGES	- considerable incinerator and still development required - limited transportability - low reliability - limited flexibility	- limited transportability - considerable incinerator development required	- requires operation of a pressure vessel

4. Pilot Plant Tests: Simulated Feed Supply

4.1 Scope and Objectives

Initially, in order to verify that the wet-oxidation waste treatment process could meet the design objectives, various portions of the process were tested separately, to establish the effectiveness of each portion. Some of the processes could be easily and inexpensively duplicated in a scaled down version in a pilot plant with standard laboratory equipment (e.g. rapid mixing, flocculation, cartridge filtration). Other processes require very expensive machines where final specifications cannot be fully determined before some initial testing is done (e.g. wet oxidation reactor, reverse osmosis (RO) units, screen filter).

In the first phase of laboratory tests, the operation of certain processes shown in figure 1 was verified using two separate feeds in two areas:

(1) the lime treatment portion (rapid mixing, flocculation, and clarification), followed by cartridge filtration and reverse osmosis treatment. This would begin immediately after wet-oxidation reactor and vacuum filter at stream #7 in figure 1.

(2) At the UV/ozone contactor at stream #14 in figure 1.

There were several reasons for beginning with (1). The reactor would have cost $120,000 and the degree to which it would have to treat the waste, and hence its specifications, would depend on the ability of the processes downstream to meet their specifications. This emphasizes the point that, in effect, all the processes are interdependent to some degree, since an inefficiency in one area has an influence on other operations downstream.

Another reason for starting with (1) was that with the exception of the reverse osmosis units, the processes downstream of the wet-oxidation reactor could be relatively easily tested on a reduced scale with minimum expense.

Tests at (2) with the UV/ozone contactor were necessary to establish performance data for our particular feedwater from the RO units to the contactor since literature on the reaction of ultraviolet radiation and ozone with refractory compounds (e.g. primarily calcium acetate for the ESM process) was scarce. In addition since there was no unit commercially available, it was necessary to design and develop a contactor with very few guidelines. It was felt that some experience had to be gained at an early stage in this area.

As it was necessary to use some type of feed for the lime treatment process, the ORF conducted a theoretical analysis to determine the constituents expected in the wet-oxidation output streams (both steam and liquid phases) after the vacuum filter, and the grey water stream (laundry, bathing, washing, and dishwashing effluents). These are stream numbers 5, 6, and 1 respectively in figure 1. Tests and analyses were carried out by the ORF in order to verify that mixtures of the simulated streams had similar characteristics to those predicted in the original design. The results of this study are given in appendix B.

An alternative approach here would have been to use an effluent stream from a wet-oxidation reactor, which itself might work from some more realistic feed. However it was more economical and practical to begin the laboratory work using the simulated wet-oxidation effluent stream, with a view to experiments later with more realistic feeds.

For similar reasons it would have been very difficult to conduct all of the UV/ozone contactor tests using reverse osmosis effluent. It would have been necessary to schedule runs and operate all the equipment simultaneously while monitoring the performance of the process. Consequently a separate study was conducted to determine the major constituents from the last reverse osmosis unit in order to simulate the feedwater for the UV/ozone contactor, and these results are also given in appendix B.

The process flow for these pilot plant tests is shown in figure 2. The processes shown here are nearly identical to those in the latter portion of the original process flow shown in figure 1 with the exception of the replacement of the screen filter with a clarifier. The reason for this change is explained in section 4.2.

As well as ensuring that the specifications given in appendix A could be met, additional objectives for these preliminary tests were as follows:

a) To determine an optimum PH value for best flocculation and separation for the lime treatment process (rapid mixer, flocculator, and clarifier).

b) To ensure that the stream after the cartridge filters and before the reverse osmosis machines has as low a value of suspended solids as possible (to prevent damage to the reverse osmosis membrane).

c) To determine if any PH adjustment of the clarified effluent stream would be required for safe and efficient reverse osmosis operations.

d) To obtain base-line performance data for the UV/Ozone process; to indicate viability of this process for the ESM application, and to facilitate design of a full-sized UV/Ozone contactor.

For most of the experiments, total organic carbon (TOC) and/or chemical oxygen demand (COD) were monitored for comparison with design objectives. These two parameters were chosen for analysis and design purposes since both provide an effective measure of the content of organic matter in a sample. The COD analysis determines the quantity of oxygen required for oxidation under specific conditions of oxidizing agent, temperature, and time. In TOC analysis, the organic carbon is converted to carbon dioxide by catalytic combustion and the quantity of carbon dioxide is measured. This quantity is directly proportional to the concentration of carbonaceous material in the sample.

4.2 Lime Treatment Tests

Tests were carried out at PH values of 9½, 10, 10½, and 11 in the rapid mixer in order to determine the optimum PH for flocculation and screen filtration. It was soon discovered that the screen filter was unsuitable at any PH as it broke up and redistributed the flocs instead of separating them out. Consequently a conventional clarifier was designed for the pilot plant tests and it performed well as was expected.

Analysis of the clarified effluent streams gave the values of suspended solids (SS), total organic carbon (TOC) and chemical oxygen demand (COD) as shown in table 4. Considering an expected combined experimental and analysis error of ±10%, these results indicate that there was no significant variation in any of the levels throughout this PH range. The data also show that the goal of reducing the COD to 2500 ppm was surpassed. Also the SS value, in the order of 25 ppm, was below the target of 80 ppm, and hence was sufficiently low to permit operation of the RO units without danger of membrane fouling from this residue.

Since the organic components of the simulated wet-oxidation effluent are unaffected by lime treatment, the reductions shown in TOC and COD must be attributable to reactions with the grey water simulation. Considering the ratios of flow rates of wet-oxidation and grey water effluent, and the observed reduction in TOC and COD, it can be shown that lime treatment can be expected to remove 75% of the TOC and COD of the grey water stream alone.

4.3 Reverse Osmosis Tests

Three RO units employing membranes of three different types (tubular, spiral wound, and hollow fibre) were operated in series at pressures of 900, 480, and 190 psi respectively. Experiments with the feed to the first RO unit from the clarifier had shown that adjustment of the PH of this stream to 5.5 by the addition of hydrochloric acid was necessary in order to prevent hydrolysis of the cellulose acetate membranes, and to prevent fouling of the membrane surface, particularly with calcium salts. Subsequent tests gave no indication of any fouling from the precipitation of any dissolved solids.

Tests were performed with all three units operating at the same water recovery rate*, for three different rates; 75%, 80%, and 85%. Analyses of feed, permeate, and concentrate streams for conductivity, TOC, and COD are given in table 5. As indicated by the reductions in conductivity, salt rejection efficiency was very high for each of the RO units with a total for the three units in the order of 90-95%.

The TOC and COD rejection efficiencies were in the order of 80%. This lower rejection value is most likely due to the low rejection efficiencies of methanol and acetaldehyde (0-30%) which were present in the simulated wet-oxidation effluent in sufficient quantity to give an initial COD of 300 ppm. Therefore the final RO effluent could not be expected to have a COD much below 300 ppm. For this reason, in determining the revised pro-

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* recovery rate: The ratio expressed as a percentage, of permeate-to-feed flow rates.

cess system consideration was given later to eliminating the methanol and acetaldehyde streams by some mechanism other than reverse osmosis.

4.4 UV/Ozone Contactor Tests

UV/ozone oxidation, specifically of refractory compounds, is a relatively new technique in the water treatment field, and there is relatively little data available on commercial equipment that is suitable for pilot plants or laboratory tests. Consequently, a UV/ozone contactor was designed and constructed at DCIEM. It was then necessary to carry out several experiments of a very preliminary nature in order to establish base-line performance data for the contactor. For more detailed information the reader is referred to appendix C which discusses at length the background to this treatment process, the design details of the contactor, the test procedures and results, and some conclusion. In general, however, it was shown that

1) The UV/Ozone treatment process performs according to its design objectives: specifically, for the best runs, the TOC of a 22 litre sample was reduced from 33 ppm to the objective of 5 ppm in less than one hour with moderate UV radiation and ozone rates (36 effective UV watts, and 10 grams/hr respectively). The effluent was clear, colourless and tasteless.

2) The use of UV radiation with ozonation can decrease oxidation time severalfold. However, certain combinations of fluid temperature, ozone rate, and UV radiation rate can actually increase the reaction time over that obtained using ozonation alone.

3) Fluid temperatures in the order of 45°C or less appear to promote faster reaction rates than those obtained at 60°C.

While more testing at different fluid temperatures, ozone rates and UV intensities should be carried out in order to optimize a final contactor design, data from the best test run indicate that a full-sized contactor for the ESM could easily be designed and constructed and would require 70 grams ozone/hr with a total UV bulb consumption of 800 watts. Further experiments and optimization might reduce both these rates.

5. Pilot Plant Tests: Municipal Sewage as Feed Supply

5.1 Scope and Objectives

In order to continue the verification of the treatment process, it was apparent that some consideration should be given to using a more realistic feed for the lime treatment process, particularly since at the time of this work the ORF had acquired for a short time a relatively large and continuous running wet-oxidation reactor which was well suited for our tests.

Consequently tests were conducted on all of the more important processes beginning with the wet-oxidation reactor using real sewage gathered from the city of Mississauga at an existing collecting point at an ORF laboratory. The wet-oxidation reactor used is shown in figure 3, and the process flow for this set of tests is shown in figure 4, in which the following minor changes were made from the original design in order to facilitate the experiments.

1) Solid waste (garbage) was not fed to the wet-oxidation reactor, since the provision of this waste feed stream would have required the acquisition and testing of the hammermill and the pump grinder. Considering the well-known performance of these two machines and the effectiveness of the wet-oxidation process in treating this relatively innocuous feed stream (compared to the black toilet water stream), it was not felt essential to test this portion of the process. Also, this approach allowed the liquid wet-oxidation effluent stream to be fed directly to the lime treatment equipment, eliminating the need for the vacuum filter at this time.

2) Grey water was simulated again as outlined in appendix B. Since this stream consists only of laundry, shower, and sink wastewaters which contain mainly detergents, soaps, and suspended solids, it is relatively easily and accurately simulated.

3) As determined in the lime treatment tests, a clarifier was used in place of a screen filter.

4) The evaporator for the concentration of the reverse osmosis residues was not tested.

In addition to verifying the process specifications, these tests had the following objectives:

1) To investigate the performance of the RO units with varying recovery rates, and to determine the maximum recovery rate before precipitation occurs on the membrane.

2) To determine whether any significant contaminants remained in the final stream which would require additional treatment.

3) To obtain a minimum of data to compare the performance of the UV/ozone contactor using this more realistic feed with the results found earlier using entirely simulated feed.

5.2 Tests with the Wet-oxidation Reactor

The sewage used as feed to the wet-oxidation reactor was obtained from a branch of a large municipal sanitary sewage line in the city of Mississauga. At this location the sewage would contain all of the grey and black (toilet) water from a large predominantly residential area. In order to extract the black water only for injection into the reactor, it was necessary to remove the grey water portion which would consist primarily of a dilute solution of soap and detergent in water. As an expedient and relatively efficient operation, the sewage was put through a double clarification and settling process to remove most of the water, with the dense sludge being drawn off and used as the black water feed to the reactor.

There were three prime objectives for the test runs on the wet-oxidation process:

1) To verify that the expected TOC and COD reductions (in the order of 75%) could be achieved.

2) To investigate the effects of PH, temperature, pressure, and the addition of a catalyst on the TOC and COD reductions.

3) To process a large quantity (1100 L) of sewage sludge for use in the pilot plant tests on the remaining downstream processes (i.e. lime, reverse osmosis, and UV/ozone treatments).

For objectives 1 and 2, and in preparation for objective 3, a small amount of sewage sludge was processed through two different wet-oxidation reactors, a two-litre batch reactor and a nine-litre semi-batch reactor. These two reactors had dissimilar operating procedures, each of which facilitated carrying out different portions of the experiments. The tests were carried out at various temperatures, pressures, with base and acid additives for PH control, and with and without a catalyst, copper oxide. A description of the reactors and the results of these tests is given in appendix D.

For objective 3, a continuous flow wet-oxidation reactor was used to process the 1100 litres of sewage sludge with no catalyst addition, and without any PH control. This reactor is similar in its operation and size to the reactor envisaged for the full size ESM, and is shown in figure 3. It operates at 2500 L/day, which is twice the flow rate required for the full size ESM process.

The data from these tests presented in appendix D show that the design objectives of a 75% reduction in TOC and COD are feasible at the standard operating pressure and temperature of a typical wet-oxidation reactor (600 PSI and 230oC) with a fluid retention time of 40 minutes. With the use of a catalyst such as copper oxide and acidification with sulphuric acid to PH3, the reaction can take place more rapidly, giving TOC and COD reductions in the order of 90% for the same retention times.

Alternatively this increased reduction rate indicates that for a given reactor size, retention time may be decreased, and hence flow rate increased, while still maintaining the desired TOC and COD reductions of 75%, provided that a catalyst and PH control are employed.

While longer retention times give greater reductions for a continuous flow process, they also would require the use of larger reactors. However, the object here is to reduce TOC and COD to a level just suitable for lime, reverse osmosis, and UV/ozone treatment in order to avoid excessively large and costly reactors.

5.3 Lime Treatment Tests

The effluent from the wet-oxidation reactor was mixed with simulated grey water producing a solution with a COD of 1600 ppm and a TOC of 500 ppm. After lime treatment to PH 10 followed by flocculation and clarification, the COD and TOC dropped to 500 and 150 ppm respectively, reductions of approximately 70%.

Suspended solids were again reduced to very low levels entirely suitable for RO processing.

Based on the previous tests using simulated wet-oxidation effluent, it had been determined that lime treatment gave TOC and COD reductions of approximately 75% in the grey water fraction. The organic components in the wet-oxidation effluent using sewage sludge feed contain intermediate and high molecular weight compounds which are susceptible to lime treatment. Considering this and the ratios of flow rates of wet-oxidation and grey water effluents along with the 70% reduction in TOC and COD found above, it can be shown that the TOC and COD of the wet-oxidation effluent portion was reduced by approximately 50%.

Thus for design purposes, TOC and COD reductions in the grey water and wet-oxidation effluent fractions can be expected to be 75% and 50% respectively.

5.4 Reverse Osmosis Tests

The same three RO units were used in series as before incorporating tubular, spiral wound, and hollow fibre membranes at pressures of 900, 480, and 190 psi respectively. Hydrochloric acid was used again to protect the membranes from fouling and hydrolysis, and there was no indication of precipitation onto the membranes during any tests, even at the 90% water recovery rate on the first RO unit which was subjected to the highest concentrations.

The experiments were performed with all three units operating at the same water recovery rate, for three different rates: 75%, 85%, and 90%.

Analyses of feed, permeate, and concentrate streams for conductivity, TOC, and COD are given in table 6. As indicated by the reductions in conductivity, salt rejection efficiency was even higher than in the previous tests, in the order of 96%-99%.

TOC and COD levels were reduced by 80%-90% of initial values, a slight increase over the previous tests with simulated wet-oxidation effluent. Assuming that the portion of the total COD attributable to methanol and acetaldehyde is the same as that of the simulated wet-oxidation effluent, then the feed COD due to these two contaminants would be in the order of 50-75 ppm, which is slightly less than the COD of the final RO permeate stream. Thus it is again evident that methanol and acetaldehyde will not be sufficiently rejected by RO treatment, and that some other technique must be devised for their removal.

5.5 UV/Ozone Contactor Tests

The majority of the tests investigating the effects of fluid temperature, UV radiation rate, and applied ozone rate on the oxidation rate were carried out previously using the simulated wet-oxidation effluent, and the results are given in section 4.4 and appendix C. However, four runs were conducted using the effluent originating from sewage sludge, and the results are shown in table 7. Comparison with figure C-9 shows that in each of these runs TOC was reduced at a faster rate than during the previous runs on simulated effluent at the same operating conditions. To some degree this is to be expected since the initial TOC levels (12 ppm at 85% and 21 ppm at 90% water recovery rates) were lower than the values for the simulated runs (33 ppm). Again, the contactor effluent was clear, colourless, odourless, and tasteless.

6. Revised Waste Treatment Process

6.1 Improvements on the Original Process

After examining the experimental test data and conducting preliminary product searches for suitable process equipment, a new revised treatment process was drawn up as shown in figure 5. Also shown are design objectives for the COD, TOC, and SS at various stages within the process. Minor changes have been made to some waste flow rates and their characteristics which reflect additional data obtained from the AVDP and other studies. The more significant changes which were made to the original process shown in figure 1 are as follows:

1) The sanitary waste rate was increased from 10.6 L/c-d to 12.6 L/c-d in order to account for the 2 L/c-d of human solid and liquid waste.

2) All glass and metal refuse would be separated out from the solid waste input stream. This could be readily accomplished at the first garbage collection point with the use of 2 receptacles, one for glass and metal refuse and one for all other refuse. This step was considered desirable as there are no reasonably sized or priced machines of the hammermill-shredder-macerator variety which could reduce the glass and metal portion of the solid stream to 1 cm particle size. Also the pump grinder could not have handled these particles without serious damage.

3) The solid (garbage) waste rate was reduced from 1 kg/c-d to 0.4 kg/c-d with a 26% moisture content in order to reflect data from a very thorough study of waste rates conducted by Forgie (32) at three northern settlements (see table 8), and in order to account for the separation and removal of the glass and metal refuse.

4) A conventional garbage compactor was included to reduce the volume of the glass and metallic refuse.

5) Product searches ruled out the use of a hammermill even for the remaining "soft" solids because of the large size, cost, and relatively poor final refuse form. However, there are several shredders and macerators available which appear ideal for treating these "soft" solids in preparation for the very effective pump grinding step.

6) The solid waste storage bin was placed after the shredder since all available shredders and macerators have very large capacities in excess of the ESM requirements, and also have hoppers to accommodate very short duration peak loads. It is expected therefore that as far as the user is concerned, solid waste brought to the ESM will be digested by the shredder-macerator instantaneously, and then stored for feeding to the black water storage tank as determined by the black water flowrate.

7) The vacuum filter was omitted as it had been included primarily to remove the ground glass and metallic solids.

8) As explained in section 4.2, the screen filter was replaced with a clarifier.

9) As explained in section 4.3, hydrochloric acid was added to the clarified effluent.

10) The second RO unit with the spiral wound membrane was not required in the final process.

11) The steam effluent from the wet-oxidation reactor was not mixed with the liquid wet-oxidation effluent and grey water streams. Instead, it was mixed with the concentrate from the first RO unit and sent to the evaporator as a refuse stream. The prime reason for this was to remove methanol and acetaldehyde from the process as 90% of these two contaminants originated in the steam phase from the reactor, and they would otherwise be very difficult to remove. Also, the heat in the steam phase could be usefully employed in the evaporator.

12) A storage tank was provided after the last RO unit to allow batch operation of the UV/ozone contactor.

13) A storage tank was provided after the UV/ozone contactor for load smoothing.

6.2 Process Description

Glass and metallic refuse is collected separately from other solid waste and fed to a compactor with a volume reduction ratio of 15:1. The remaining soft solids are fed to a machine of the shredder-macerator type which grinds the refuse to approximately 1 cm particle size, or to longer filaments. The effluent is mixed with the black water from the toilets and sent to a holding tank incorporating a submerged pump grinder which thoroughly macerates this stream to a slurry. Any glass or metallic particles which are inadvertently admitted to the shredder will not be drawn to the grinder, but will collect in the holding tank, to be manually removed periodically.

The pump grinder effluent is transferred to the wet-oxidation reactor in which high molecular weight organics are oxidized in a process similar to burning. (See appendix A for more details on the wet-oxidation reactor and process). This reactor would be approximately one half the size of the one used in the pilot plant tests shown in figure 3, and would incorporate three stirrers rather than the four shown. Additional equipment required for reactor operation would be a heat exchanger for transferring heat from the liquid wet-oxidation effluent to the waste reactor feed stream, and a 2 HP air compressor.

After the heat exchanger the the reactor liquid phase effluent is mixed with the grey water and undergoes rapid mixing with lime, flocculation and clarification in order to remove suspended solids. The clarified effluent passes through a cartridge filter to remove any residual solids. It is then acidified to PH 5.5 for RO membrane protection and sent to the two-stage RO unit to remove and concentrate soluble organics and inorganics. The first RO unit employs a tubular membrane and operates at a 90% water recovery rate. The concentrate from the first RO unit is mixed with the steam phase from the reactor and fed to an evaporator for volume reduction and concentration of this refuse stream. The evaporator gives off a low concentration water solution containing the methanol and acetaldehyde from the reactor steam effluent, and a high concentration sludge which is mixed with the clarifier sludge for disposal. The permeate from the first RO unit flows to the second RO unit which employs a hollow fibre membrane and operates at a water recovery rate of 75%. The concentrate from this second RO unit is recycled to the feed of the first RO unit. The permeate from the second RO unit flows to a holding tank before being processed in a batch operation by the UV/ozone contactor which destroys any residual organics. The resultant water is of potable quality, and is recycled within the ESM.

6.3 Process Equipment Specifications

(a) Compactor:

Capable of reducing 20 kg/day of glass and metal refuse through a volume reduction of 15:1. This quantity of refuse will be handled in relatively small packages of about 2 kg each. These packages must be compacted within one minute or less if possible as several people will require use of the machine in rapid succession. Small household and industrial compactors typically operate at ratios up to 20:1 and rates of 100 kg/min with typical dimensions of 0.6 m W. X 0.8 m L. X 1.8 m H.

(b) Shredder (macerator/crusher)

Capable of reducing 40 kg/day of "soft" refuse (i.e. typical household garbage excluding all glass and metallic refuse) to a particle or filament size with two dimensions of 1 cm X 1 cm maximum. Actual time required for the processing of typical 2-5 kg bags should be as short as possible, within one minute if practical. Consumption rates for the smallest available machines of this type are in the order of 10 kg/min. There are numerous different configurations available, but a space 1.2 m W. X 0.6 m L. X 1.2 m H. should suffice for preliminary design considerations.

(c) Pump Grinder

Capable of passing 1260 L/day of a solution with a maximum input particle or filament size of 1 cm X 1 cm, and producing an effluent with a maximum particle size of ½ cm. It is desirable that this unit be employed in a closed loop recycling system in order to allow several passes of the solution through the grinder to ensure small final particle size. This would require flow rates several times the design rate of 1260 L/ day, however, the smallest pump grinders available are capable of pumping in the order of 10,000 L/hr. This machine would be a submersible type and would occupy no additional floor area as it would be set within the black water storage tank.

(d) Wet-Oxidation Reactor

Complete with heat exchanger (heat transfer from liquid reactor effluent to waste input stream), 2 HP (minimum) air compressor, reactor feed pumps, controls, etc. To operate continuously at a temperature of 230°C and a pressure of 600 psi and a flow of 1260 L/day with a fluid retention time of 30-40 minutes. COD, TOC, and SS to be reduced as shown in figure 5. These machines are designed to order, and in particular the controls and monitoring equipment would be designed to meet the customers' requirements. It is estimated that all of the necessary equipment could be fitted within a volume of 3.3 m L. X 0.9 m W. X 1.8 m H.

(e) Lime Treatment

Lime slurry, rapid mixing (30 seconds detention time), flocculation and clarification equipment operating continuously to supply 5 kg of lime/day to a solution of 4460 L/day to maintain a PH of 10. The clarifier should reduce the SS level to less than 50 ppm with a daily sludge output of 8 kg solids in 60 L of fluid. TOC and COD to be reduce as shown in figure 5.

These machines are often complete packaged units of much larger capacity. For the ESM, a special low capacity design would be commissioned from a qualified manufacturer in the field. The dry lime storage, shaker, and feed bin, along with the rapid mixer, would occupy a space 0.6 m L. X 0.6 m W. X 1.8 m H. while the combined flocculator and clarifier would occupy a volume 0.6 m L. X 1.2 m W. X 1.8 m H.

(f) Cartridge Filtration

To remove suspended solids down to 5 microns for RO membrane protection. These are very inexpensive, and small (10 cm O.D. X 30 cm L.) and many varieties are available. RO units often are supplied with them as standard equipment.

(g) Reverse Osmosis

Two RO units in series; the first with tubular membranes and the second with hollow fibre membranes, to operate on feeds of 5740 L/day and 5170 L/day respectively. Each to run in a continuous mode with 90% and 75% water recoveries respectively with TOC and COD reductions as shown in figure 5. The two RO units will have dimensions of 0.9 m W. X 1.2 m L. X 1.8 m H. and 0.5 m L. X 0.5 m W. X 1.8 m H. respectively, and are both readily available.

(h) UV/Ozone Contactor

Capable of oxidizing up to 50 ppm of low molecular weight organic acids to a TOC and COD of less than 5 ppm and 10 ppm respectively. To operate as a batch process with a capacity of 3875 L/day (a minimum of several batches/day). The contactor could be designed at DCIEM, and would contain approximately 20 3-foot UV bulbs with a total power consumption of about 800 watts. It would occupy about 1/3 sq. m of floor space, and would require a separate ozone generator. Ozone generators complete with air dryers of the appropriate size (approximately 70 grams of ozone production per hour) are available, and would occupy a space of 2.4 m L. X 0.9 m W. X 1.7 m H.

(i) Evaporator

Capable of evaporating 825 L/day of a concentrated salt-soluble organic solution by the utilization of waste diesel heat. Evaporators of this type are often used for water purification on small water craft, and typically occupy a space of 0.6 m L. X 0.3 m W. X 0.6 m H.

7. Potable Water Treatment from External Source

It is forseen that any type of water source could be a candidate for the freshwater supply system: e.g. polluted lakes, rivers, or wells, brackish or sea-water, melted snow or ice, etc. It would be impracticle and inefficient at this time to design a treatment system capable of handling all types of source water found in the Arctic. Consequently a survey of all available processes for this purpose was undertaken with the intention of identifying the processes having the most flexibility and capability considering the quality of the feedwater used.

For relatively poor source water, the distillation/evaporation process was chosen as the most promising approach as it was capable of disinfecting, pasteurizing, and desalinating most streams encountered. Moreover commercially available units can operate on waste heat from diesel generator exhausts. For the ESM requirements, a diesel generator of only 25 kw capacity would be required to produce sufficient waste heat. Additional, though minor, equipment required for this process would be an activated carbon cartridge filter to improve taste and colour, and an ultra-violet sterilizer near the point of usage to provide further disinfection due to contamination during storage which could occur after the distillation/ evaporation process.

If the raw water source can provide relatively clean water, then it would be more economical to use a reverse osmosis unit preceded by a water softener and followed by an ultra-violet sterilizer.

8. Peripheral Facilities

After studying data from the AVDP and examining the various household water conserving devices now available, it became apparent that the waste treatment process equipment could be greatly reduced in size and cost by minimizing the per capita water demand rate. Consequently the toilets, showers, and laundry equipment recommended below for use in the ESM are of a type not usually employed in southern urban areas, although they have been extensively used for specific unique applications. With such devices, total water consumption has been reduced four-fold from 210 L/c-d to 47 L/c-d as shown in figure 6.

Wastewater Transport

The conventional method of collecting and transporting wastewater is by gravity-induced flow, a simple, dependable and economical method which requires large quantities of water and large pipe sizes. An alternative to this method is the vacuum sewer system in which slugs of wastewater are transported by air pressure rather than gravity. This allows the use of small piping and rises in pipe elevation in the flow direction, and greatly reduces the quantity of water required as a carrier. This type of system has been employed for more than ten years in northern settlements and for shipboard use. Two such systems are recommended for the ESM for the two separate streams, i.e. the black water and the grey water.

Toilets

A special toilet has been developed for the vacuum sewer system which uses approximately one tenth as much water as conventional toilets. Since toilets are responsible for 60% of normal household consumption, the saving here alone more than justifies the additional cost of the vacuum sewer system. As shown in figure 6, total toilet water consumption has been reduced from 122 to 11 L/c-d.

Showers and Saunas

The use of saunas has proved to be a good method of reducing shower water use in the AVDP where it was found that much of the actual bathing took place in the sauna with the showers used largely for rinsing. Shower consumption of 11 L/c-d has also been kept low by the use of specially designed shower heads which maximize flow dispersion and limit the flow rate.

Laundering

Laundry facilities exist which reuse some of the washwater, with a consequent small reduction in consumption.

9. Conceptualized Module Layouts

9.1 Process Equipment

Preliminary product investigations have established the approximate floor areas required for the treatment process equipment. The layout in figure 7 shows one very compact arrangement of the equipment within the rear half of three Hercules aircraft sized sub-modules joined together side by side, in order to facilitate rapid and economical transportation.

9.2 Peripheral Facilities

The layout shown in figure 8 is intended to indicate how a minimum facility module might be laid out within the front half of three sub-modules joined together, side by side, using the peripheral facilities described in section 8. Of course the actual number of facilities required will depend on several factors: e.g. the location chosen, whether the facility is temporary or permanent, the number and type of personnel (civilian, military and/or native), the method of waste disposal currently in use in the settlement, local acceptance of the sauna, etc. However, the actual number and mix of toilets, showers, etc. can easily be changed or increased with only a moderate increase in floor area, and with no change in size of the treatment equipment.

10. Costs

Existing Service Costs

For comparative purposes the following costs are presented for certain services for the community of IGLOOLIK (population 700) in the Northwest Territories. These costs are quite representative for many small northern settlements.

Electricity:	25¢/kwh
Fresh Water Delivery and Grey Water Removal:	2.2¢/L of fresh water delivered to holding tanks in homes. While of fair quality, because of frequent handling this water is always boiled before being used for drinking purposes. Grey water consists of dishwater and bathing and laundry waste water, and the cost of its removal from holding tanks in homes is included in this charge.
Human Waste Removal:	$1.25/honeybag removal by truck. The honeybag is a simple plastic bag receptacle used in toilets in homes, and lasts approximately 6 man-days.

Solid Waste (Garbage) Removal:	$1.25/45 gallon drum

Using this data, and assuming that 150 people were to use in their homes the same amount of water for the same level of service as has been designed for in the ESM, the total cost for the existing separate services in IGLOOLIK would be $330. per day. The relative contribution of the various components is shown in figure 9.

ESM Costs

A breakdown of the costs for each major item in the ESM is given in table 9, which was prepared after preliminary inquiries only had been made for each item. It is fully expected that the final individual costs will fluctuate but that the total value should not increase much above that shown. For most items product searches showed that the smallest available units had much more capacity than was required for the ESM. Therefore final capital costs may decrease if more suitable equipment can be found. Alternatively, larger populations may be supported by one ESM facility. However, as a first conservative approximation for a 150-man facility the estimated capital cost, as shown in table 9, is $257,000. Amortizing this over 15 years at 9% and adding electrical operating expenses of approximately $87 per day gives an ESM cost for fuel and capital repayment of $171 per day.

To this must be added the operation and maintenance costs. By examining the reports on five years of experience with similar systems in the Alaska Village Demonstration Project (in particular see reference #67), one can estimate that these latter costs should be about $147 per day. This gives a total daily ESM cost of $318. Figure 9 shows the relative contribution of the components of this total.

Comparison of ESM cost with existing service costs

As shown above, costs for the two methods of servicing are very close ($318 for ESM, $330 for the existing services). While the values used here are approximate only, as actual costs will fluctuate depending on location, time, population type and size, final design etc., existing costs for smaller settlements with ESM-sized populations of 150 would most likely be higher than those for IGLOOLIK with a population of 700. Also, as noted above, the ESM may be capable of servicing many more people depending on the performance of the final process equipment selected, thereby increasing its cost effectiveness further over that of the existing services.

In addition it should be stressed that two distinctly different types of service are being considered here. Existing service systems provide water and waste removal to and from homes with no treatment of any wastes. An ESM installation would require the use of a centralized facility in order to completely treat all waste streams.

11. Summary and Recommendations

As shown in figure 10, the ESM is designed to provide full water purification and waste treatment services for 100-200 people through the daily production of 4700 litres of potable water, 82% of which is recycled from garbage, human waste, and laundry, bathing, and toilet wastewaters. The remaining 18%, or 875 L/day, is supplied from separately treated source water drawn from an external raw water source for drinking and food preparation purposes only. This low demand rate from the environment is adequate for the population served, and represents only 4% of the average water requirement for southern urban populations using conventional water treatment installations; this reduction in consumption has been made possible by extensive use of recycling techniques, and by employing modern water conserving devices.

With a daily requirement of 350 kwh of electricity and 5 kg of lime, the module treats all of the garbage and human sanitary waste to produce a sterile residue of 20 kg/day of solids, and 885 litres of liquid.

For maximum utilization the module is designed to serve as a centralized facility to which all garbage and all human waste is carried or transported through a piped system. With the exception of water for drinking and cooking purposes, all other water consumption should occur at the facility in order to control the total consumption rate and to ensure collection of all waste water.

As shown in figure 11 all of the treatment equipment and the toilets, showers, saunas and laundry facilities can be fitted within three air transportable modules (Hercules Transportable Camp Units) which are purchased as empty shells and joined in the south to be outfitted and put into operation. These Camp Units measure 2.79 m W. X 2.59 m H. X 11.89 m L. and are shipped separately to be joined together again in the North to form a single facility 8.38 m W. X 2.59 m H. X 11.89 m L.

Amortizing the capital cost of the ESM and adding operation and maintenance expenses shows that the ESM should cost less than existing services in the north consisting of delivery and pickup of fresh water and waste by truck. The ESM has the added benefits of eliminating the need for dump sites which are a major source of disease and pollution, and of reducing the quantity of water required from limited water sources. Alternatively, larger populations can be supported by any existing water source.

The process design has proved to be sound and effective through the pilot-plant tests at DCIEM and subsequent analyses by the ORF, using municipal sewage as a feed and producing a clear, colourless, odourless, tasteless, sterile, non-toxic effluent entirely suitable for reuse. Selection of hardware has been carried out to the extent that the costs and layouts shown should not have to be significantly changed in the final design process.

In view of the advantages of the wet-oxidation process over other combustion based sterilization methods, the competitive cost of servicing with the ESM compared with conventional service costs in the north, the benefits to the environment and health of communities by eliminating hazardous dump sites, and the success of the pilot plant tests, it is clear that the foundation has been laid for the next major phase of the program. This would be to construct and check-out the operation of the ESM at DCIEM in preparation for a trial period in a northern community.

12. BIBLIOGRAPHY

The following bibliography is intended for use as a guide to some of the more pertinent work which has been carried out, concerning not only data relating directly to this study, but also to most matters connected with the implementation of the Environmental Service Module in the Arctic community. Thus the objective is to provide a broad background to enable the reader to see the completed mozaic within which the Service Module is only a small but vital piece. Seven topic areas have been identified below, and a short description of the more specialized areas of interest is given within each section.

A. Background Data on the ESM Specifications
B. Peripheral Hardware Facilities
C. Installations Employing Recycled Water
D. The Arctic Community
E. Water Sources, Collection and Distribution Methods
F. Arctic Waste and Sewage Collection and Disposal Methods
G. Miscellaneous Topics

A. Background Data on the ESM Specifications

This section was included to give the reader a feeling for the raison d'etre, and the magnitude of the specifications for the ESM, and in particular to enable him to become familiar with the water consumption rates for various purposes, and effluent rates of all types, e.g. solid (garbage) waste, and liquid and solid sanitary waste.

Reference is also made to material which would supply data of a much more detailed nature than was required for this stage of the programme, and it was provided here mainly for future reference.

Water Consumption Rates

The Department of National Defence recommends at least 450 L/c-d of water for all purposes in static locations (100). In the field, 23 L/c-d is considered adequate, while 5 L/c-d is the absolute minimum. Another source suggests 2 L/c-d as a minimum, and 9 L/c-d minimum for all purposes, (133), both in the field. NATO standard suggests 5 L/c-d in emergency conditions (112). Water requirements for the U.S. Navy in polar camps are set out in (123) and actual rates for numerous uses are tabulated. Detailed rates for a large (6000 man) portable military camp are given in (119).

The Canadian government has investigated actual water consumption rates in various communities in the Canadian Arctic. The most comprehensive of these studies gives the rates for 10 specific communities, which range from 3.9 to 450+ L/c-d, depending in part on the method of delivery and household distribution system employed (16). These figures are in agreement with another comprehensive study in which the effects of increasing the frequency of trucked deliveries, constructing piped systems, and the upgrading of plumbing facilities are discussed as in (33), and (121).

Rates for an experimental washcar-incinerator complex are given in (35), and (128).

Studies carried out in Alaska are described in (3, 74, 125), in which rates from 7 to 490 L/c-d are reported. The Alaska Village Demonstration Project is based on a concept similar to that of the ESM, and recommended consumption rates for various purposes have been determined, totalling about 38 L/c-d for all uses combined. (70, 94, 97, 66, 67, 64).

Studies of typical urban water consumption rates are given in (8, 71, 44).

Water Quality Standards

For wastewater disposal, guidelines for northern Canadian communities are set out in (108), and additional information may be found in (107). Similar data for Alaska wastewaters is given in (2).

Canadian drinking water standards are given in (99, 107) and additional information may be found in (110, 124, 13). Comparable Canadian Armed Forces standards are given in (100, 133), and NATO standards are in (113, 112). Potable water standards published by U.S, Public Health Service and the World Health Organization are given in (102, 8, and 103), respectively. Potable and wash water quality standards for the U.S. space program are given in (80, 118, 120, 132). Separate standards for each of bathing water, general washing and cleaning, irrigation and toilet flushing are given in (8).

Liquid and Solid Waste Effluent Rates

Solid (garbage) municipal waste rates are given in (33, 134, 85, 37) and range between 0.5 and 2.3 kg/c-d. The most comprehensive study on small Canadian Arctic communities established solid waste rates of .5 to .7 kg/c-d, (32). Studies carried out in Alaska mainly on fixed military installations, gave rates of 1-3 kg/c-d (18, 127).

Examples of typical liquid and solid sanitary waste rates from various sources may be found in (8, 32, 39, 58, 92, 123, 128, 30, 131, 10, 67).

Waste Analysis

The diagnosis of the constituents of solid (garbage) waste from large municipal sources is given in (33, 34, 134, 85). Comparable data for smaller Arctic communities is given in (32, 39). The main difference in content is a higher percentage of tin cans and a lower percentage of paper products in the Arctic communities. This difference also affects the calorific values of waste from each source. Excluding sanitary waste, calorific values for all other types of waste are given in (33, 134), as approximately 4,300 calories/gm (dry) from municipal sources, and as 3,050 calories/gm (dry) in (32, 70), from Arctic communities.

Analysis of laundry, shower and/or toilet wastewaters is given in (66, 67, 51).

Human waste analysis are contained in (35, 36, 58, 92, 100, 103, 123, 128).

B. Peripheral Hardware Facilities

This section provides a source of material for describing the various types of peripheral facilities and plumbing fixtures which are commercially available and provide the interface between the ESM treatment processes and the users.

Material on specific makes of toilets can be found in (114, 29, 20, 39, 42, 43, 75, 123) and further information on the evaluation of various types is given in (5, 8, 32, 35, 70, 97, 121, 89, 114, 29, 101). Some operating and capital costs information is supplied in (8, 20, 39, 42, 75).

A very complete study of urban household plumbing fixtures is given in (8) in which as well as minimum flush toilets, the author discusses urinals, automatic clothes washers, dishwashers, and limited flow valves for showers and basins.

C. Installations Employing Recycled Water

These installaions are in general not yet proved for widespread use, although numerous temporary and partial systems have been built and tested. The recycled water may originate from any one of several sources e.g. black and/or grey effluent, and may be reused for flushing purposes only if in a relatively impure condition, or, if of high quality, for all purposes, including drinking.

Of particular relevance to this study is the work carried out by the U.S. Environmental Protection Agency in the Alaska Village Demonstration Project and the Alaska Safewater Project, which saw the construction and operation of a number of facilities similar in nature to that proposed for the ESM (70, 94, 97, 66, 64, 67, 51). Wastewater was treated to varying degrees and in several facilities was recycled and reused for laundry water and flush water.

A wastewater treatment system is being developed for the U.S. Army Medical Service with the goal of producing water of potable quality (20, 121). Wastewater reclamation for laundry use is also being used in conjunction with the Bare Base water and sewage systems for the U.S. Air Force (91, 119).

For total service integration beyond the scope intended for the ESM, the U.S. Dept. of Housing and Urban Development is developing a Modular Integrated Utility System (MIUS) to generate electricity, recover waste heat, treat the water supply, incinerate solid waste and treat liquid waste with recycling of the effluent for all purposes except drinking, (11, 56, 62). Additional information on a similar project is given in (22).

Reclamation of municipal wastewater at Lake Tahoe in the United States produces water of potable quality. However, it is not used for drinking purposes, the objective of the treatment system being to enable safe discharge of the wastewater into the lake without increasing eutrophication (63).

Research on recycling water for shipboard use is presented in (54, 88).

Portable work camps employing recycled wastewater for shower and toilet flushing uses are also currently being tested, (20, 35, 98).

Further information on the types of processes which have been researched primarily for recovery and production of potable water for manned space flights may be found in (59, 80, 92).

D. The Arctic Community

Attempts at improving living conditions in the Canadian Arctic have frequently failed because of a lack of understanding of the root causes of the problems involved, and the constraints placed on solutions by severe climatological and economic conditions. In order to provide insight in this area, the following literature is suggested: literature which describes that portion of the lifestyle which is affected by the environment and in particular the lack of adequate sanitation and water supply services, (16, 20, 21, 48, 49, 84, 121, 85, 101. 41).

Literature of a comparable nature specifically for Alaskan communities is given in (2, 3).

E. Water Sources, Collection and Distribution Methods

Reference is made here to literature on water supply systems, or the lack of such, mainly in small Arctic communities.

Water is normally obtained from lakes or rivers, (40, 101, 3, 38, 23, 133), the melting of ice or snow, (3, 6, 23, 38, 124, 101, 78, 125) or salt (sea-water) or brackish ground water (3, 123, 125, 101). Chemical analyses of municipal water supplies and surface waters in the Arctic are given in (86, 72). Computer printouts of more recent data may be obtained from the Inland Waters Directorate, Environment Canada.

Distribution of the water may be by means of utilidors (40, 20, 21, 23, 38, 49, 109, 121), trucked delivery systems (14, 16, 20, 21, 23, 48, 49, 121, 40), or by individual effort in the smallest communities.

F. Arctic Waste and Sewage Collection and Disposal Methods

The emphasis here is on the methods employed by people in the small settlements in the Arctic, and therefore conventional municipal-type treatment processes have been excluded from consideration.

For solid waste collection the commonly accepted method involves gathering the waste in drums or bags to be picked up by trucks (1, 16, 21, 32, 132, 39, 121, 128, 129, 126). For sewage, the most common techniques employed are: honey bags, (plastic containers), (126, 16, 20, 21, 32, 121, 12, 81) pump-out tanks, (32, 121, 128, 1, 129) piped systems, (5, 20, 74, 121, 128, 1, 129) and utilidors (20, 23, 49, 109, 121, 129).

The ultimate disposal of these wastes may be accomplished by open burning in dump areas (16, 39, 126), digestion in lagoons (sewage oxidation ponds), or low swamp areas (17, 20, 23, 31, 39, 45, 46, 74, 100, 109, 1, 79, 110, 121, 128, 129) landfill, (18, 39, 100, 130, 1, 126) or by incineration, (18, 20, 33, 34, 35, 39, 57, 81, 83, 127, 128, 130, 1, 129, 126).

G. Miscellaneous Topics

Information on the desalination of sea water is given in (115, 122).

A description of the various treatment systems which have been considered and used for the treatment of shipboard wastes before discharging is given in (4, 54, 76, 88).

The effect of the Arctic Environment on pathogenic organisms and the spread of infectious diseases is discussed in (7, 41, 55).

Specialized sewage treatment facilitites for permafrost areas using modification of conventional systems is presented in (69, 73).

Some additional background material consulted in developing the ESM treatment process, and concerning specific hardware items necessary for operation of an automated, full-sized ESM may be obtained from (9, 12, 19, 26, 28, 50, 61, 68, 87, 116).

A survey of Antarctic water supply and waste disposal practices is given in (25), and a very thorough bibliography on waste disposal and treatment in permafrost areas is given in (82). A more recent symposium covering these and additional topics, and specifically describing the current state of the art in Canada was given by the Environmental Protection Service in 1976 (Utilities Delivery in Arctic Regions). (135).

A comprehensive and concise general description of water quality parameters and their measurement, and conventional sewage treatment processes may be found in (24, 53).

The experimental use of ultra-violet radiation with ozonation for the destruction of refractory compounds and bacteria is discussed in (53, 60, 95, 96, 136, 137).

Complete literature on the wet-oxidation process and its use in treatment systems is given in (15, 52, 77, 111, 123, 76).

In addition to these topics, further information may be obtained from "A bibliography of Arctic Engineering" (47). Canadian government involvement in Arctic programs is outlined in "Government Activities in the North" for the years 1971 (104), 1972 (105), and 1973-4 (106). Statistical data for the smaller Arctic communities may be found in "Population: Unincorporated Settlements" (117).

REFERENCES

1. Alter, A.J., "An Evaluation of Waste Disposal Practices in Alaskan Villages". Symposium on Wastewater Treatment in Cold Climates, pg. 1-28, E.P.S. Report 3-WP-74-3, March 1974.

2. Alter, A.J., "Sewerage and Sewage Disposal in Cold Regions", Cold Regions SCience and Engineering Monograph III-(5b, Oct. 1969).

3. Alter, A.J., "Water Supply in Cold Regions", Cold Regions Science and Engineering Monograph III - (5a, Jan. 1969).

4. Ard, R.W. Jr., and Scarano, T.S., "Marine Wastewater Treatment Systems", Env. Sci. Tech., 8, 219 (1974).

5. Averill, D.W. and Heinke, G.W., "Vacuum Sewer Systems", DIAND, Northern Science Research Group, Sept. 1974.

6. Awano, S. and Maita, S., "Cold and Hot Water Making Equipment Utilizing the Exhaust Gas Energy of Diesel Engines Coupled with Electric Generators", paper presented at the Symposium on Antarctic Logistics, National Academy of Sciences, Washington D.C. 1963.

7. Babbott, J.G., et. al., "Arctic Environment and Intestinal Infection", Amer. J. Med. Sci., 231, 338 (1956).

8. Baily, J.R. et. a., "A Study of Flow Reduction and Treatment of Wastewater from Household", Water Pollution Control Res. Ser. No. 11050, FKE, Dec. 1969.

9. Bennet, B., "Continuous On-Line Monitoring of Total Organic Carbon", Air Force Civil Engineering Centre, Tyndall Air Force Base, Fla., Aug., 1975.

10. Best, C.H. and Taylor, N.B., "The Physiological Basis of Medical Practise". Williams and Wilkins Co., Baltimore, Md. 1966.

11. Boegly, W.J., et. al., ORNL-HUD-MIUS-16. "MIUS Technology Evaluation: Collecting Treatment and Disposal Liquid Wastes".

12. Botros, M., and Best, W., "Laboratory Results of Laundry Wastewater Treatment", U.S. Army Facilities Engineering Sup-Port Agency, Ft. Belvoir, Va., April 1977.

13. Bovet, E.D., "Economic Concepts and Techniques Pertaining to Water Supply, Water Allocation, and Water Quality", U.S. Army Engineering Institute for Water Resources, Ft. Belvoir Va., Dec., 1975.

14. Boyd, W.L. and Boyd, J.W., "Water Supply and Sewage Disposal Development in the Far North", Journal of American Water Works Association, V. 57, July 1965.

15. Bridges, E.W. and Fassel, W.M., "Pilot Plant Demonstration of Wet Oxidation for Treatment of Shipboard Wastewaters", Final report on U.S. Coast Guard Contract DOT-CG 31323-A by Barber Colman Co., Feb. 1974.

16. Cadario, P.M. and Heinke, G.W., "Revised Draft, Manual for Trucking Operations for Municipal Services in Communities in the Northwest Territories", Dept. of Civil Engineering, U. of T., Oct. 1972.

17. Clark, S.E. et. al., "Biological Waste Treatment in the Far North", Federal Water Quality Administration, College, Alaska, June 1970.

18. Comen, J.B., "Solid Waste Disposal in Permafrost Areas", paper presented at the Second International Conference on Permafrost in Yakutsk, July, 1973.

19. Cunningham, M.L., "Submarine Solid Waste Compactor/Encapsulator Evaluation", Naval Ship Engineering Centre, Philadelphia Div., Philadelphia, Pa., July, 1975.

20. Deans, B. and Heinke, G.W., "Household and Community Waste Disposal Systems for Northern Communities", Dept. of Civil Engineering, University of Toronto, Feb. 1972.

21. Deans, B. and Heinke, G.W., "Water Supply and Waste Disposal for Frobisher Bay, N.W.T.: A Conceptual Look at Alternate Systems: Dept. of Civil Engineering, University of Toronto Feb., 1972.

22. Demetroulis, N.M., "Technical Review and Analysis of the Total Utility Demonstration Plant Design and Operational Concept", U.S. Army Facilities Engineering Support Agency, Ft. Belvoir, Va., Sept., 1976.

23. Dickens, M.B., "Water Supply and Sewage Disposal in Permafrost Areas of Northern Canada", National Research Council, Div. of Building Research.

24. Dolivo-Dobrovolskiy, L.B., Kulskii, L.A., "Chemistry and Microbiology of Water", Cold Regions Research and Engineering Lab, Hanover, N.H., Dec. 1975.

25. Drobny, N.L., "Survey of Antarctic Water Supply and Waste Disposal Facilities, Practices, and Problems". Naval Civil Engineering Lab., Port Hueneme, Cal., Report #TN-N-708, April, 1965.

26. Echelberger, W.F. and Tenney, M.W., "Automation of Water Supply Systems", Army Construction Engineering Research Lab., March, 1975.

27. Eden, G.E., Truesdale, G.A. et al., "Water from Sewage Effluents". Chem. & Ind. 1517, 1966.

28. Ehrlich, K., Klein, E., Smith, J.K., "Development of an On-Line Biological Detector", U.S. Army Medical Research & Development Command, Washington, D.C., July, 1976.

29. Eklund, L.T., "The Non-Flush Toilet is Possible", Water and Pollution Control Journal, Feb. 1974.

30. Fair, G.M. and Geyer, J.C., "Water Supply and Wastewater Disposal", John Wiley & Sons Inc., New York, 1954.

31. Fisher, C.P., "Water Stablization Ponds in the Canadian North", Paper presented at the International Conference on Water for Peace, Washington, D.C., May, 1967.

32. Forgie, D.J.L., "Characterization of Solid Wastes from Three Northern Communities", Internal Report to be published, Water Pollution Control Directorate, Environment Canada.

33. Friedrich, F.W., "Equipment for Incineration of Municipal Waste", Dept. Energy, Mines and Resources, Mines Branch, Ottawa, Technical Bulletin, TB 132, April 1971.

34. Friedrich, F.W., "The Incineration of Polymers - A combustion Engineers Viewpoint", Dept. Energy, Mines and Rsources, Mines Branch, Ottawa, Technical Bulletin TB 135, April 1971.

35. Given, P.W. and Chambers, H.G., "Work Camp Sewage Disposal Washcar, Incinerator Complex", Internal Report to be published Water Pollution Control Directorate, Environment Canada.

36. Goldblith, S.A. and Wick, E.L., "Analysis of Human Fecal Components and Study of Methods for their Recovery in Space Systems", United States Air Force, Aeronautical Systems Division. Tech. report #61 - 419, Aug. 1961.

37. Graf, R.O., Whittenberger, W.W., "Models for Predicting Solid Waste Generation at Selected Military Facilities Based on Facility Parameters", Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, Jan. 1975.

38. Grainge, J.W., "Water Supplies in the Central and Western Canadian North, Journal of American Water Works Association, Volume 51, Jan. 1959.

39. Grainge, J.W., Edwards, R., Heuchert, K.R. and Shaw, J.W., "Management of Waste from Arctic and Sub-Arctic Work Camps" Environmental Social Program, Northern Pipelines, DIAND Report #73 - 19, Sept. 1973.

40. Grainge, J.W., "Arctic Heated Pipe Water and Waste Water Systems", Water Research, Pergamon Press V. 3, pp. 47-71, 1969.

41. Grainge, J.W., Shaw, J.W., "Community Planning for Satisfactory Sewage Disposal in Permafrost Regions", Second Int. Symposium or Circumpolar Health, Nordic Council for Arctic Medical Research, Finland, June 1971.

42. Grainge, J.W., Shaw, J.W. and Slupsky, J.W., "Report on Toilet Units", Div. of Public Health Engineering, Dept. National Health and Welfare, Manuscript Report Nr-71-2, Dec. 1, 1971.

43. Grainge, J.W. and Slupsky, J.W., "Report on Toilet Units", Div. of Public Health Engineering, Dept. National Health and Welfare, Manuscript Report #NR-68-4, April 1, 1968.

44. Haney, P.D. and Hamann, C.L., "Dual Water Systems", American Water Works Association, Vol. 57, No. 9, Sept., 1965.

45. Hartland-Rowe, R., "Use of Swampland as a National Sink for Receipt of Sewage Effluent", Environmental Social Program. Northern Pipelines, DIAND, Report #73-15, Sept., 1973.

46. Hartland-Rowe, R. and Wright, P.B., "Swamplands for Sewage Effluents: Final Report", Environmental Social Program, Northern Pipelines DIAND report #74-4, May, 1974.

47. Heinke, G.W., "Bibliography of Arctic Engineering", Northern Science Research Group, DIAND, Nov. 1972.

48. Heinke, G.W., "Report on Municipal Services in Communities of the Northwest Territories", DINA Report #NSRG 73-1.

49. Heinke, G.W., "Solid Waste Disposal in Communities of the Northwest Territories", Dept. of Civil Engineering, U. of T., Feb., 1973.

50. Hinterberger, J.A., Lindsten, D.C. and Ford, A., "Use of Reverse Osmosis and Ultrafiltration for Removing Micro-organisms from Water", Army Mobility Equipment Research and Development Centre, Ft. Belvoir, Va., Sept., 1974.

51. Hypes, W.D., Batten, C.E., Wilkins, J.R., "The Chemical/Physical and Microbiological Characteristics of Typical Bath and Laundry Waste Waters", NASA TN D-7566, Langley Research Centre, Hampton, Va., March 1974.

52. Jagow, R.B., "A Study to Evaluate the Feasibility of Wet-Oxidation for Ship board Wastewater Treatment Applications", Final Report on U.S. Coast Guard Contract DOT-CG-23034-A, by Lockheed Missiles and Space Co., Jan., 1974.

53. Klatzenstein, L.B., and Braswell, J.A., "Virus Elimination in Water and Wastewater", Naval Coastal Systems Lab., Panama City, Fla., Jan., 1976.

54. Lederman, P.B. and Librizzi, W.I., "Review of Environmental Protection Agency Research in Waste Treatment for Water Craft", paper presented at the Intersociety Conference on Environmental Systems, San Diego, California, July 16-19, 1973.

55. Legros, P.G., "Viruses in Polar Sanitation: A Literature Review", Naval Civil Engineering Lab., Port Hueneme, Cal. Dec., 1966.

56. Leighton, G.L., "The Modular Integrated Utility System-A New Approach to the Supply of Utility Services", paper presented at the 8th Intersociety Energy Conversion Engineering Conference, Philadelphia, August 13-17, 1973.

57. Logan, S.A., Obert, E.G. and Palovic, A., "Sewage Disposal at 60oC", Wastes Engineering, V.32, N. 130, 1961.

58. London, S.A. and Bieverdorf, F.W., "A Study of Microbiological Waste Treatment Techniques", Air Force Systems Command, Technical Documentary Report #AMRL-TDR-62-142, Nov. 1962.

59. London, S.W., and West, A., "Microbiological Criteria for Aerospace Potable Water Systems", Air Force Systems Command, Technical Report #AMRL-TR-67-37, Sept., 1967.

60. Mauk, C.E., Prengle, H.W. and Payne, J.E., "Oxidation of Pesticides by Ozone and Ultraviolet Light", U.S. Army Mobility Equipment Research and Development Command, Ft. Belvoir, Va., Report #7206, July, 1976.

61. McGarry, M.G., "The Reclamation of Drinking Water from Sewage", U.S. Army Research and Development Group (Far East), San Francisco, Feb., 1975.

62. Miller, A.J., et. al., "Technology Evaluation for MIUS", paper presented at the 8th Intersociety Energy Conversion Engineering Conference, Philadelphia, August 1317, 1973.

63. Moyer, H.E., "Water Reclamation". The Military Engineer V-60 N.I., Jan-Feb., 1968.

64. Myers, C.E., Wright, D.R., Mitchell, M.A. and Puchtler, B., "The Alaska Village Demonstration Projects", Arctic Bulletin, Fall Issue, 1973.

65. Nehlsen, W.R., "Polar Camp Water Systems", U.S. Naval Civil Engineering Laboratory, Technical Dept. R-122 (1960).

66. Puchtler, B. and Reid, B.H., "The Alaskan Villiage Demonstration Project", The Northern Engineer, V. 7, N. 2, 1975.

67. Puchtler, B., Reid, B. and Christianson, C., "Water-Related Utilities for Small Communities in Rural Alaska", U.S. EPA Corvallis, Oregon, #EPA-600/3-76-104 Sept., 1976.

68. Puzatkina, L.A., "Purification of Waste Waters by Filtration Through Finely Dispersed Activated Carbon", Army Foreign Science and Technology Centre, Charlottesville, Va., Nov. 1974.

69. Reed, S.C. and Buzzell, T.P., "A Sewage-Treatment Concept for Permafrost Areas", National Academy of Sciences Pub. #2115, Washington, pg. 706-712, 1973.

70. Reid, B.H., "Alaska Village Demonstration Projects: First Generation of Integrated Utilities for Remote Communities", U.S. Environmental Protection Agency, Arctic Environmental Research Laboratory, College, Alaska, Working Paper #22, 1973.

71. Reid, G.W., "Projection of Future Municipal Water Requirements", Southwest Water Works Journal, March 1965.

72. Reid, R.W., Block, H.O., and Korchinski, M., "Water Quality Studies in the McKenzie Drainage Basin", Dept. of Environment, Water Quality Branch, July, 1974.

73. Reid, S.C. and Crowther, A.V., "Single Tank Secondary Sewage Treatment for the Arctic". Cold Regions Research Symposium 21st. Alaska Science Conference, Univ. of Alaska, 1970.

74. Ryan, W.L., "Design and Construction of Practical Sanitation Facilities for Small Alaskan Communities", paper presented at the Second Conference on Permafrost in Yakutsk, July, 1973.

75. Rybcznski, W. and Ortega, A., "Stop the Five Gallon Flush", Minimum cost Housing Studies, McGill University, 1973.

76. Scarano, T.S. and Ard, R.W. Jr., "Coast Guard Research and Development in Shipboard Wastewater Treatment", paper presented at the SAE-ASME-AIAA-ASMA-AICHE Intersociety Conference on Environmental Systems, San Diego, California, July 16-19, 1973.

77. Schatzberg, P., Jackson, D.F. and Kelly, C.M., "Experimental investigations of the Wet Oxidation Destruction of Ship-Board Waste Streams", U.S. Naval Ship Research and Development Centre, Materials Dept., Oct., 1974.

78. Slaughter, C.W., Mellor, M., Sellmann, P.V., Brown, J. and Brown, L., "Accumulating Snow to Augment the Fresh Water Supply at Barrow, Alaska", Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Jan., 1975.

79. Sletten, R.S. and Uiga, A., "Wastewater Treatment in Cold Climates", Cold Regions Research and Engineering Lab., Hanover, N.H., 1976.

80. Slonim, A.R., Roth, A.J., Hearld, A.B., London, S.A. and West, A., "Potable Water Standards for Aerospace Systems", Aerospace Medicine, Aug., 1967.

81. Smith, D.W. and Straughn, R.O., "Refuse Incineration at Murphy Dome Air Force Station", Arctic Health Research Centre, U.S. Public Health Service, Fairbanks, Alaska, 1971.

82. Snodgrass, M.P., "Waste Disposal and Treatment in Permafrost Areas", Dept. of Interior, Washington, D.C., March 1971.

83. Straughn, R.O., "Evaluation of Refuse Incineration at Murphy Dome Air Force Station", Arctic Health Research Centre, U.S. Public Health Service, Fairbanks, Alaska, June 1970.

84. Taylor, E.G., "An Arctic Water Supply System", Canadian Section Conference, American Waterworks Assoc., 22 April, 1968.

85. Tester, F.J. "Attitudes, Values, Communication Principles, and the Analysis of Waste Management Policy for Cold Climates", Master's Thesis, University of Calgary, Calgary Aug., 1975.

86. Thomas, J.F.J. and Gale, R.M., "Industrial Water Resouces of Canada", Water Survey Report #15, Inland Waters Directorate, Dept. of the Environment.

87. Torian, R.L., "Solid Waste Management: Foreign Research and Development", Army Foreign Science and Technology Centre, Charlottesville, Va., Nov., 1974.

88. Van Hees, W. and Constant, A.E., "Shipboard Sanitary Waste Treatment/Management Systems", paper presented at the Intersociety Conference on Environmental Systems, San Diego, Cal., July 16-19, 1973.

89. Van Hees, W. and Gills, L.C., "Laboratory Evaluation of the GATX Evaporative Toilet System", Naval Ship Research and Development Centre, Report #3948, July, 1973.

90. Vilee, C., "Biology", W.B. Saunders Co., Philadelphia, Pa., 1967.

91. Vlahakis, V.G., "Air Mobile Wastewater Reclamation Unit, 200 Hour Service Test", Air Force Civil Engineer Centre, Tyndall, A.F.B. Feb., 1975.

92. Wallman, H. and Barnett, S.M., "Water Recovery Systems (Multi Variable)", General Dynamics Corp., Wright Air Development Div., WADD Technical Report #60-243, March 1960.

93. White, L.A. and Spence, M.R., "Persistance of Human fecalborne Bacteria on the Tundra", D.R.E.S., Dept. of National Defence, May, 1974.

94. Wright, D.R. "Integrated Utilities for Remote Alaskas Villages", paper presented at the 8th Intersociety Energy Conversion Eng. Conference Proceedings, Aug., 1973.

95. Zeff, J.D., Shuman, R. and Alhadeff, E.S., "UV-Ozone Water Oxidation/Sterilization Process", U.S. Army Medical Research and Development Command, Washington, D.C. Report #1501, Dec. 1975.

96. Zeff, J.D. et. al., "UV-Ozone Water Oxidation/Sterilization Process", U.S. Army Medical Bioengineering Research and Development Lab., Ft. Detrich, Md., Nov., 1976.

97. "Alaska Village Demonstration Project: Report to the Congress". U.S. Environmental Protection Agency, Office of Research and Development, July, 1973.

98. "Arctic Utility Systems", Compro Pacific Inc. Seattle.

99. "Canadian Drinking Water Standards and Objectives, 1968", Dept. of National Health and Welfare and the Canadian Public Health Association, April, 1969.

100. Canadian Forces Publication - 213.

101. Design Manual: Cold Regions Engineering", NAVFAC DM-9, Dept. of the Navy, Alexandria, Va., March, 1975.

102. "Drinking Water Standards", Public Health Service, U.S. Dept. of Health, Education, and Welfare, 1962.

103. "Environmental Health Engineering Handbook - Water Pollution". Aerospace Medicine, Dept. of the Air Force, Army and Navy, Aug. 14, 1969.

104. "Government Activities in the North, 1971". Advisory Committee on Northern Development, DIAND.

105. "Government Activities in the North, 1972". Advisory Committee on Northern Development, DIAND.

106. "Government Activities in the North, 1973-4". Advisory Committee on Northern Development, DIAND.

107. "Guidelines for Water Quality Objectives and Standards". Technical Bulletin #67, Inland Waters Branch, Dept. of the Environment, 1972.

108. "Interim Guidelines for Wastewater Disposal in Northern Canadian Communities", Environment Canada, Water Pollution Control Directorate, June 1974.

109. "International Symposium on Wastewater Treatment in Cold Climates". University of Saskatchewan, Aug. 22-4, 1973.

110. "Manual for Public Health Inspectors", Canadian Public Health Association, 9th edition (revised) 1961.

111. "Materials for Wet-Oxidation Processing Equipment", National Materials Advisory Board, Nov., 1973.

112. "Minimum Standards for Water Potability", STANAG-2136, NATO, Military Agency for Standardization, Oct. 1974.

113. "Minimum Standards of Water Potability (Short and Long Term Use)", QSTAG-245, NATO, Military Agency for Standardization.

114. "A Minimum Water Toilet Fixture", U.S. Dept. of Agriculture, San Dimas, Cal., #2300, March, 1973.

115. Office of Saline Water, U.S. Dept. of the Interior, Washington D.C., Annual Report, 1960.

116. "The Operational Evaluation of a Commercial Garbage Compacter", Final Report, Project OPVAL/SE 412, Jan., 1974.

117. "Population Unincorporated Settlements", Statistics Canada, 1971.

118. "Recommended Tentative Standards for Washwater in Manned Spacecraft", Advisory Centre on Toxicology, NAS-NRC, Dec. 1971.

119. "Report on Engineering Design Study for the Development of Bare Base Water and Sewerage Systems for the U.S. Air Force Systems Command", Aeronautical Systems, Div. Wright Patterson Air Force Base, Ohio, Dec., 1968.

120. "Report of the Panel on Potable Water Quality in Manned Spacecraft", Committee on Toxicology, NAS-NRC, Aug. 1972.

121. "A Review of the Proposed Water and Sanitation Policy with Recommendations on Implementation", Associated Engineering Service Ltd., Aug., 1973.

122. "Saline Water Conversion", Advances in Chemistry Series #27 American Chem. Soc., 1960.

123. "Sanitary Waste Disposal for Navy Camps in Polar Regions", Clark and Groff Engineers, Salem, Oregon, May, 1962.

124. "Sanitation Manual for Isolated Regions", 5th Edition, Health and Welfare Canada, Health Protection Branch.

125. "Science in Alaska", paper presented at the Eleventh Alaskan Science Conference, 1960.

126. "Solid Waste Management in the Canadian North", Stanley Assoc. Engineering Ltd., Edmonton, Alta., March, 1973.

127. "Solid Waste Management in Cold Regions", State of Alaska Dept. of Health and Welfare, Alaska Water Laboratory, College Alaska, Aug., 1969.

128. "Some Problems of Solid and Liquid Waste Disposal in the Northern Environment", Environmental-Social Program, Northern Pipeline, Report #74-10, July 1974.

129. "Symposium on Wastewater Treatment in Cold Climates", EPS 3-WP-74-3, Water Pollution Control Directorate, Environment Canada, March, 1974.

130. "Technical Evaluation Study: Solid Waste Disposal, Fort Greely, Alaska", Corps of Engineers, U.S. Army, Office of the District Engineer, Anchorage, Alaska, July, 1972.

131. "Waste Recovery Processes for a Closed Ecological System", National Academy of Sciences, National Research Council Publication 898, Washington, D.C., 1961.

132. "Water Quality Standards for Long-Duration Manned Space Missions", Report of an ad Hoc Panel, Space Science Board of the National Academy of Sciences, Sept., 1967.

133. "Water Supply and Petroleum Installations", Military Engineering Vol. 6, WO #7489, 1956.

134. Western Canada Water and Sewage Conference, Proceedings of the 25th Annual Conventions, Winnipeg, Manitoba, Sept., 19-21, 1973.

135. "Symposium on Utilities Delivery in Arctic Regions", Environment Canada, Edmonton, Alberta, March, 1976.

136. Hewes, C.G., et al., "Oxidation of Refractory Organic Materials by Ozone and Ultraviolet Light", U.S. Army Mobility Equipment Research and Development Centre, Ft. Belvoir, Va., Nov., 1974.

137. Prengle, H.W., et al., "Ozone-U.V. Process Effective Wastewater Treatment", Hydrocarbon Processing, V. 54 N. 10, 1975.

Appendix A

Preliminary Design of Waste Treatment Process

Process Description (see figure 1)

The solid and honey-bucket wastes are moved to a hammermill where they are ground to a small fraction of their initial bulk. The material then moves to a storage tank which receives the black water (sewage) from toilets. A pump grinder macerates and transfers this material to the wet-oxidation reactor, a horizontal, compartmentalized, individually stirred autoclave operating at a temperature of 230°C and a pressure of 600 psi. Air or oxygen is added to the liquid within the reactor which is agitated vigorously and flows from one compartment to the other consecutively, and is retained for a total of 30-40 minutes. (See figure 3 for a photograph of a typical wet-oxidation reactor).

Wet-oxidation is a chemical reaction occurring in a liquid phase between oxygen and suspended or dissolved combustible matter. Thermodynamically such a reaction is similar to that of simple burning in that the products and heat liberated are the same. High molecular weight organics are oxidized to carbon dioxide and water and other low molecular weight compounds such as acetic acid or calcium acetate.

The reaction is exothermic and, provided sufficient organic matter is present, the heat liberated is sufficient not only to maintain a self-sustaining reaction, but also to provide excess heat for energy recovery. In wet combustion, the reaction occurs and the energy is liberated in the water phase with no barrier to the heat transfer, hence steam is produced with the highest degree of efficiency. The solids in the effluent are stable and easily compacted to only a few percent of the original solids volume. The elimination of air pollution is ensured because the products are automatically and thoroughly scrubbed, and complete sterilization of the effluent is guaranteed.

The liquid and steam phases exiting from the reactor are heat exchanged with the incoming waste in order to help sustain combustion.

The liquid phase, which contains a high content of inorganic residue, passes through a vacuum filter to remove solids, and this stream is mixed with the steam phase and the grey (laundry, bathing, washing, and dishwashing) water. Lime is added in a rapid mixer, and a flocculator is used to promote coagulation of the suspended material.

The effluent after lime treatment is passed through a screen filter to achieve particle separation down to the 50 micron range. Cartridge filters are employed to polish the effluent further and to ensure against the build-up of lime scale.

The clarified effluent then passes through a three-stage reverse osmosis unit to remove and concentrate the soluble organics and inorganics at an 80%-90% rejection level. (Neutralization prior to reverse osmosis may be required to obtain the required removal of ammonia). The first two reverse osmosis concentrates are sent to an evaporator to further concentrate this residue stream. The resulting distillate is sterile and can be discharged safely to the environment.

The permeate (filtrate) from the last reverse osmosis unit passes through a combination ultra-violet (UV)/ozone contactor in which the residual organics are oxidized to carbon dioxide and water. The resultant water is of potable quality, and can be recycled for use in toilets, showers, sinks, laundry, etc.

Process Equipment Requirements

In addition to the following, design objectives for chemical oxygen demand (COD) and suspended solids (SS) are given in figure 1 for each treatment process.

Hammermill

Capable of handling 100 kg/day of garbage containing various types of materials including glass and tin cans. Size reduction to about 1 cm diameter.

Pump Grinder

Capable of handling 0.7 L/min of a 28% solution with a maximum particle size of 1 cm diameter. Size reduction to 0.5 cm diameter is required.

Wet Oxidation Reactor

Complete with heat exchanger, stirrers, compressor, pumps etc., to handle 0.7 L/min of solution. Operating temperature and pressure to be in the order of 230°C and 600 psi. Retention time to be 30 to 40 minutes.

Vacuum Filter

Capable of 95% solids capture from an 8% solution at a flow rate of 0.5 L/min. Concentration of coke to 30% moisture.

Lime Treatment

Lime slurry, rapid mixing (20 seconds detention time), and flocculating equipment (15 minutes detention time) to supply 7 kg/day of lime to a solution of 3.5 L/min to obtain PH 11.

Screen Filter

Capable of removing solids down to 50 microns with a sludge concentration of 5%-10%.

Cartridge Filters

To remove solids down to 5 microns, some organics, and lime scale. To be employed as an effluent polishing step prior to reverse osmosis.

Reverse Osmosis

Capable of handling 3.5 L/min of a solution containing 1500 ppm salt and 2500 ppm organic calcium salts. Filtrate (purified) water production of 3.0 L/min minimum. The purified water is to contain less than 50 ppm organics and negligible salt.

UV/Ozone Contactor

Capable of oxidizing up to 50 ppm of low molecular weight organic acids in a stream of 3.0 L/min. Employed to provide final disinfection of the water as well.

Evaporator

Capable of handling up to 1.0 L/min of a concentrated salt soluble organic solution. To produce a maximum volume of distillate and a minimum of concentrated residue. It would be preferable to utilize waste heat (diesel, or other type) to operate the process.

Appendix B

Simulation of Grey Water, Wet-oxidation, and Reverse Osmosis Effluent Streams

Grey Water Effluent

This stream is made up of two wastewater streams having the same flowrates: a) laundry effluent, and b) shower and sink effluents. The following list of the major constituents of these two streams was obtained from published literature.

Laundry Wastewater

Detergent	≃	2800 ppm
Suspended Solids	≃	900 ppm
Salts (Primarily NaCl)	≃	400 ppm
Oils	≃	160 ppm

Shower and Sink Wastewater

Soap	≃	800 ppm
Oil	≃	40 ppm
Suspended solids	≃	100 ppm

Adding these two streams together in equal quantities gave the following concentrations for the grey water constituents:

Grey Water Effluent

Detergent	≃	1400 ppm
Suspended solids*	≃	500 ppm
Soap	≃	400 ppm
Salts (primarily NaCl)	≃	300 ppm
Oil†	≃	100 ppm

Wet-Oxidation Effluent

Previous work at ORF has identified a large number of possible constituents of wet-oxidation effluent depending on the feed stream, reactor pressure, temperature, residence time, etc. After analyzing the ESM input feed stream, the following list of wet-oxidation effluent consitituents was determined.

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* e.g. Bentonite Powder

† e.g. Corn Oil

Detergent	≃	1100 ppm
Acetic acid	≃	1000 ppm
Soap	≃	320 ppm
Propionic acid	≃	250 ppm
Methanol	≃	220 ppm
Acetaldehyde	≃	100 ppm
Oil†	≃	80 ppm
Butyric acid	≃	50 ppm
Formic acid	≃	50 ppm
Glutamic acid	≃	50 ppm
Glycerol	≃	30 ppm
Ammonia	≃	300 ppm
Salts (primarily NaCl)	≃	250 ppm
Suspended Solids*	≃	900 ppm

Samples of grey water and wet-oxidation effluent were prepared in the proportions given by the ESM specifications according to the two lists above, and an analysis of the solution gave the following:

Chemical Oxygen demand	≃	3000 ppm
Total organic carbon	≃	800 ppm
Suspended solids	≃	900 ppm
Total solids	≃	4600 ppm
Total volatile solids	≃	1400 ppm

The values of chemical oxygen demand (COD) and suspended solids which had been estimated for this mixture in the original design were 3101 ppm and 1074 ppm respectively. These values compared well with the analysis above, providing some verification that the simulation is realistic.

Reverse Osmosis Effluent

This stream should have a COD of approximately 40, with 30 ppm attributable to calcium acetate and 10 ppm to methanol. Traces of acetaldehyde, formic acid, propionic acid, and acetone in the range of 0.1-1.0 ppm were ignored for the simulation. Thus the simulated stream should consist of 56 mg. calcium acetate/L plus 5 mg. methanol/L. Analysis of solutions with these constituents gave a COD of 33 ppm.

* e.g. Bentonite Powder

† e.g. Corn Oil

Appendix C UV/Ozone Treatment Process

C-1 Background

The use of UV radiation with ozone for the oxidation of refractory organics, such as calcium acetate in the ESM treatment processes, is a relatively new development when compared to other treatment processes. In fact there is no commercially available UV/ozone contactor available at the present time.

Photo-chemical molecular excitation by UV radiation has been reported to increase oxidation rates up to 10,000 fold, making possible short reaction times for various applications. However, experimental determination of optimized reaction rates has been hindered by the large number of parameters and phenomena involved, some of which act in opposition to each other.

Figure C-1 shows results from Prengl (136) indicating the very large effect of UV radiation on the destruction of acetic acid by ozone. More information is available which attempts to show the effects of agitation, temperature, ozone flow rate, etc. on the oxidation rate for various compounds. Although both increased temperature and UV radiation accelerate the oxidation rate, they also accelerate the auto-decomposition of ozone which is normally unstable, reverting to oxygen. For any given situation then, experimentation is often required in order to determine the optimum operating conditions.

C-2 Contactor Design

Based primarily on data from Prengl (136) and Hewes (137), the contactor was designed to treat approximately 20 litres of RO effluent to COD less than 10 ppm and a TOC less than 5 ppm in approximately three hours in a batch process. Provision was made to maintain the fluid temperature at either 45°C or 60°C (±1°C) and to maintain a fixed UV bulb temperature in order to ensure constant UV production. Total UV energy input could be set at either 1.6 or 0.8 watts/L, and ozone flow rate into the fluid at 3, 6, or 10 grams/hr.

A photograph of the contactor which was designed for these requirements and constructed at DCIEM is shown in figure C-2. A top view of the contactor column assembly showing the assembly within the lucite column is given in figure C-3. This closed loop device consisted of a vertical lucite column with a stainless steel interior liner. A quartz tube containing three UV bulbs was placed within the stainless steel liner in such a way that the fluid could circulate from the bottom to the top of the column in the cavity between the stainless steel and the quartz. Air was circulated through the quartz tube from top to bottom at a precise rate in order to maintain a fixed bulb temperature of 35°C during all tests, and readings of the UV intensity were taken through a quartz window in the lucite with two UV meters operating at two different wavelengths (365 and 254 nanometers) within the UV portion of the spectrum. No significant variation in intensity was observed during the tests.

The fluid entered the column at the base after passing through the anodized aluminum and lucite vortex generator which fed ozone into the stream in fine bubbles. The fluid exitted at the top of the column to pass through PVC tubing to the thermostatically controlled heating and cooling coils, on past the sample injection mechanism, and down to the stainless steel pump where it was again fed to the vortex generator.

C-3 Test Procedure

In view of the rapid decomposition of ozone to oxygen particularly under the influence of UV radiation, and other factors affecting the oxidation reaction and the dissolved ozone concentration, a precise sequence of steps was carefully prepared and followed throughout this test program. These measures were necessary in order to ensure the achieving of steady-state conditions within known time frames, and to ensure consistent results. The following is an outline of these steps.

1) The contactor was filled with fresh distilled water.

2) The fluid pump and ozone generator were turned on and the water temperature brought to the desired level.

3) While the water temperature was being adjusted, the ozone generation rate was also adjusted by ozone sampling and rate determination using the iodometric method. The ozone was vented to the atmosphere while the rate was being set.

4) After the desired fluid temperature had been achieved, the ozone was fed to the vortex generator and the UV bulbs were turned on. Fluid samples were withdrawn at regular time intervals to ascertain the dissolved ozone concentration and thus determine when steady state conditions had been achieved.

5) Using the injection system, a known quantity of calcium acetate and methanol was injected into the contactor to give a solution of the desired concentration, and so simulate the effluent from the last RO unit. For studying TOC variations, the time of injection was defined as time zero.

6) Fluid samples were withdrawn at regular time intervals for TOC, PH, and dissolved ozone analysis.

C-4 Test Results

Preliminary tests were undertaken using distilled water in the contactor in order to determine the effect of fluid temperature, ozone flow rate, and UV intensity on the steady state dissolved ozone concentration level, and in order to determine the times required to achieve these levels. This was necessary to verify that the vortex generator was functioning reasonably well and consistently, and to assist in running and interpreting later tests on simulated feeds from the RO units. The results of these tests are shown in figures C-4 through C-8 inclusive.

Figure C-4 shows that even at the maximum ozone rate, the ozone dissolved in the fluid was only a small fraction of the maximum possible (approx. 100 mg/L) indicating that the vortex generator could be improved for this application, and that faster oxidation times might then be achieved.

The data from figures C-5 through C-8 suggests that a UV radiation level of 0.8 watts/L reduces the dissolved ozone concentration level by 50% at all ozone rates and temperatures studied. Increasing the radiation level to 1.6 watt/L reduced the ozone concentration by 90% at all temperatures and ozone rates.

The tests with simulated RO effluent were carried out at UV intensities of 1.6 and 0.8 watts/L, temperatures of 45°C and 60°C, and at ozone rates of 6 and 10 grams/hr. The time history of the variation in TOC from this set of tests is shown in figures C-9 and C-10. The objective of these tests was to reduce the TOC to less than 5 ppm. Examination of these data indicates the following:

1) UV radiation alone is ineffective.

2) In general ozonation alone gives a slow-reaction rate compared with that obtained when some optimum UV radiation level is applied simultaneously. However, application of UV radiation at certain levels can actually increase reaction time over that obtained without UV radiation.

3) Without UV radiation, ozonation alone could only reduce the TOC to 5.0. The data appear to indicate that no further reduction will take place within any reasonable time.

4) Overall best performance was obtained at 45°C and an ozone flow rate of 10 grams/hr.

5) At the higher ozone rate (10 gm/hr), increasing the temperature to 60°C from 45°C increased the reaction time.

C-5 Conclusions

The UV/ozone treatment process is effective and can be usefully employed within the ESM treatment process. The tests above showed that the TOC level of 22 L. of simulated RO effluent could be reduced from 33 ppm to less than 5 ppm within one hour with moderate and appropriate UV radiation and ozone rates.

While there is a need for more experimentation to explore a wider range of temperatures, UV and ozone rates, the data collected also show the importance which UV radiation exerts in increasing the oxidation rate.

Concerning temperature, it would appear that 45°C gives faster reaction times than 60oC, and that more data should be obtained at lower temperatures.

For UV radiation, 1.6 effective watt/L should be considered a minimum, with more tests at higher levels.

Similarly, an ozone rate of 0.5 grams/litre-hour should be considered a minimum, with more tests at higher levels in order to achieve or approach more closely, the maximum concentration of dissolved ozone.

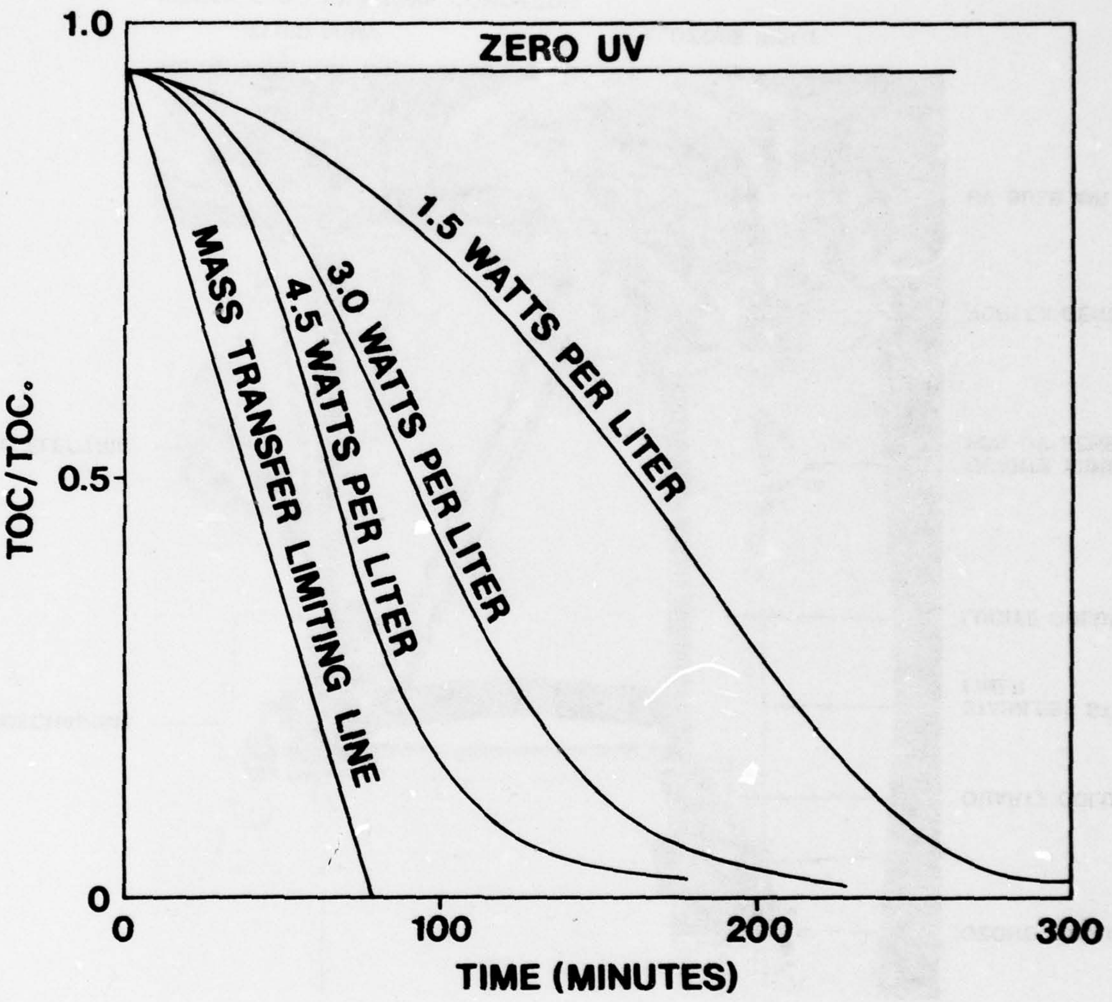


FIGURE C-1: U.V.-OZONATION OF ACETIC ACID (from Prengle,(136) et. al.)

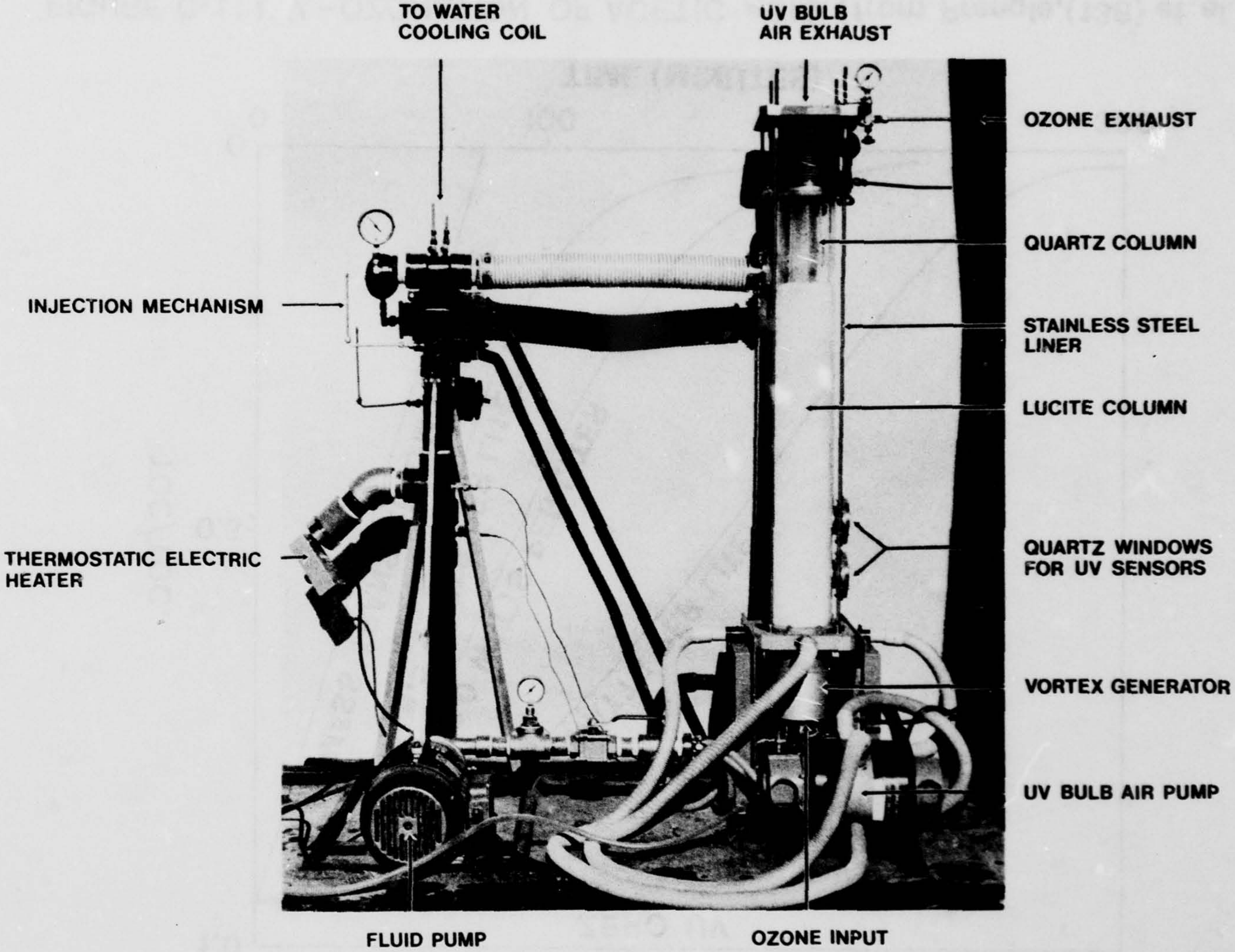


FIGURE C-2 : UV/OZONE CONTACTOR

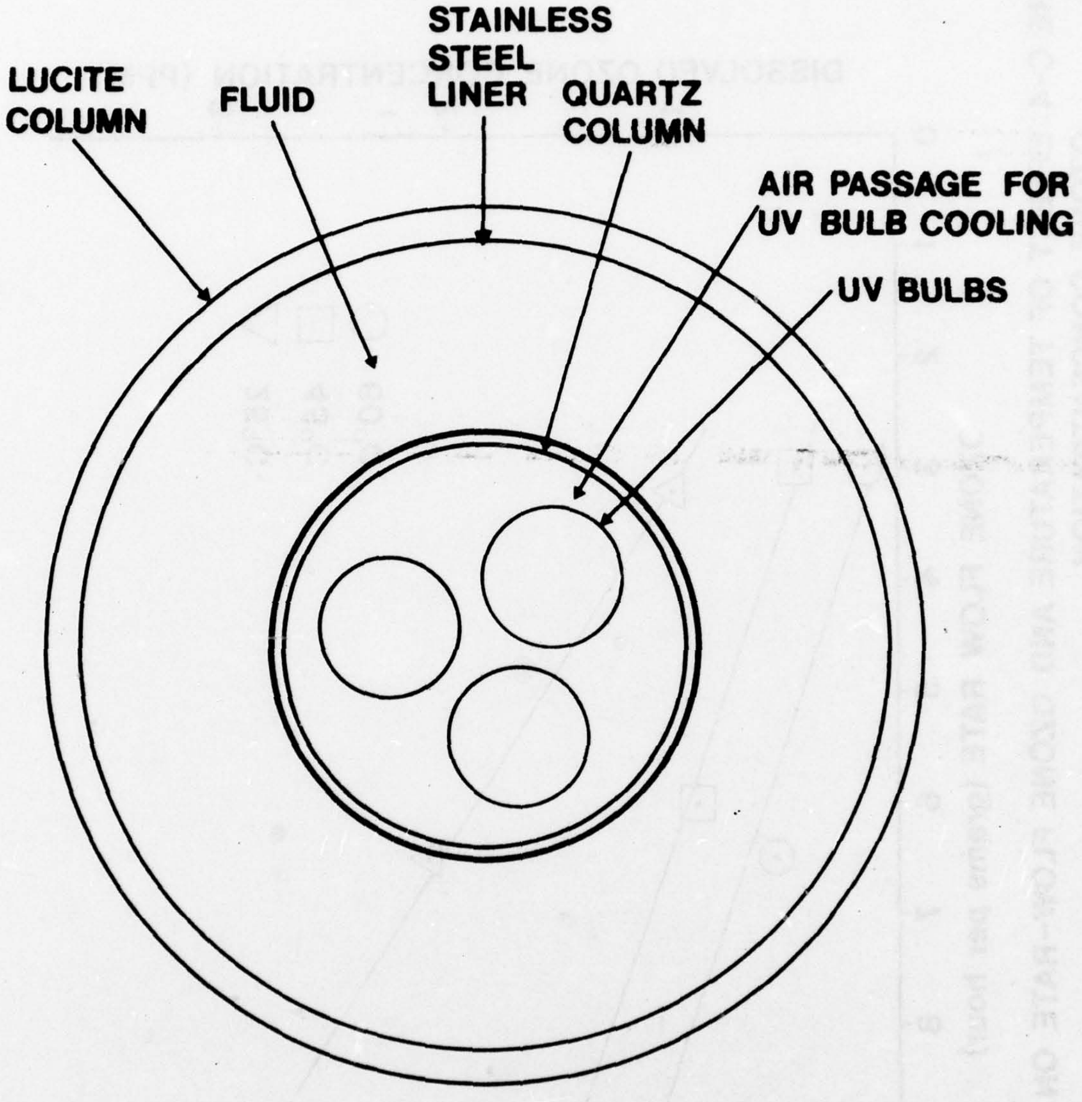


FIGURE C-3: TOP VIEW OF CONTACTOR COLUMN ASSEMBLY

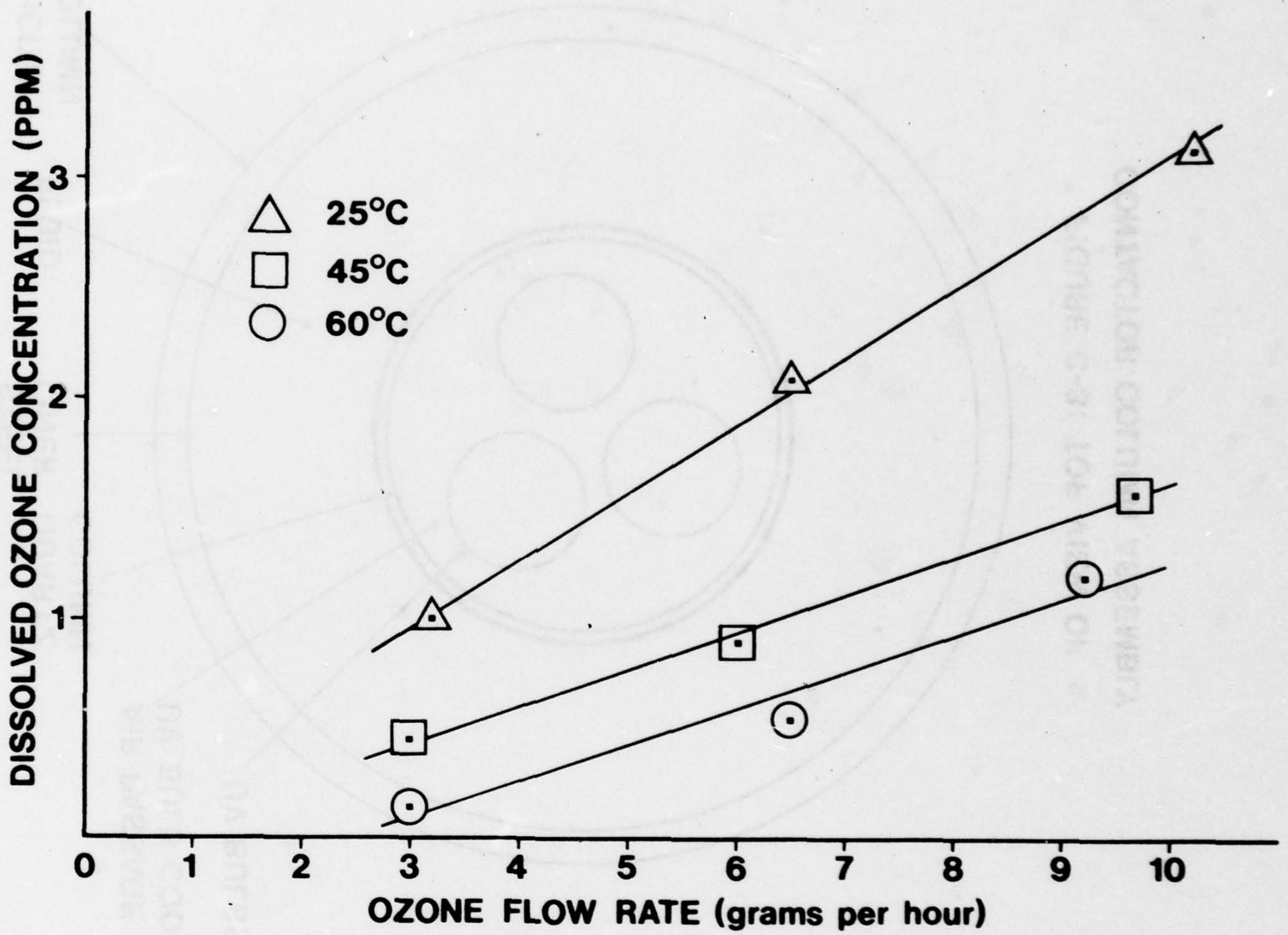


FIGURE C-4: EFFECT OF TEMPERATURE AND OZONE FLOW-RATE ON DISSOLVED OZONE CONCENTRATION

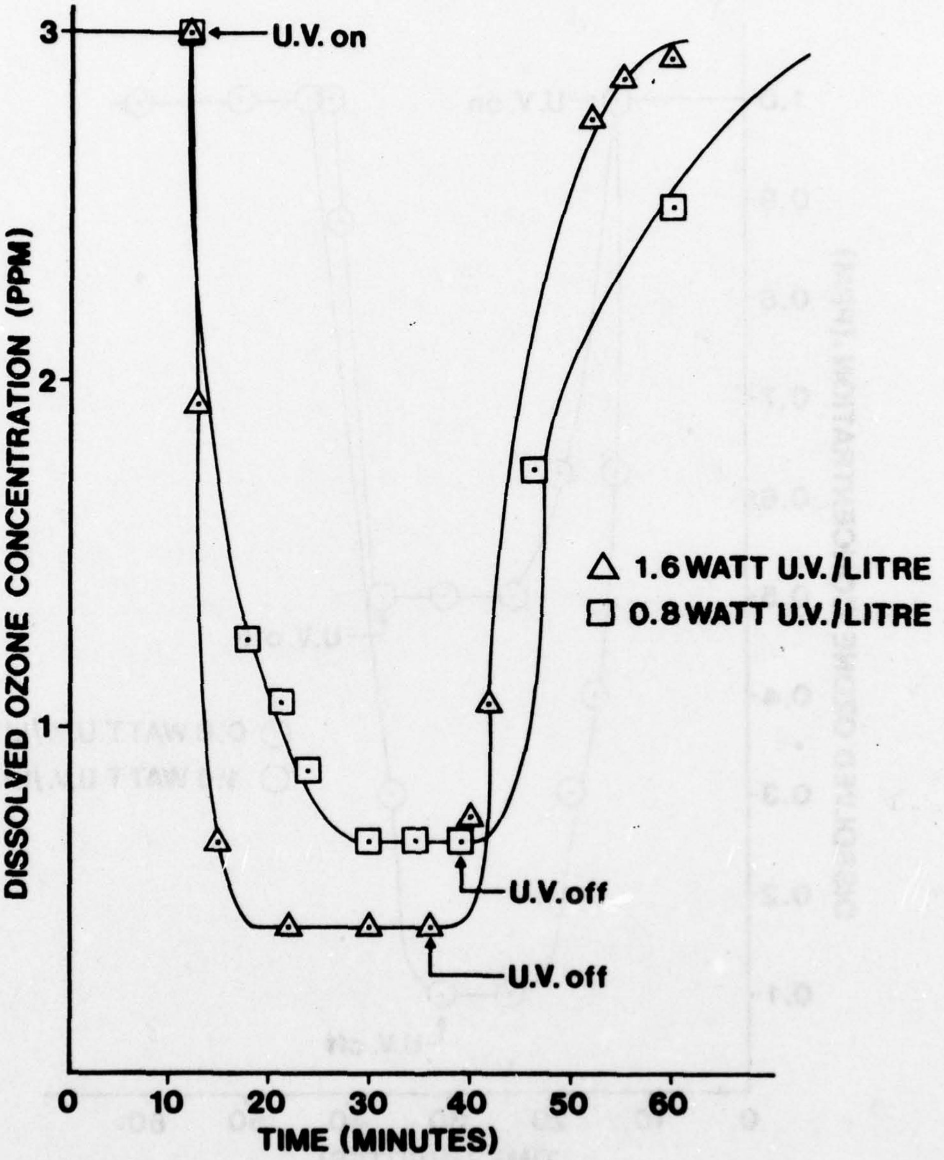


FIGURE C-5: EFFECT OF U.V. ON DISSOLVED OZONE CONCENTRATION AT 25°C, $10 g \cdot hr^{-1}$ O_3 FLOW

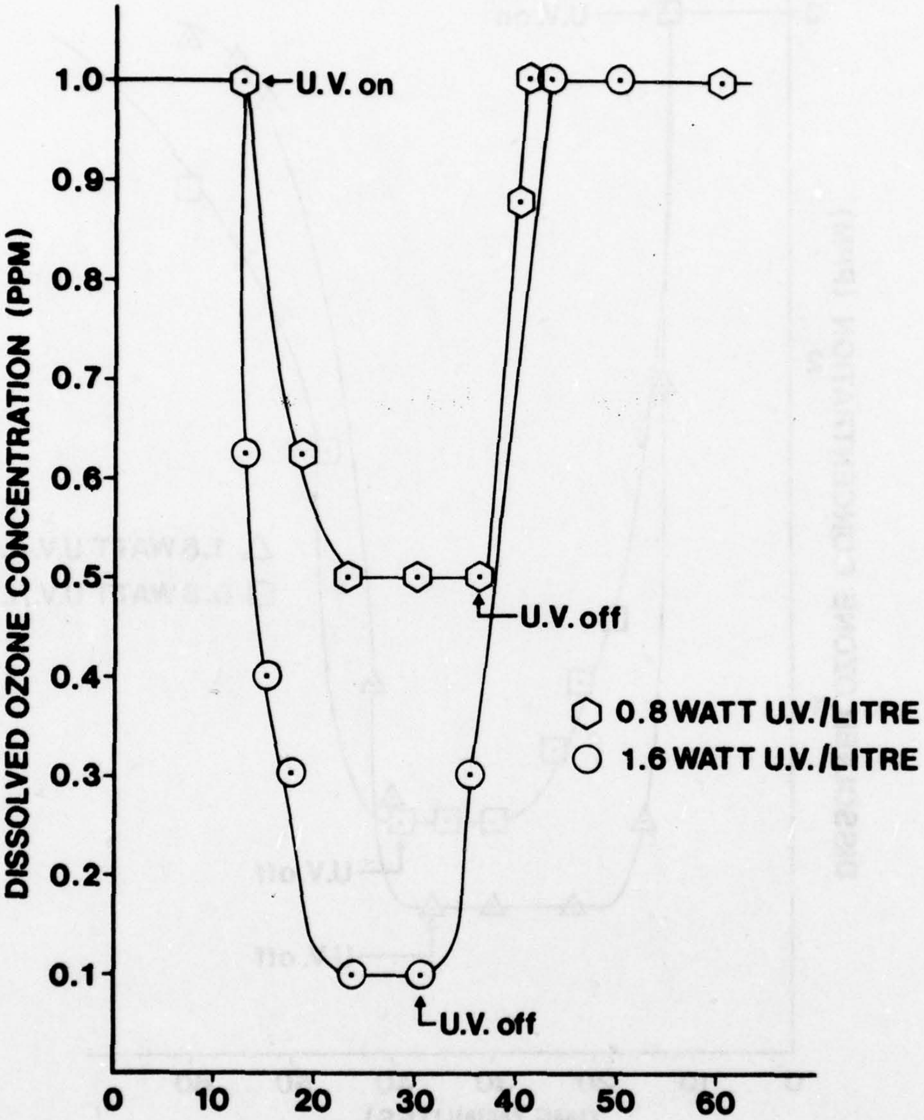


FIGURE C-6: EFFECT OF U.V. ON DISSOLVED OZONE CONCENTRATION AT 25°C, $3g \cdot hr^{-1}$ O_3 FLOW

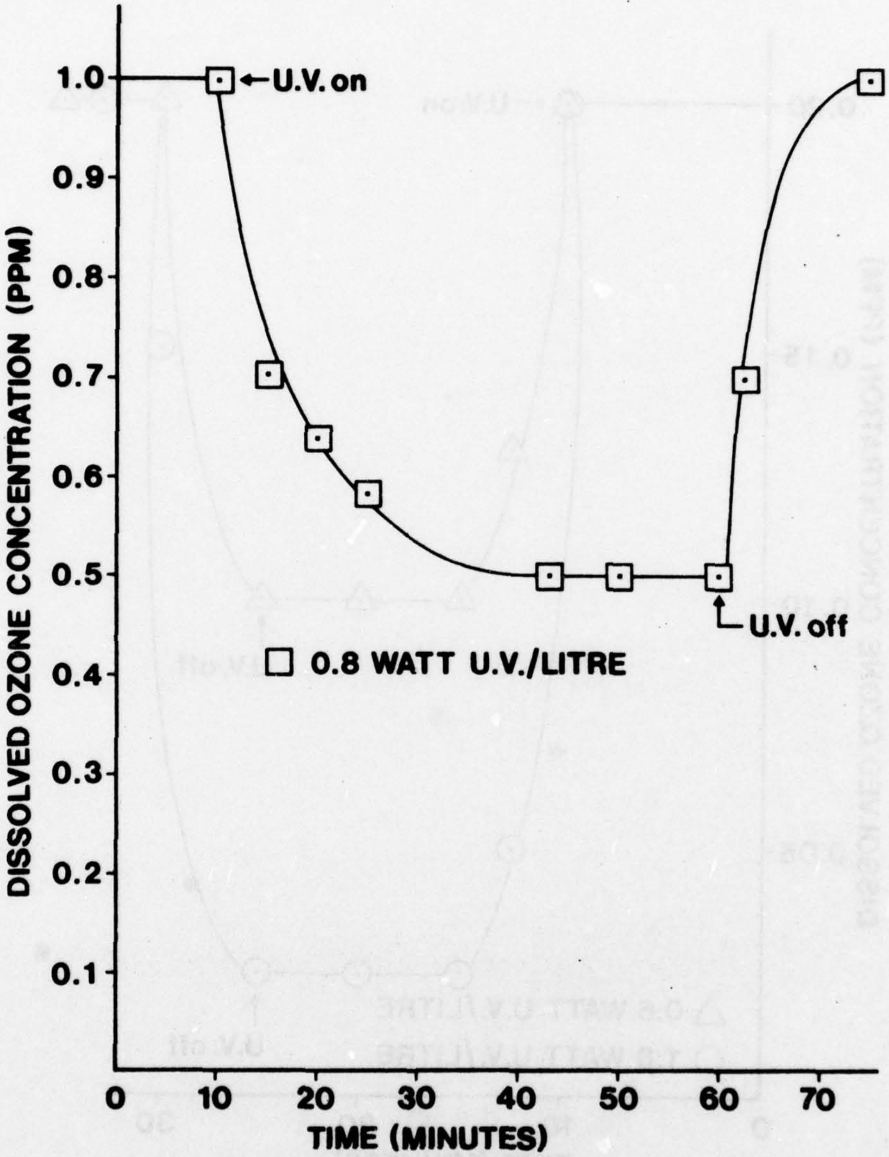


FIGURE C-7: EFFECT OF U.V. ON DISSOLVED OZONE CONCENTRATION AT 60°C, 10g·hr^{-1} O_3 FLOW

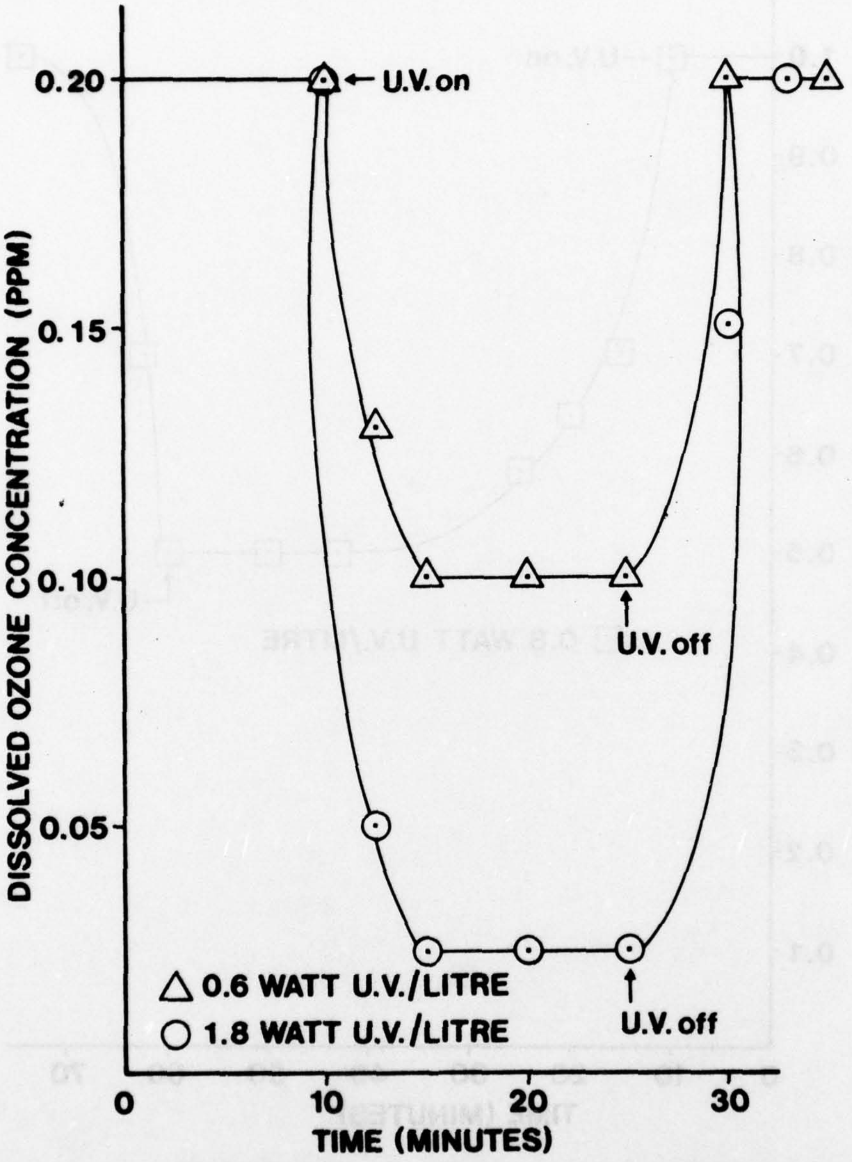


FIGURE C-8 EFFECT OF U.V. ON DISSOLVED OZONE CONCENTRATION AT 60°C, $3 g \cdot hr^{-1} O_3$ FLOW

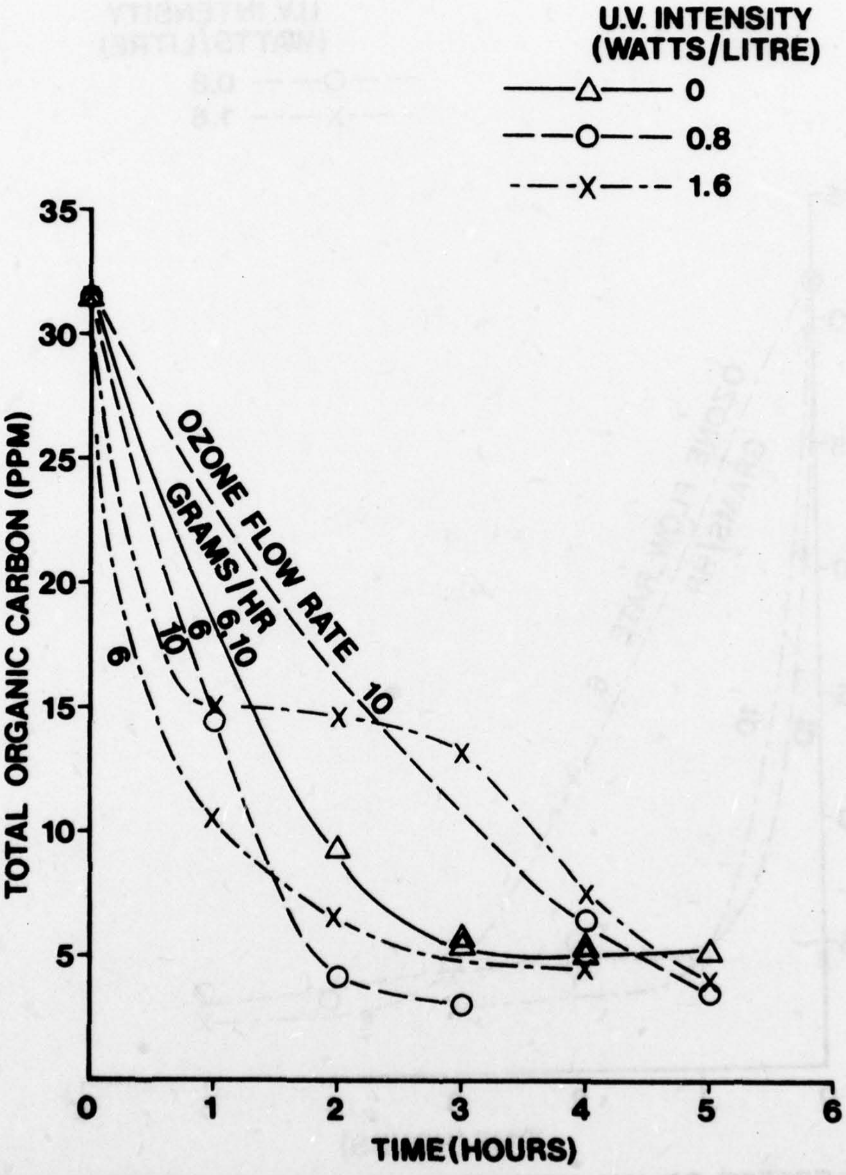


FIGURE C-9 : EFFECT OF U.V. INTENSITY AND OZONE FLOW RATE ON TOC AT 60°C

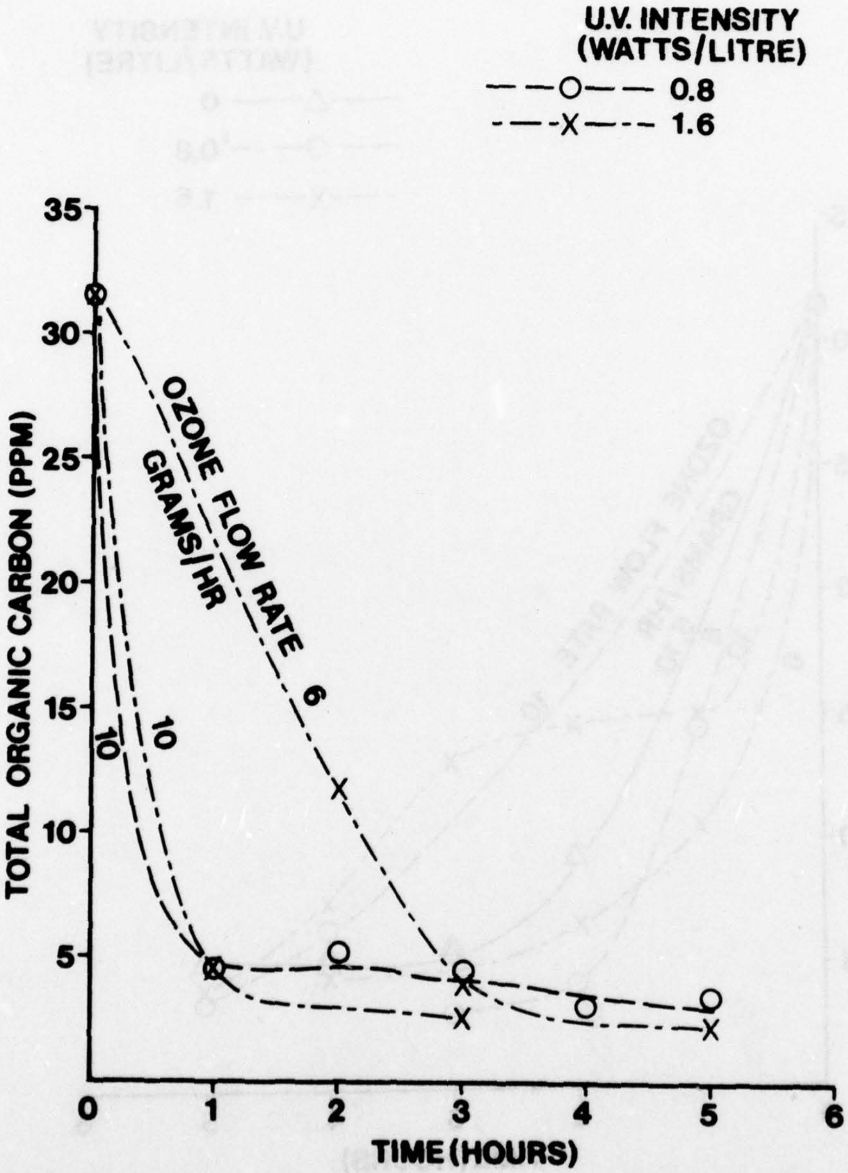


FIGURE C-10: EFFECT OF U.V. INTENSITY AND OZONE FLOW RATE ON TOC AT 45°C

Appendix D Wet Oxidation Tests

D-1	Effects of Various Operation Conditions
D-2	Continuous Flow Tests for the Pilot Plant
D-3	Discussion

D-1 Effects of Various Operating Conditions

These tests were conducted using batch and semi-batch reactors in order to determine the effect of PH, temperature, pressure, and the addition of a catalyst on the oxidation rate as indicated by TOC and/or COD reductions. In order to simplify the tests and their analysis, all of the wet-oxidation experiments were carried out using sewage sludge only without any solid (garbage) waste input. While the addition of solid waste would raise the TOC and COD levels considerably, the percentage reductions in TOC and COD with and without the solid waste stream should remain approximately the same.

The batch tests were conducted using a two-litre sealed reactor in which a known quantity of fluid and oxygen was heated to the desired temperature before injection of the sludge. Samples were withdrawn at intervals for TOC analysis.

The semi-batch tests were performed in a nine-litre commercial Wetox unit using full strength sludge as a feed and with continuous air transfer to and from the reactor for oxidation. Samples were withdrawn at regular intervals and analyzed for COD level.

Effect of Temperature and Pressure

Six experiments were performed using the batch reactor. Duplicate tests were performed under each of the following conditions: 200°C, 450 psi; 225°C, 600 psi and 250°C, 700 psi. The results are presented in figure D-1 and show that TOC reductions of 50%, 69% and 72% were achieved under the three conditions studied with a retention time of one hour. At 250°C, an overall COD reduction of 74% was obtained.

Effect of pH

Tests were performed using the batch reactor on sewage sludge treated with sodium hydroxide to a pH of 10, and with sulphuric acid to a pH of 3 for comparison to the raw sludge at a pH of 7.5. All of these tests were performed at 225°C and 600 psi. The results of these experiments are provided in figure D-2 and show that the TOC removal at a pH of 10, 7.5 and 3 was 63.0%, 69.0% and 83.5%, respectively. The overall COD reduction at pH = 3 was 91%.

Effect of a Catalyst

Tests were performed with the batch reactor at 225°C and 250°C with and without 250 ppm of copper oxide added as a catalyst. The results are presented in figures D-3 and D-4 and show that the addition of the catalyst reduced the TOC by an additional 15% and 20% at 225°C and 250°C respectively after one hour's retention time, achieving total reductions of 85% and 91%.

Effect of pH Control with Catalyst Addition

These tests were carried out using the semi-batch reactor at 232°C and 600 psi with and without 250 ppm of copper oxide to produce a solution of pH 3 and 7.5 respectively. As shown in fiure D-5, TOC was reduced an additional 5%, for a total of 80%.

D-2 Continuous Flow Tests for the Pilot Plant

The purpose of these tests was primarily to supply 1100 litres of wet-oxidation effluent for use in the downstream processes (i.e. lime, reverse osmosis, and UV/ozone treatments) and to monitor the performance of the Wetox model 4-10 continuous-flow pilot plant system, the reactor of which is shown in figure 3. This unit is capable of processing 2500 L/day of sewage sludge, approximately twice that required for the full-scale ESM process.

The sewage sludge was pumped continuously from a head tank through a heat exchanger and into the horizontal four-compartment, stirred reactor. The vapour-phase condensate and liquid-phase effluent form the reactor flowed through the heat exchanger to heat the incoming waste stream. Compressed air was continuously added to each compartment in the following proportions: 50% to the first compartment, 25% to the second and 12.5% to each of the third and fourth compartments. After the desired temperature had been achieved, waste was pumped for two hours before samples were withdrawn from each of the four compartments and from the liquid and vapour phase effluents in order to ensure steady state concentration levels throughout the process.

TOC data were collected from each of the reactor's compartments, using a total residence time of approximately 52 minutes without pH adjustment or catalyst addition, and at temperatures of 224°C, 219°C, and 227°C. The results of the analysis are presented in figure D-6 and show TOC reductions ranging from 50% to 66% for the vapour and the liquid phases combined, using a sewage sludge feed to the reactor with a COD and TOC of 6200 ppm and 2250 ppm respectively.

It was also observed that allowing the suspended solids in the liquid phase effluent to settle, without any assistance from lime treatment, resulted in an additional 5-10% COD reduction. Consequently the reactor effluents were mixed together and allowed to settle to produce a final effluent stream for the pilot plant with a COD and TOC of 1600 ppm and 550 ppm respectively.

D-3 Discussion

For the ranges of the parameters investigated, the data collected show considerable variation in TOC and COD reductions as a function of temperature and pressure (22% variation), residence time (100% variation), pH (20% variation), and catalyst action (20% variation). In addition, the type of oxidant used (air or oxygen) and the feed composition will influence the reaction rate.

An examination of all the data on the ESM waste feed stream shows that a reduction in TOC and COD of 75% should be easily attained with a residence time of 40 minutes at typical reactor operating conditions of 230°C and 600 psi without catalyst addition or pH control. The data also shows that if the need arose, pH control and a catalyst could be employed to extend the capacity of an installed reactor.

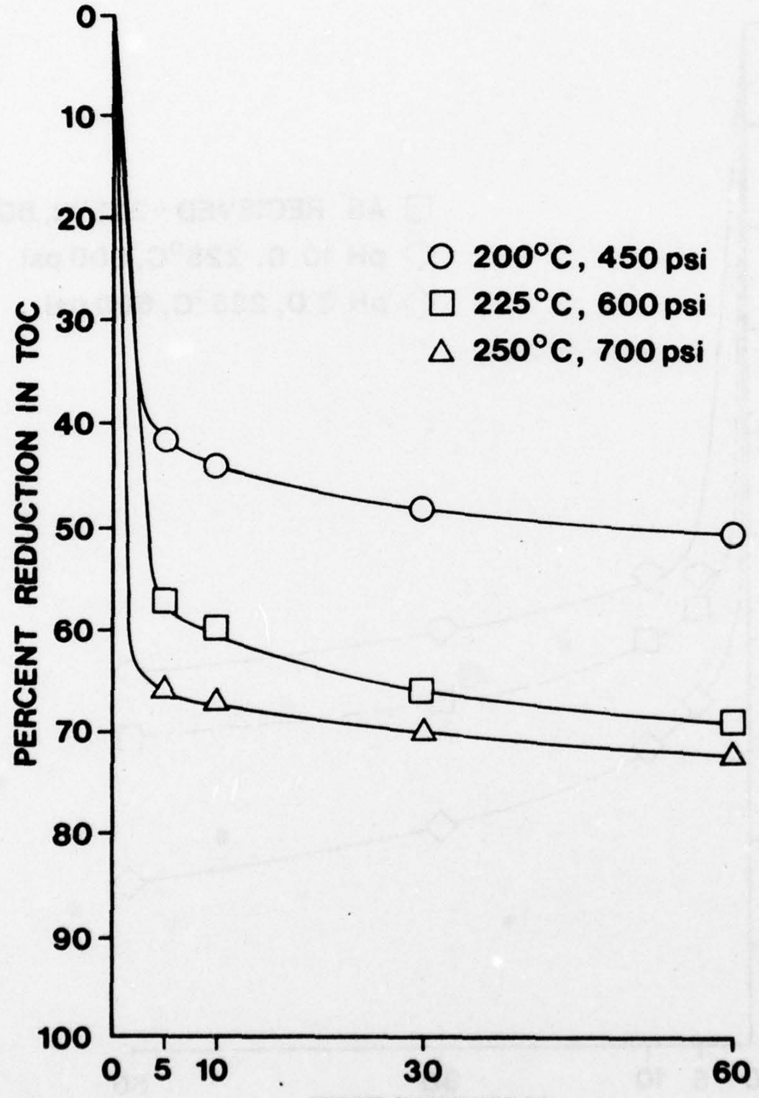


FIGURE D-1: EFFECT OF TEMPERATURE AND PRESSURE ON TOC

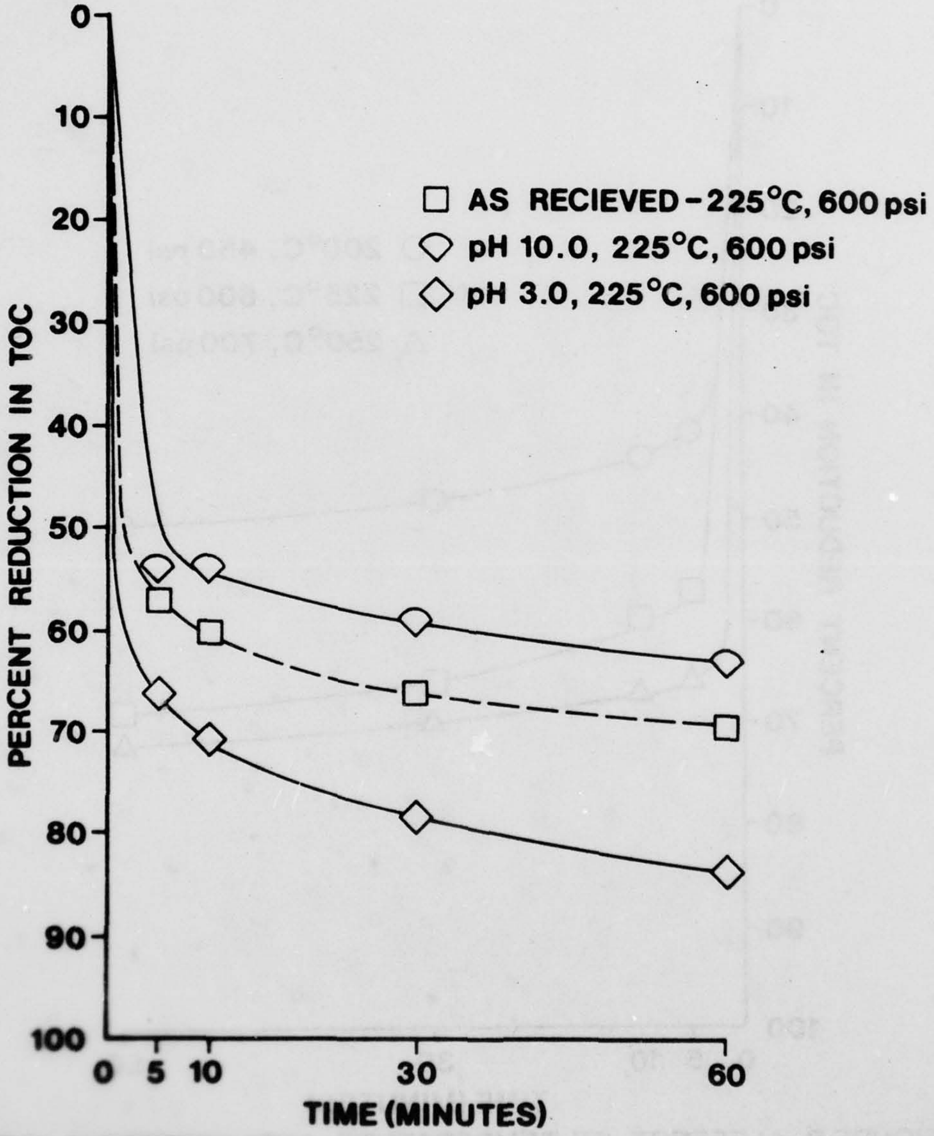


FIGURE D-2: EFFECT OF pH - ON TOC

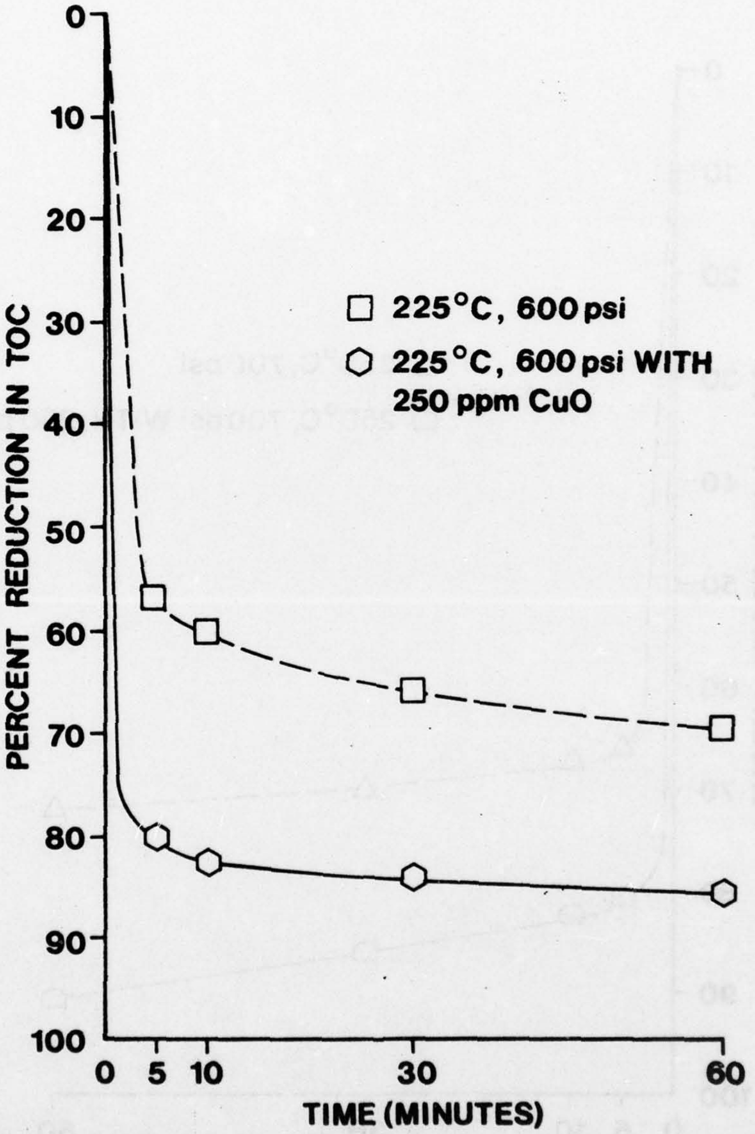


FIGURE D-3: EFFECT OF CATALYST ON TOC AT 225°C

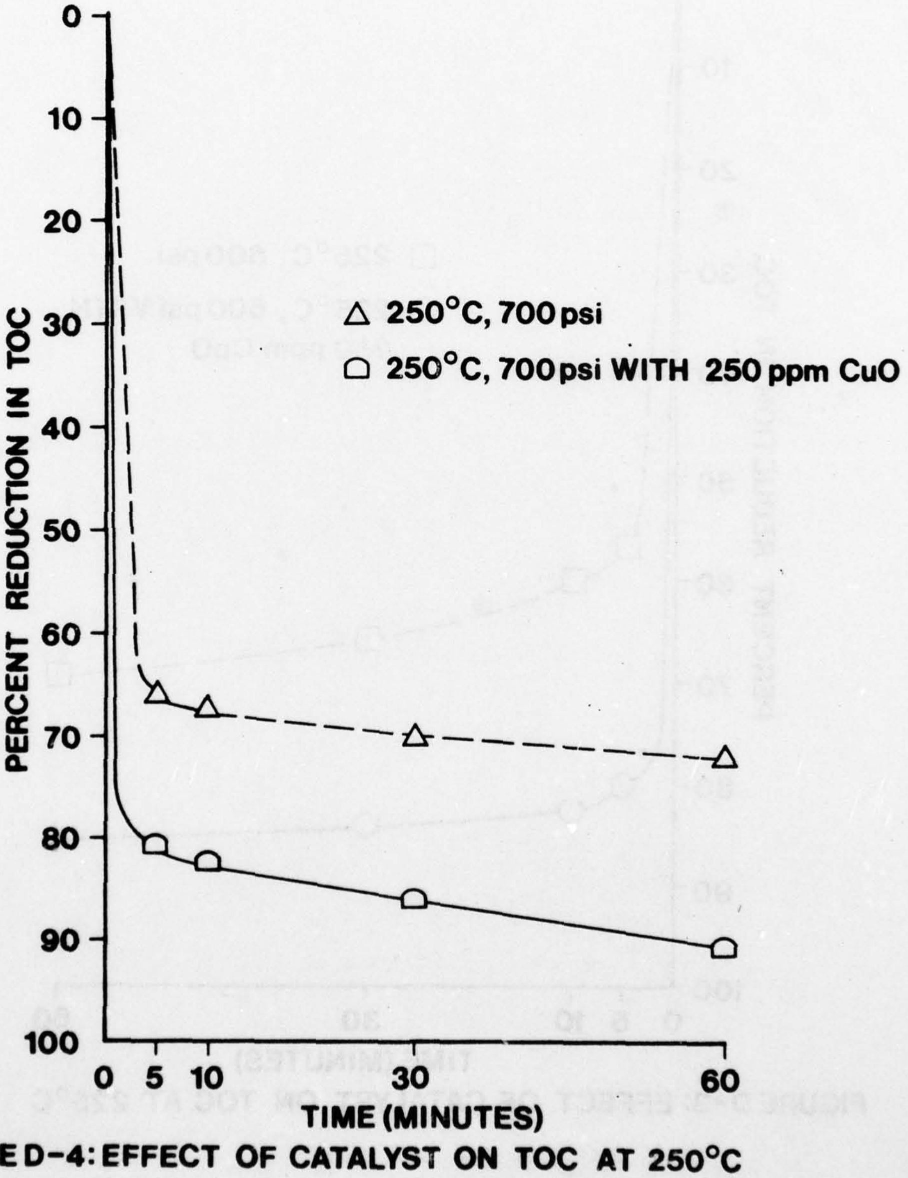


FIGURE D-4: EFFECT OF CATALYST ON TOC AT 250°C

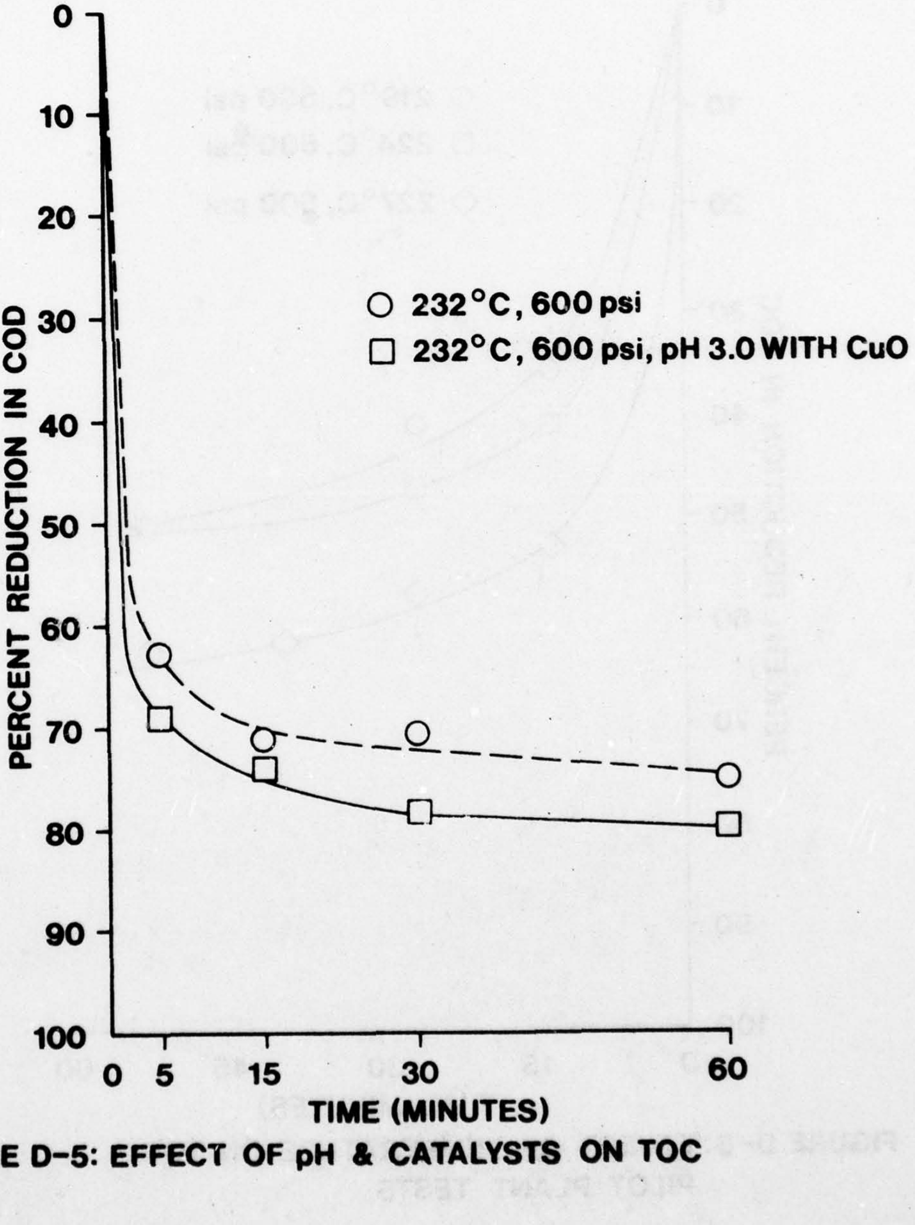


FIGURE D-5: EFFECT OF pH & CATALYSTS ON TOC

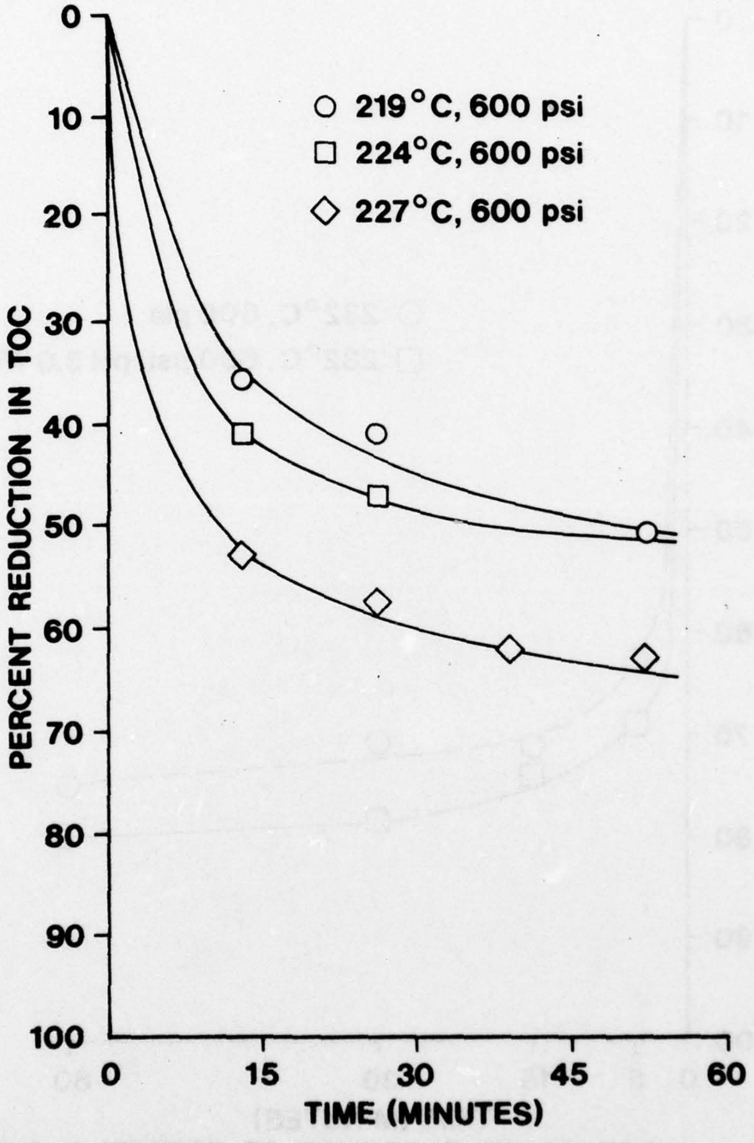
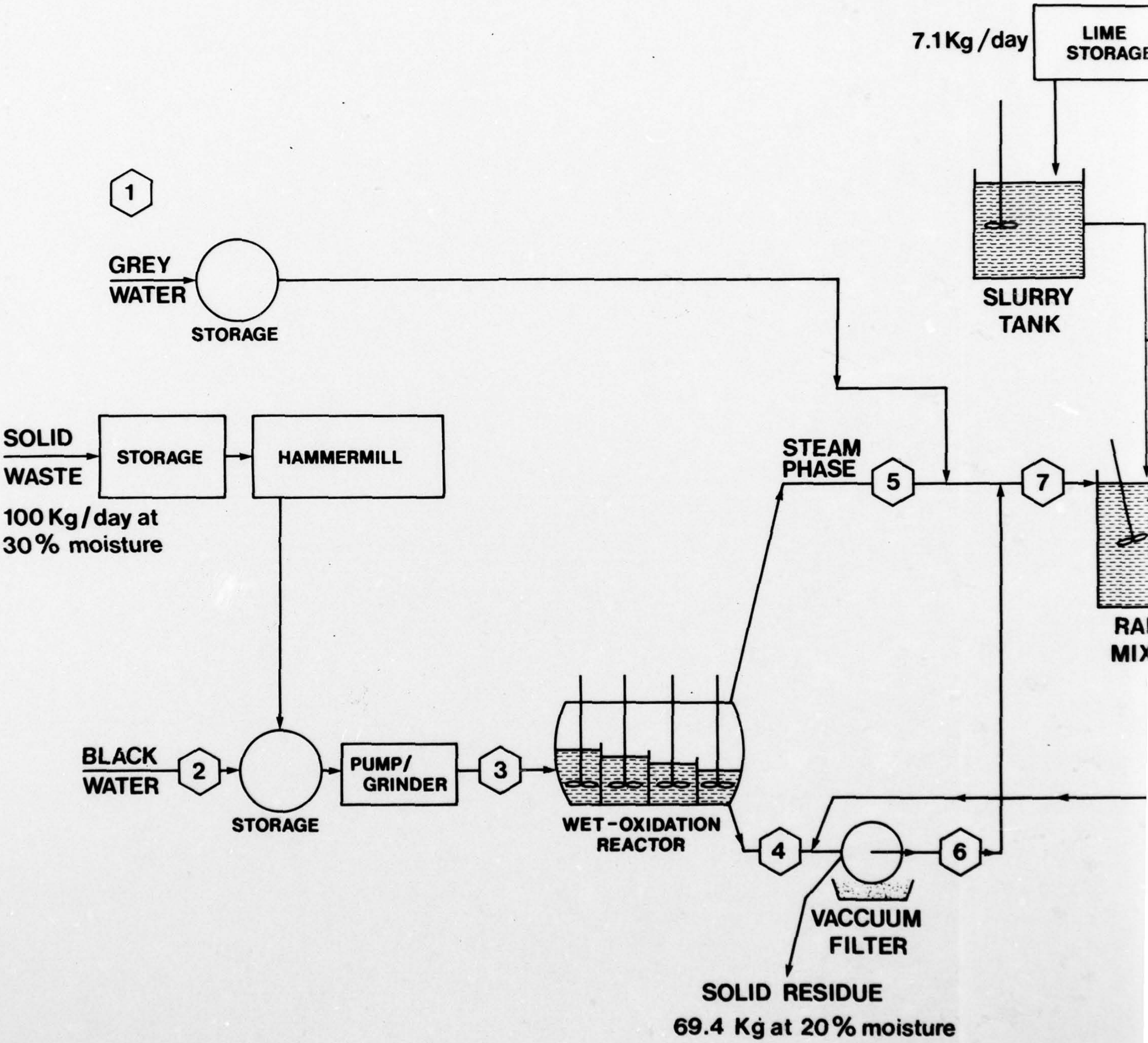


FIGURE D-6: EFFECT OF TEMPERATURE ON TOC: PILOT PLANT TESTS


7.1 Kg / day
LIME STORAG
SLURRY TANK
1
GREY WATER
STORAGE
SOLID WASTE
STORAGE
HAMMERMILL
100 Kg / day at 30 % moisture
STEAM PHASE
5
7
RA
MIX
BLACK WATER
2
STORAGE
PUMP/ GRINDER
3
WET-OXIDATION REACTOR
4
6
VACCUUM FILTER
SOLID RESIDUE
69.4 Kg at 20 % moisture

KEY	FLOW (LITRES/DAY)	COD (PPM)	S.S. (PPM)		FLOW (LITRES/DAY)	COD (PPM)	S. (PP
1	3,940	1,450	730	9	5,010	2,500	
2	1,060	8,490	13,210	10	5,010	2,500	
3	1,060	63,300	79,240	11	800	15,380	
4	650	9,770	68,000	12	40	310,000	
5	440	8,440	0	13	760	<5	
6	650	9,500	3,830	14	4,210	40	
7	5,030	3,100	1,070	15	4,210	0	
8	20	155,000	375,000				

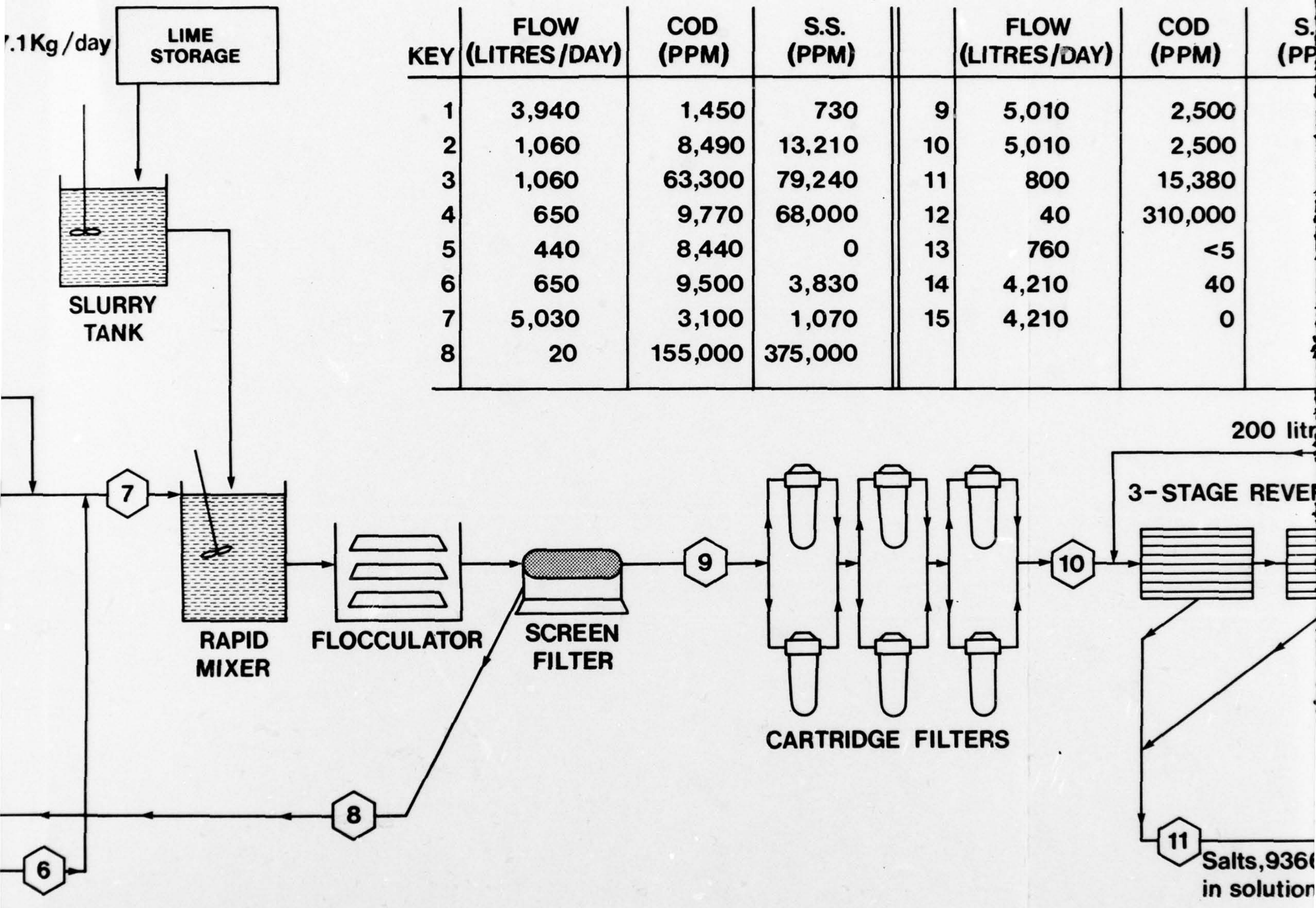


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FIGURE 1: P
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OD PM)	S.S. (PPM)		FLOW (LITRES/DAY)	COD (PPM)	S.S. (PPM)
1,450	730	9	5,010	2,500	80
8,490	13,210	10	5,010	2,500	0
3,300	79,240	11	800	15,380	0
9,770	68,000	12	40	310,000	
8,440	0	13	760	<5	
9,500	3,830	14	4,210	40	0
3,100	1,070	15	4,210	0	0
5,000	375,000				

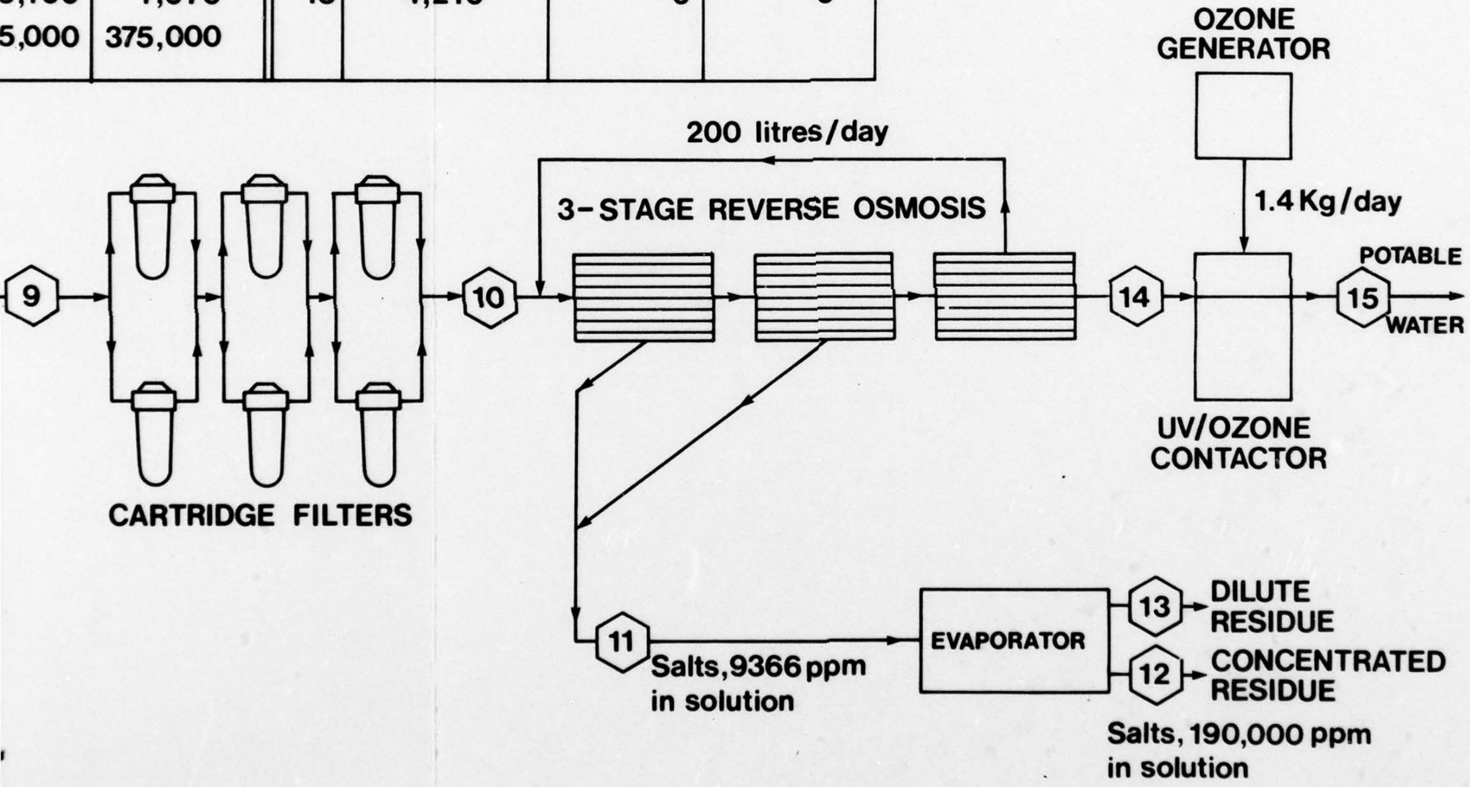
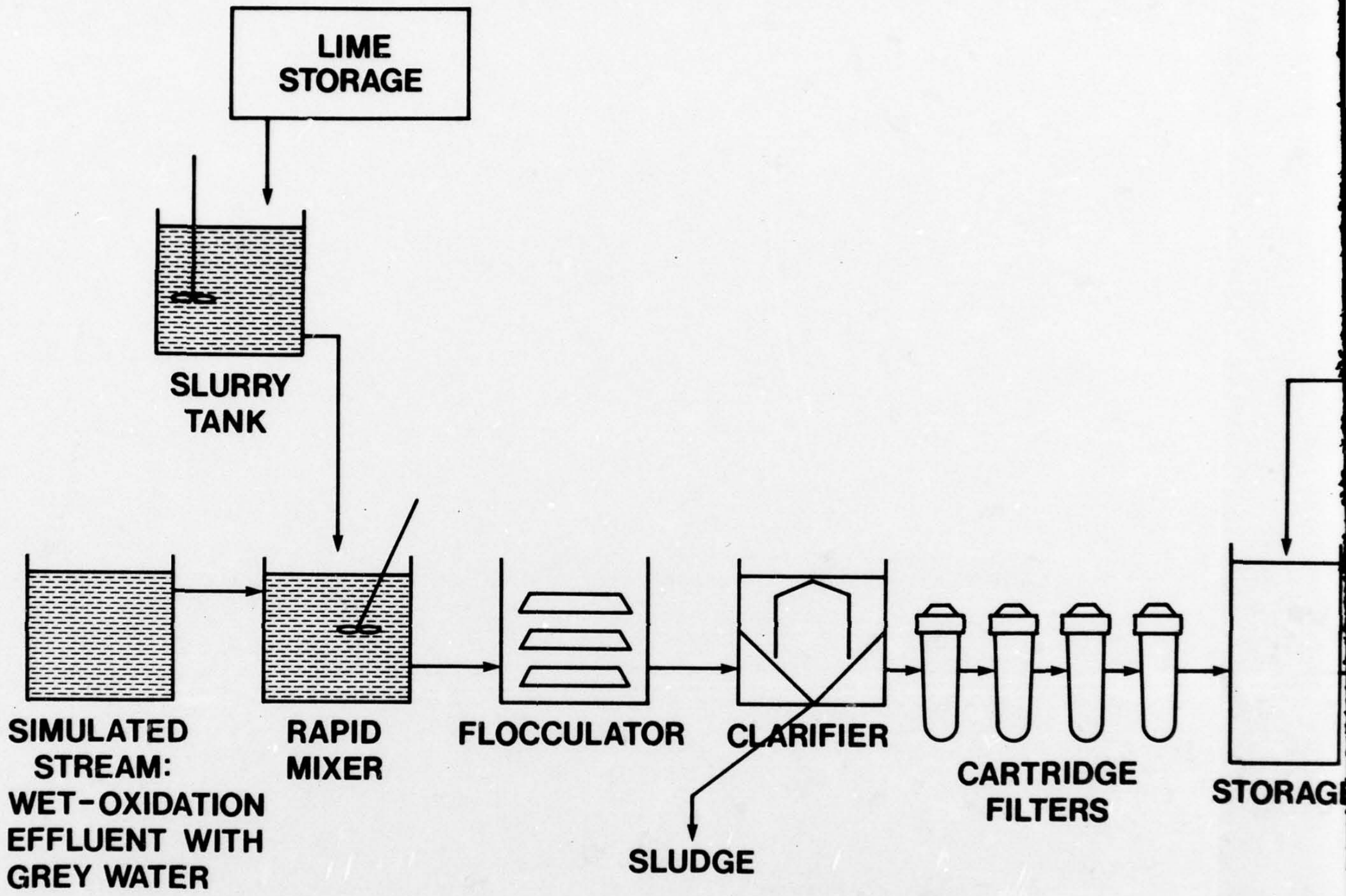
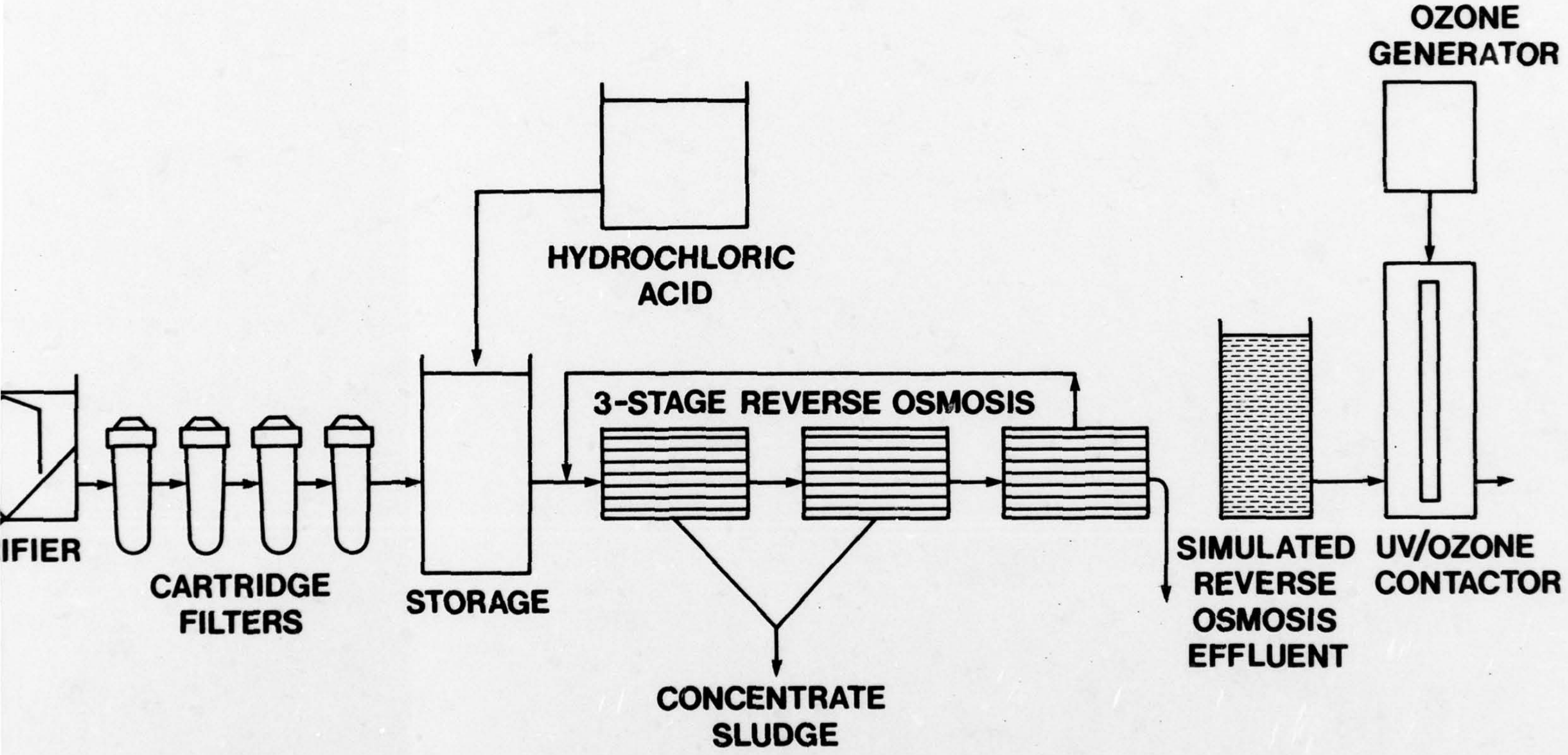


FIGURE 1: PRELIMINARY DESIGN OF WASTE TREATMENT PROCESS

FIGURE 2 PILOT PLANT PROCESS FLOW FOR SIMULATED WET-OXIDATION EFFLUENT TESTS


LIME STORAGE
SLURRY TANK
SIMULATED STREAM: WET-OXIDATION EFFLUENT WITH GREY WATER
RAPID MIXER
FLOCCULATOR
CLARIFIER
SLUDGE
CARTRIDGE FILTERS
STORAG


OZONE GENERATOR
HYDROCHLORIC ACID
3-STAGE REVERSE OSMOSIS
IFIER
CARTRIDGE FILTERS
STORAGE
SIMULATED REVERSE OSMOSIS EFFLUENT
UV/OZONE CONTACTOR
CONCENTRATE SLUDGE

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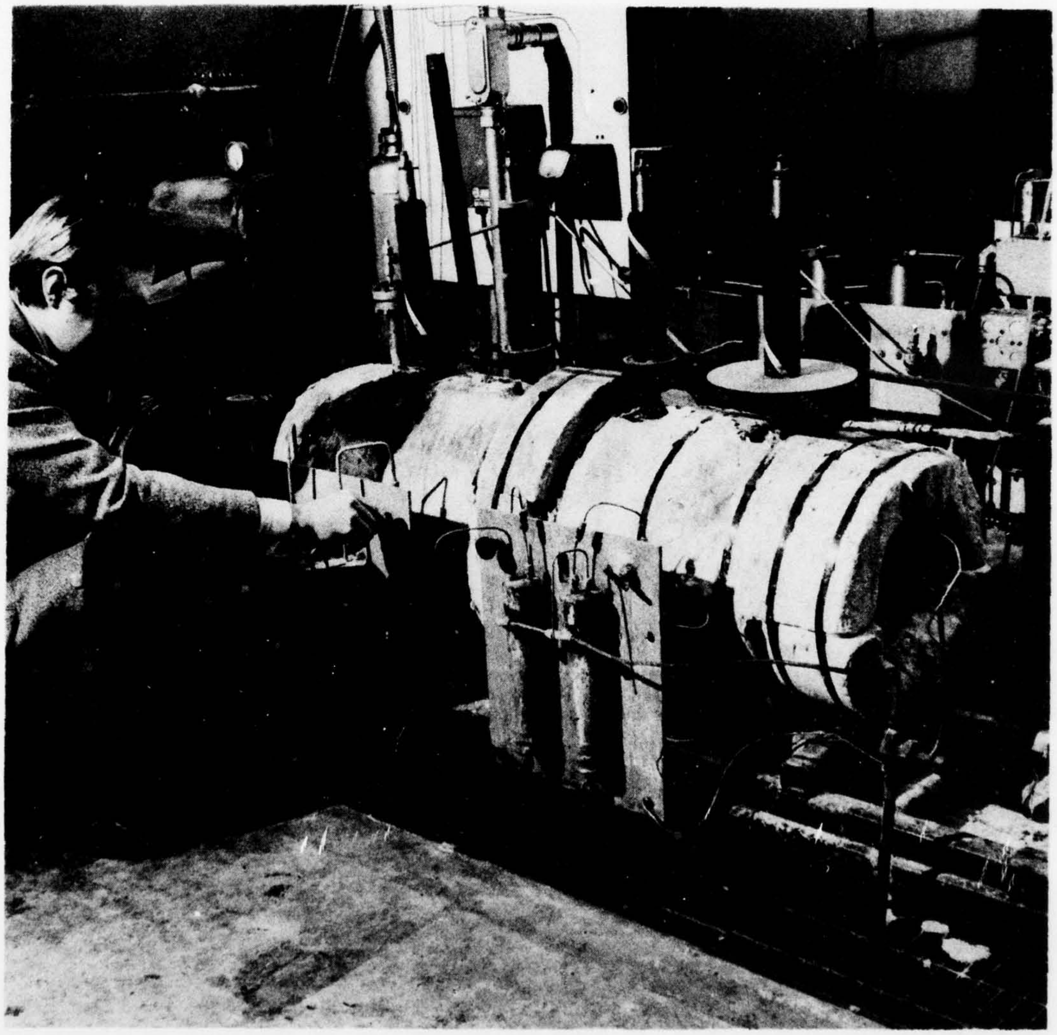
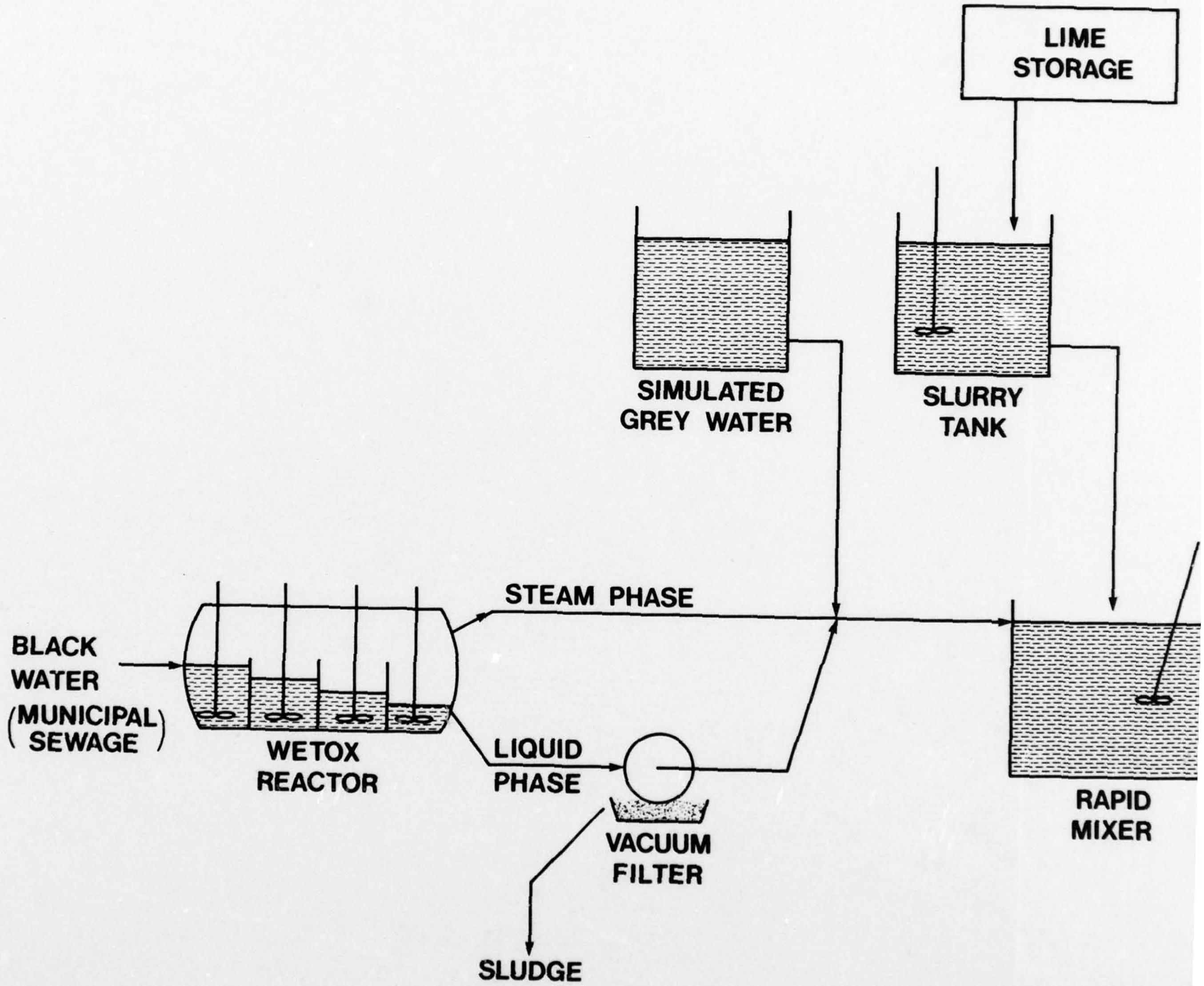
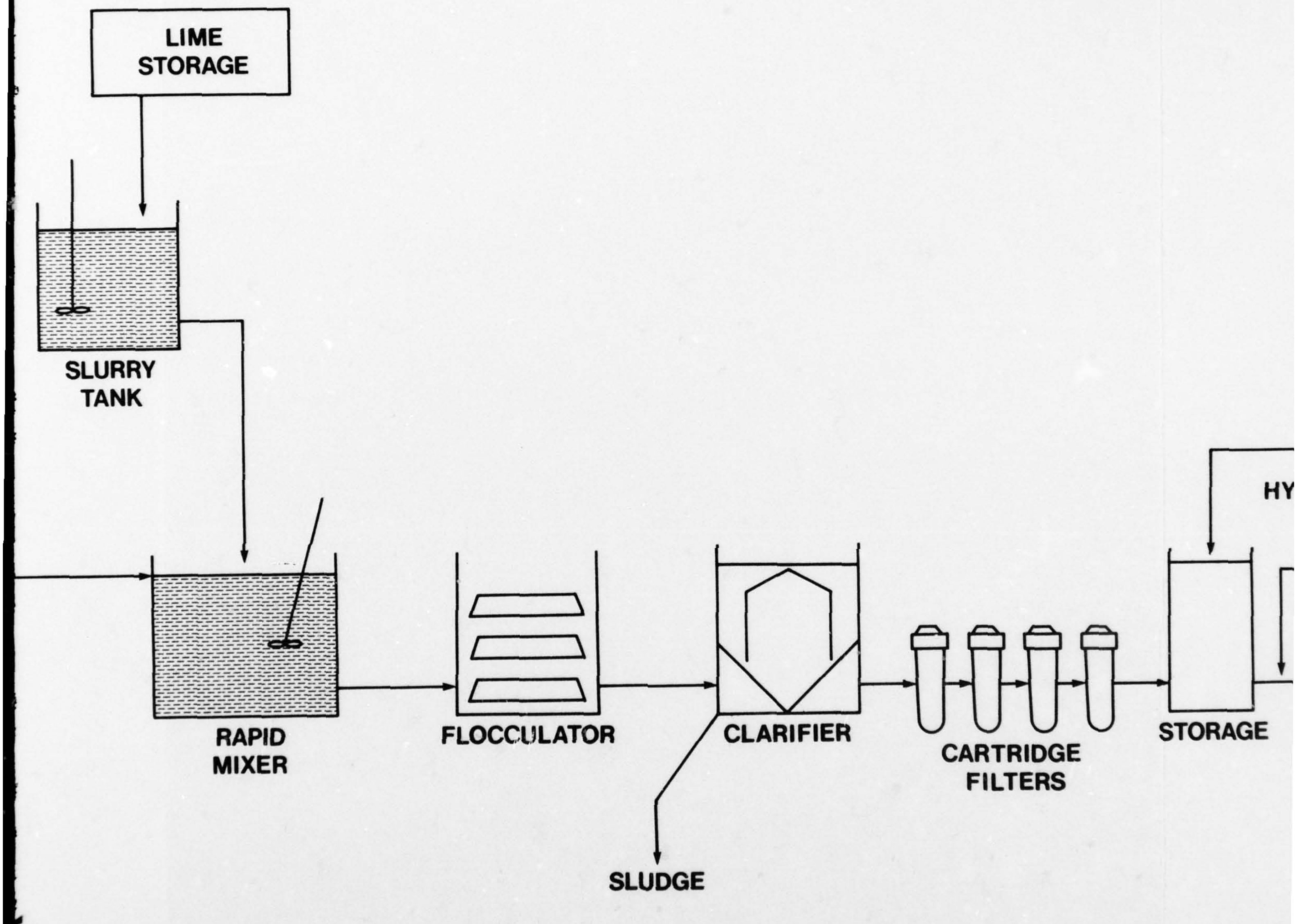


FIGURE 3: CONTINUOUS FLOW WET-OXIDATION REACTOR USED IN PILOT PLANT TESTS


LIME STORAGE
SIMULATED GREY WATER
SLURRY TANK
STEAM PHASE
BLACK WATER (MUNICIPAL SEWAGE)
WETOX REACTOR
LIQUID PHASE
VACUUM FILTER
RAPID MIXER
SLUDGE


LIME STORAGE
SLURRY TANK
RAPID MIXER
FLOCCULATOR
CLARIFIER
SLUDGE
CARTRIDGE FILTERS
STORAGE
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RESEARCH AND DEVELOPMENT TOWARDS A FACILITY FOR WATER PURIFICAT--ETC(U)
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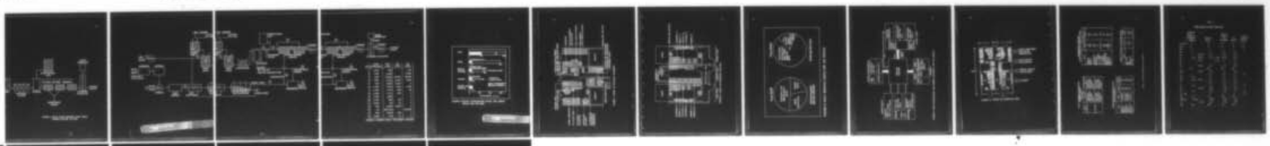

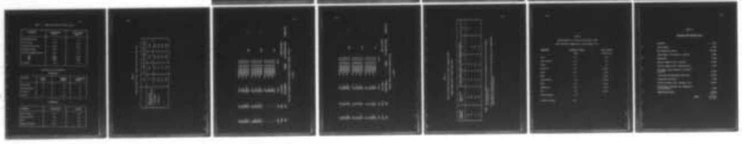

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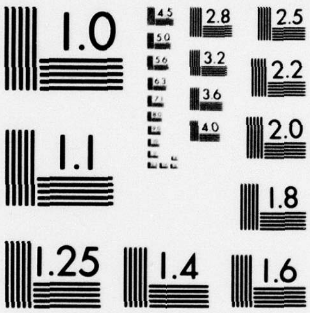

1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

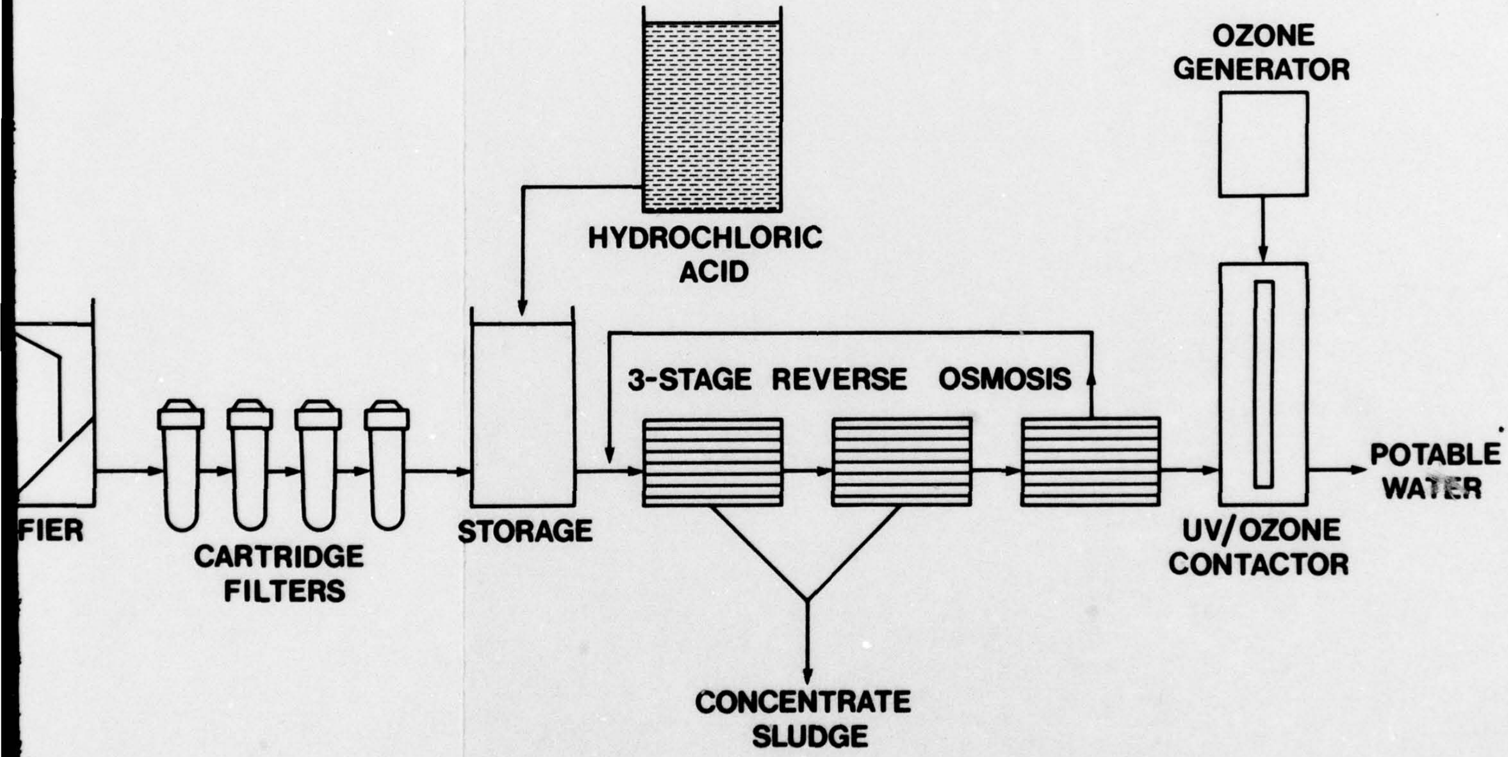
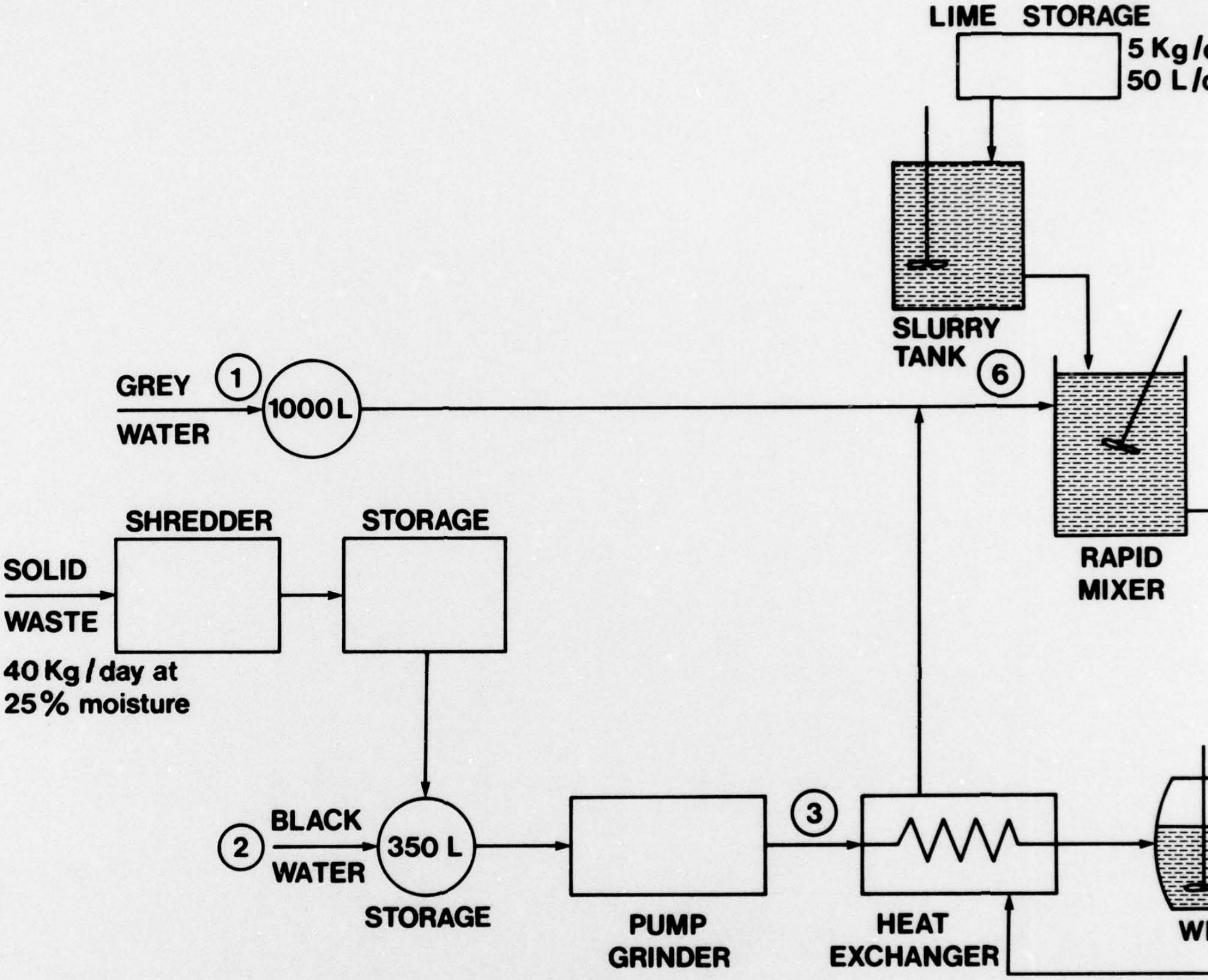
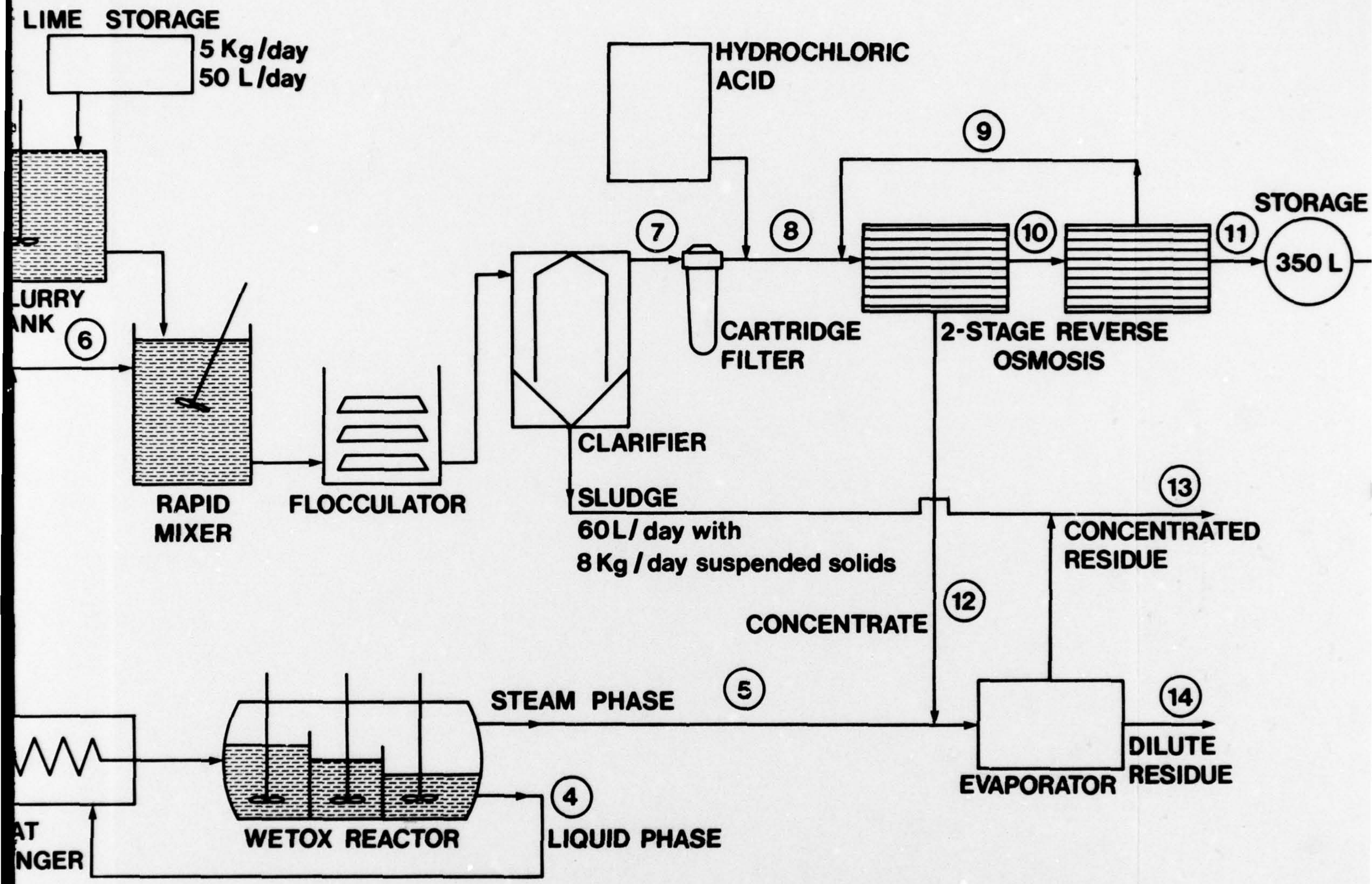
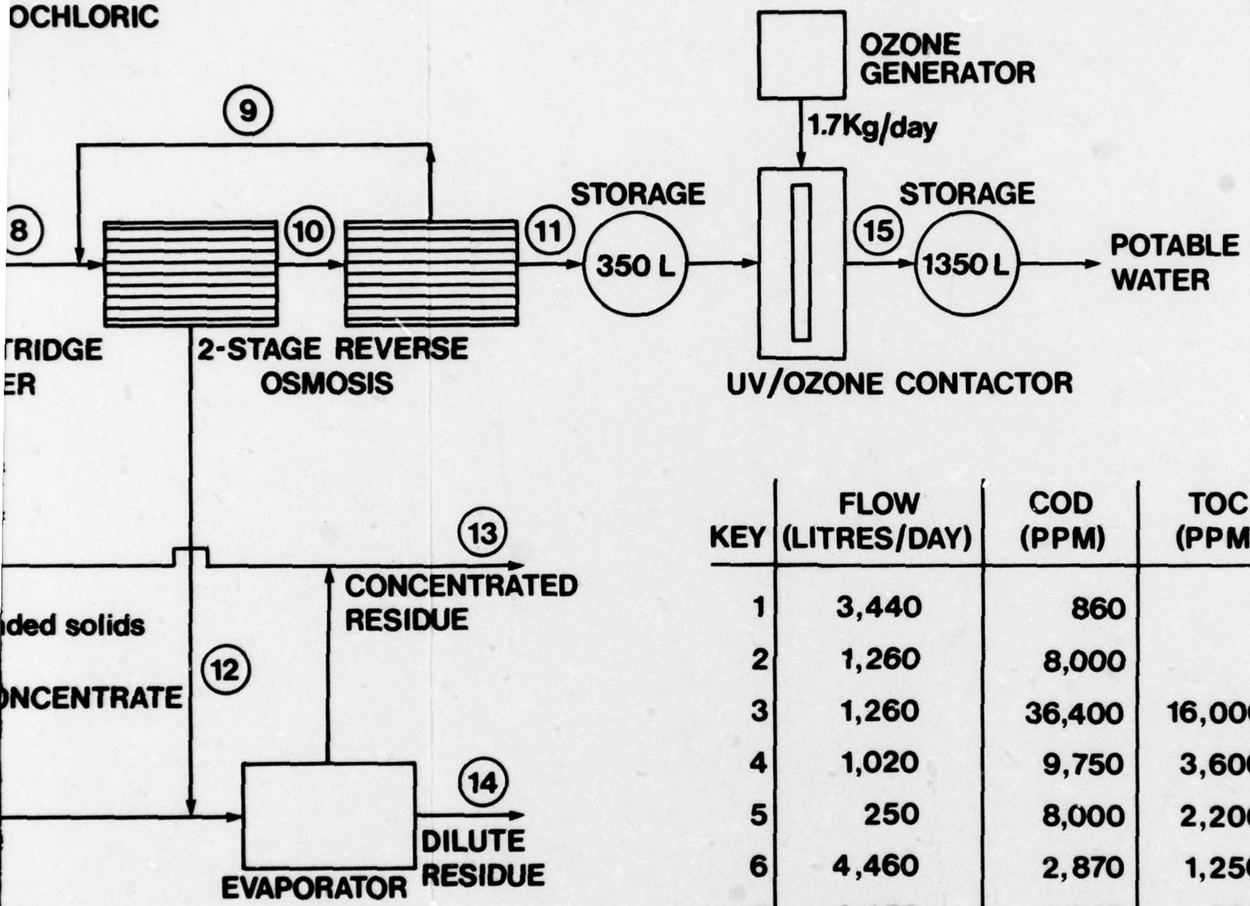


FIGURE 4: PILOT PLANT PROCESS FLOW USING SEWAGE SLUDGE AS FEED

3


LIME STORAGE
5 Kg/
50 L/
SLURRY TANK
6
1
GREY WATER
1000 L
RAPID MIXER
SHREDDER
STORAGE
SOLID WASTE
40 Kg/day at 25% moisture
2
BLACK WATER
350 L
STORAGE
PUMP GRINDER
3
HEAT EXCHANGER
WI


LIME STORAGE
5 Kg/day
50 L/day
HYDROCHLORIC ACID
9
STORAGE
7
8
10
11
350 L
LURRY
ANK
6
CARTRIDGE FILTER
2-STAGE REVERSE OSMOSIS
CLARIFIER
RAPID MIXER
FLOCCULATOR
SLUDGE
60L/day with
8 Kg/day suspended solids
13
CONCENTRATED RESIDUE
12
CONCENTRATE
STEAM PHASE
5
14
DILUTE RESIDUE
EVAPORATOR
4
LIQUID PHASE
WETOX REACTOR
AT
NGER



KEY	FLOW (LITRES/DAY)	COD (PPM)	TOC (PPM)	S.S. (PPM)
1	3,440	860		430
2	1,260	8,000		12,400
3	1,260	36,400	16,000	30,000
4	1,020	9,750	3,600	2,000
5	250	8,000	2,200	0
6	4,460	2,870	1,250	1,050
7	4,450	1,270	500	80
8	4,450	1,270	500	0
9	1,290	1,380		0
10	5,170	390	150	0
11	3,875	55	20	0
12	575	9,450	4,000	0
13	85	200,000		150,000
14	800	2,000	700	0
15	3,875	<10	<5	0

FIGURE 5: REVISED WASTE TREATMENT PROCESS

3

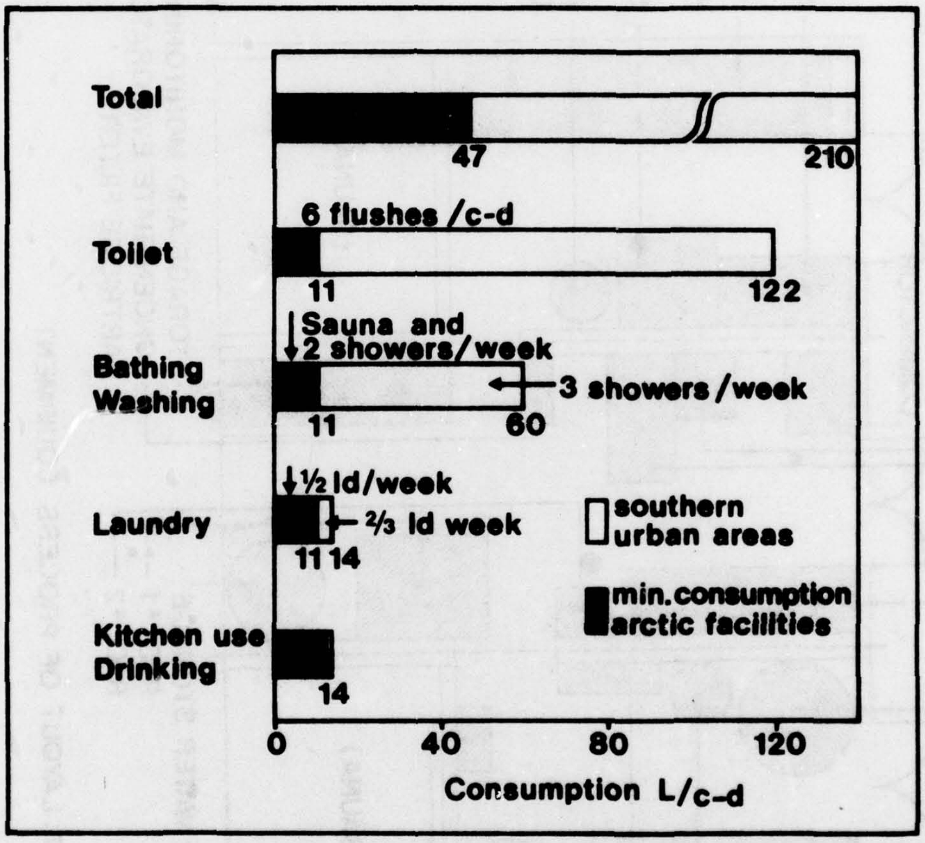


FIGURE 6: WATER CONSUMPTION RATES FOR URBAN AREAS AND THE ESM.

[redacted]

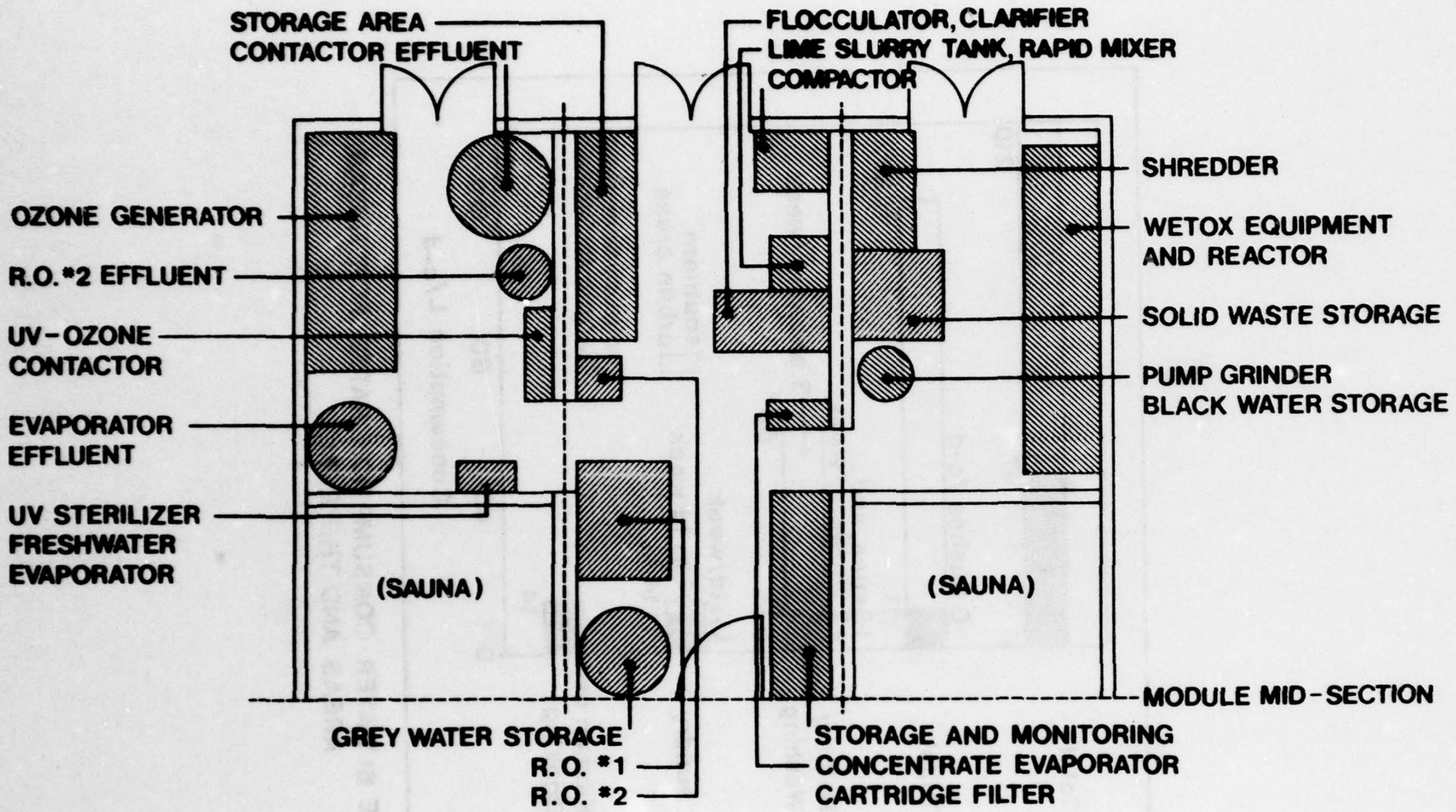


FIGURE 7: LAYOUT OF PROCESS EQUIPMENT

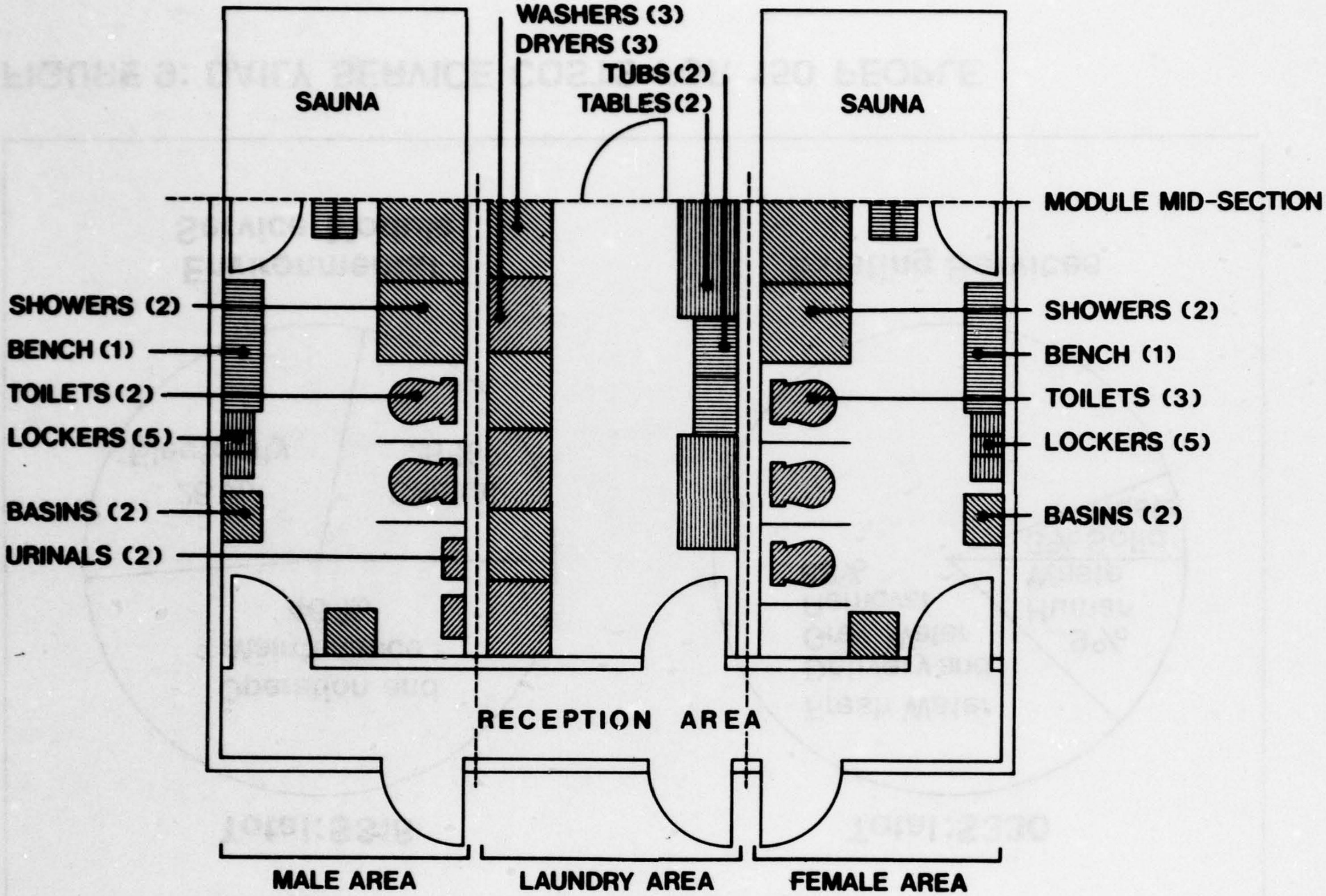


FIGURE 8: LAYOUT OF PERIPHERAL FACILTIES

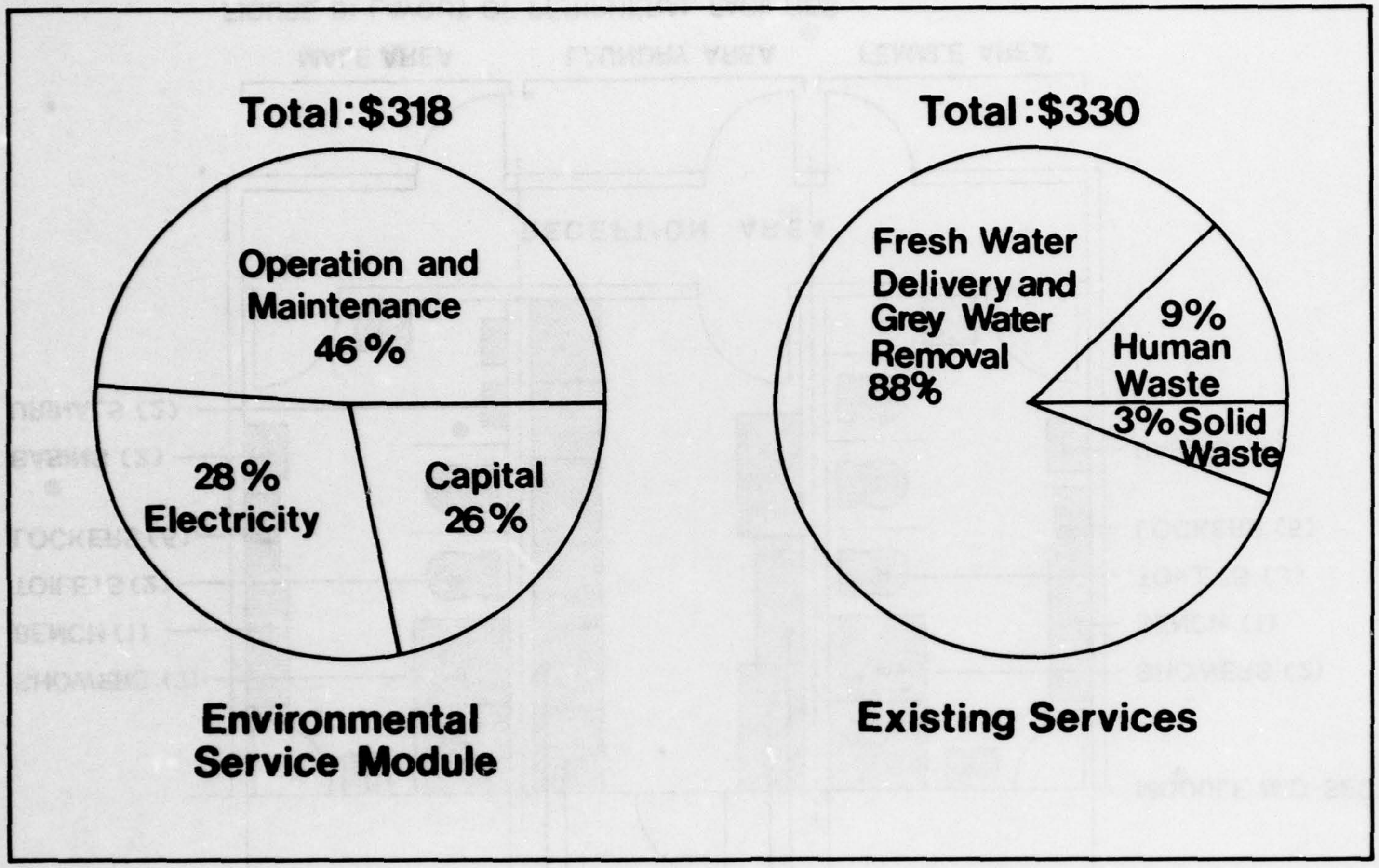


FIGURE 9: DAILY SERVICE COSTS FOR 150 PEOPLE

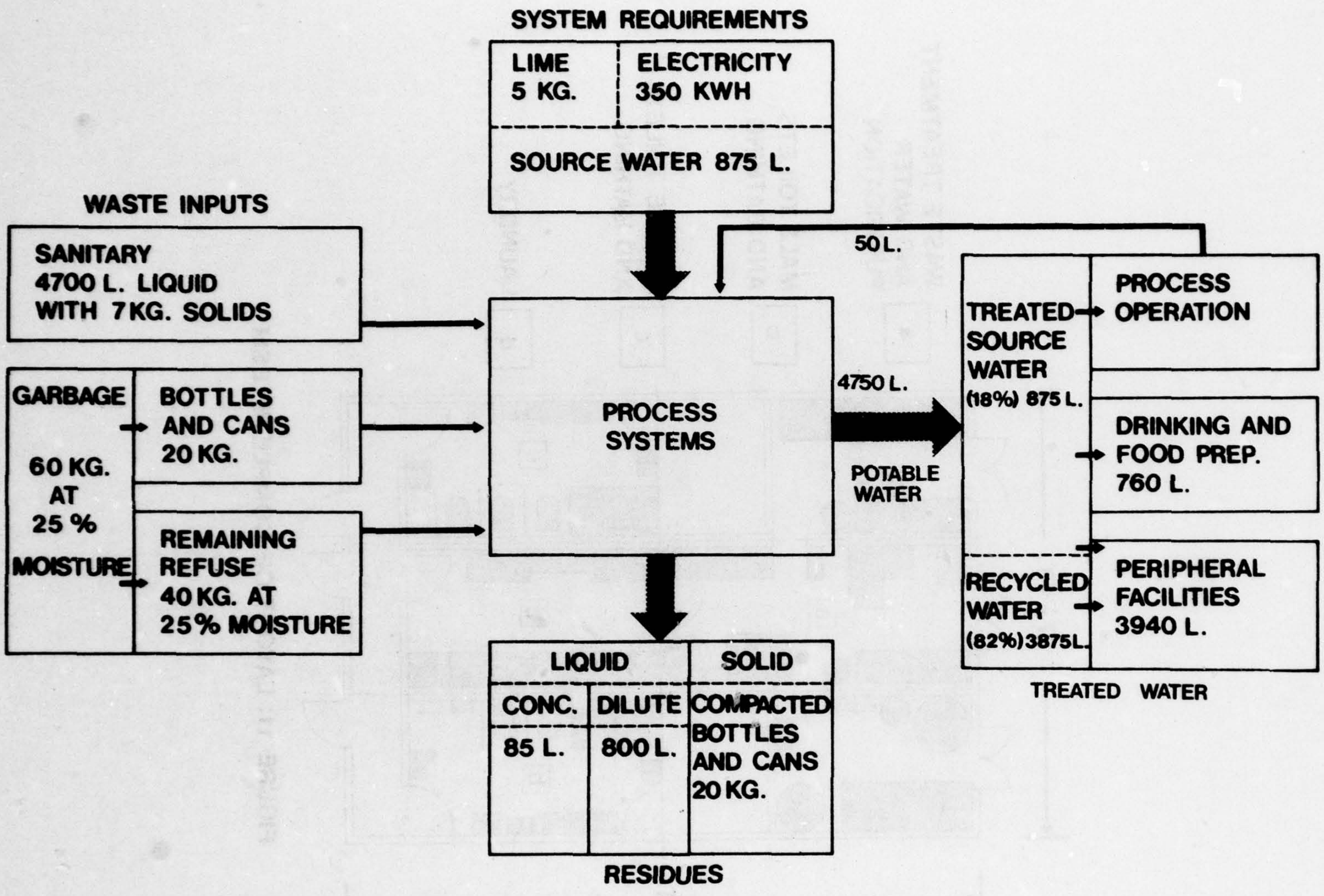


FIGURE 10: DAILY SYSTEM MASS AND ENERGY BALANCES FOR 100 PEOPLE

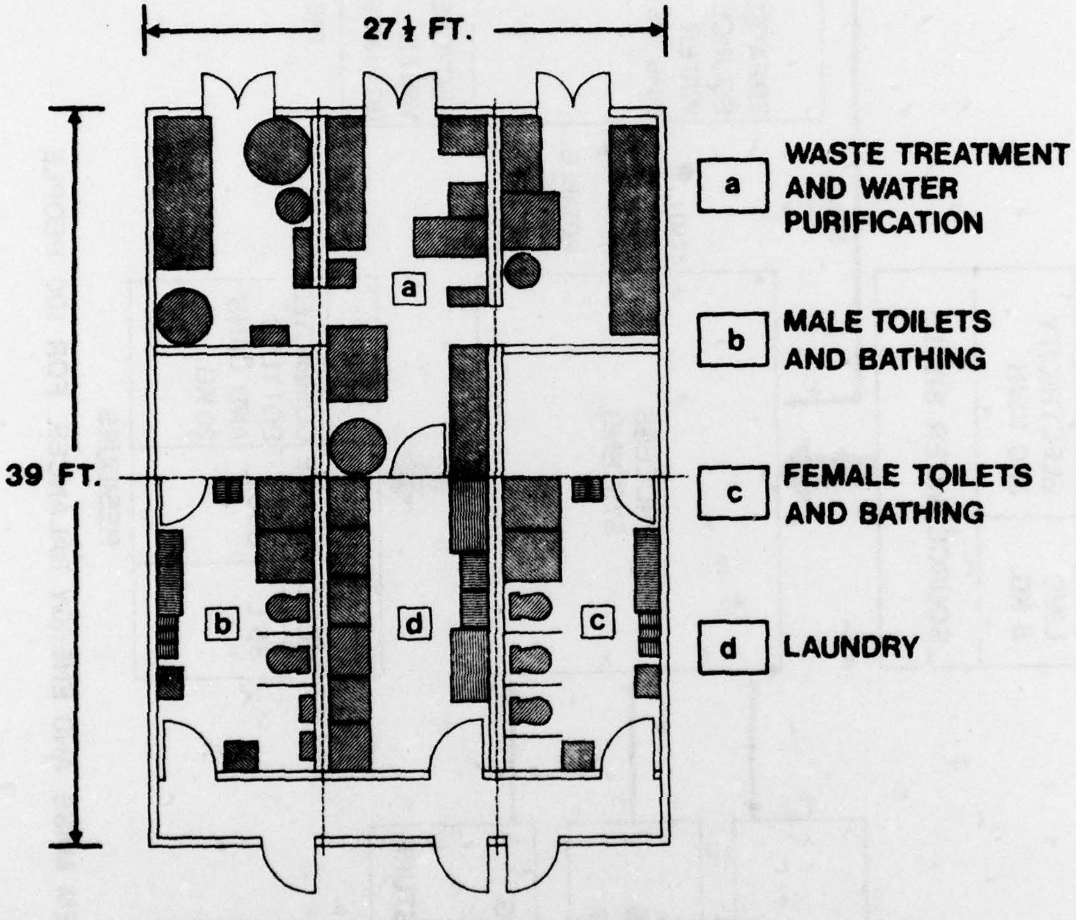


FIGURE 11: LAYOUT OF COMPLETE ESM

TOTAL COLIFORM STANDARDS FOR DRINKING WATER

(MPN METHOD)

Objective	*Acceptable Limit*	*Maximum Permissible Limit*
(a) No coliforms	At least 95% of the samples in any consecutive 30-day period should be "negative" for total coliform organisms.	At least 90% of the samples in any consecutive 30-day period should be "negative" for total coliform organisms.
(b) No coliforms	None of the samples "positive" for total coliform organisms should have an MPN index greater than 4 per 100 ml.	None of the samples "positive" for total coliform organisms should have an MPN index greater than 10 per 100 ml.

RECOMMENDED LIMITS FOR OTHER CHEMICALS IN DRINKING WATER

Chemical	Limit — mg/1	
	Objective	*Acceptable*
Ammonia as N	0.01	0.5
Calcium as Ca	<75	200
Chloride as Cl	<250	250
Copper as Cu	<0.01	1.0
Iron (dissolved) as Fe	<0.05	0.3
Magnesium as Mg	<50	150
Manganese as Mn	<0.01	0.05
Methylene Blue Active Substances	<0.2	0.5
Phenolic Substances as Phenol	Not Detectable	0.002
Phosphates as PO_4 (inorganic)	<0.2	0.2
Total Dissolved Solids	<500	1,000
Total Hardness as $CaCO_3$	<120	
Organics as CCE + CAE	<0.05	0.2
Sulphate as SO_4^{--}	<250	500
Sulphide as H_2S	Not Detectable	0.3
Uranyl Ion as UO_2^{++}	<1.0	5.0
Zinc as Zn	<1.0	5.0

DRINKING WATER STANDARDS FOR TOXIC CHEMICALS

Toxicant	*Objective mg/1*	*Acceptable Limit—mg/1*	*Maximum Permissible Limit—mg/1*
Arsenic as As	Not Detectable	0.01	0.05
Barium as Ba	Not Detectable	<1.0	1.0
Boron as B	—	<5.0	5.0
Cadmium as Cd	Not Detectable	<0.01	0.01
Chromium as Cr^{+6}	Not Detectable	<0.05	0.05
Cyanide as CN	Not Detectable	0.01	0.20
Lead as Pb	Not Detectable	<0.05	0.05
Nitrate+Nitrite as N	<10.0	<10.0	10.0
Selenium as Se	Not Detectable	<0.01	0.01
Silver as Ag	—	--	0.05

PHYSICAL QUALITY OF TREATED WATER

Parameter	*Objective*	*Acceptable Limit*
Colour — TCU	<5	15
Odour — T.O.N.	0	4
Taste	Inoffensive	Inoffensive
Turbidity — JTU	<1	5
Temperature — °C	<10	15
pH — Units	—	6.5 — 8.3

TABLE 1 Canadian Drinking Water Standards

TABLE 2

USPHS Limits of Water Impurities

	Drinking Water Standards (mandatory limit)		Bathing Water		General Washing and Cleaning	Irr. Waters	Toilet Flushing Waters
Turbidity	5		10		10	10	20
Color	15		15		15	15	30
Odor	3		3		3	3	6
ABS	0.5		1.0		2.0	1.0	
Ag		(0.05)*	0.05		0.05	0.05	
As	0.01	(0.05)	0.01	(.05)	0.05	0.05	
Ba		(1.0)		(1.0)	1.0	1.0	
Bo						1.0	
Cd		(0.01)	0.01		0.01	0.01	
Cl	250		500		500	500	
Cr+6		(0.05)	0.05		1.5	0.05	
Cu	1		2.0		2.0	1.0	1.0
CCE	0.2		0.2		0.4	0.4	
CN	0.01	(0.2)	0.2		0.2	0.2	
F			6.0		6.0	6.0	
Fe	0.3		1.0		1.0	1.0	1.0
Pb		(0.05)	0.05		0.05	0.05	
Mn	0.5		0.05		0.05	0.5	0.5
Fe + Mn			1		1	1	1.0
NO_3	45		90		180	180	
Phenols	0.001		0.005		0.01	0.05	
Se		(0.01)	0.01		0.01	0.01	
SO_4	250		500		500	500	

Table 3 Combined Wastewater Characteristics

PARAMETER	CONCENTRATION (mg/ℓ)	TOTAL WEIGHT (gm/cd)
Settleable Solids	33.7	7.1
Total Solids	4,630	231.5
Volatile Total Solids	2,218	110.9
Suspended Solids	1,482	74.1
Volatile Suspended Solids	1,226	61.3
COD	2,943	147.2
BOD	1,502	75.1
TOC	818	40.9
Chlorides	358	17.9

Distribution of Contaminants

(PERCENTAGE)

FRACTION	TOTAL SOLIDS	ORGANIC MATTER	NITROGENOUS MATTER
Settleable	18	30	23
Supracolloidal	11	19	34
Colloidal	7	13	11
Soluble	64	38	22

(PERCENTAGE)

PARAMETER	PARTICULATES	SOLUBLES
Total Solids	34.7	63.3
Volatile Solids	57.6	42.4
COD	77.3	22.7
Organic Nitrogen	80.5	19.5

Table 4

Lime Treatment Tests: Effect of PH on SS, TOC, COD

	PH	SS (PPM)	TOC (PPM)	COD (PPM)
Feed to Lime Treatment Process	5.5	925	1400	3100
Clarified Effluent	9.5	28	860	2380
	10.0	23	1160	2180
	10.5	25	990	2300
	11.0	28	960	2500

Table 5

Reverse Osmosis Tests On Simulated Wet-Oxidation Effluent

Test Number	Water Recovery on each R.O. Unit	Sample	Conductivity (μmhos/cm)	TOC (ppm)	COD (ppm)
		Feed	2,500	800	1,800
1	75%	R.O. #1 Permeate	750	-	-
		R.O. #1 Concentrate	7,000	-	-
		R.O. #2 Permeate	300	-	-
		R.O. #2 Concentrate	1,500	-	-
		R.O. #3 Permeate	50	-	-
		R.O. #3 Concentrate	1,000	-	-
2	80%	R.O. #1 Permeate	650	225	575
		R.O. #1 Concentrate	9,800	2,750	7,400
		R.O. #2 Permeate	250	150	400
		R.O. #2 Concentrate	2,100	500	1,300
		R.O. #3 Permeate	25	125	300
		R.O. #3 Concentrate	1,200	250	750
3	85%	R.O. #1 Permeate	900	250	450
		R.O. #1 Concentrate	10,500	2,300	7,700
		R.O. #2 Permeate	450	200	400
		R.O. #2 Concentrate	3,400	450	725
		R.O. #3 Permeate	175	175	350
		R.O. #3 Concentrate	2,100	350	625

Table 6

Reverse Osmosis Tests on Sewage Sludge

Test Number	Water Recovery on each R.O. Unit	Sample	Conductivity (µmhos/cm)	TOC (ppm)	COD (ppm)
		Feed	2,000	150	500
1	75%	R.O. #1 Permeate	300	50	150
		R.O. #1 Concentrate	5,000	400	1,000
		R.O. #2 Permeate	100	30	100
		R.O. #2 Concentrate	500	50	150
		R.O. #3 Permeate	25	25	65
		R.O. #3 Concentrate	300	50	150
2	85%	R.O. #1 Permeate	700	45	110
		R.O. #1 Concentrate	9,300	650	1,350
		R.O. #2 Permeate	250	25	80
		R.O. #2 Concentrate	2,500	135	230
		R.O. #3 Permeate	30	15	55
		R.O. #3 Concentrate	1,500	90	230
3	90%	R.O. #1 Permeate	750	60	160
		R.O. #1 Concentrate	11,800	825	1,900
		R.O. #2 Permeate	400	40	120
		R.O. #2 Concentrate	4,000	225	525
		R.O. #3 Permeate	85	25	80
		R.O. #3 Concentrate	3,700	125	450

Table 7

Effect of Ozone Flow Rate on UV/Ozone Treatment Using Sewage Sludge Feed of Various Recoveries

Ozone Flow Grams/HR	Recovery Of Feed, % *	Total Organic Carbon at Time Indicated (Hours)			
		0	1	2	3
10	85	12	3.6		2.6
6	90	21	4.3	4.2	
6	85	12	8.3	2.8	
10	90	21	4.1	2.9	

NOTE: All tests were conducted at a fluid temperature of 60^{o} and a UV intensity of 0.8 watts/litre.

* This refers to the recovery rate of the two reverse osmosis units immediately preceding the UV/Ozone contactor.

Table 8

Characteristics of Typical Solid Waste From

Three Northern Communitites (From Forgie) (32)

Component	Percent of Total (dry)	Heat Content (Btu/lb.dry)
Cans	14.5	124
Other metals	6.9	124
Glass	11.5	63
Plastics	8.7	13,376
Paper	23.0	7,544
Rags	6.7	7,781
Putrescibles	8.5	8,002
Wood	8.5	8,487
Cardboard	13.0	7,635
Dirt	3.6	5,610
Miscellaneous	0.5	–
Moisture Content	26.1	

Table 9

Estimated ESM Capital Costs

Shredder	$ 5,000
Pump Grinder	2,000
Wet-oxidation reactor	120,000
Rapid mixer, flocculator, clarifier	8,000
Evaporator	5,000
Reverse osmosis unit, (tubular)	25,000
Reverse osmosis unit, (hollow fibre)	3,000
Air dryer, ozone generator, UV-ozone contactor	25,000
3 Hercules Transportable Camp Units	30,000
Peripheral facilities	5,000
Control systems, misc. hardware, etc.	10,000
Fresh water treatment (eg. evaporator, UV sterilizer)	9,000
Engineering Design	10,000
TOTAL:	$257,000