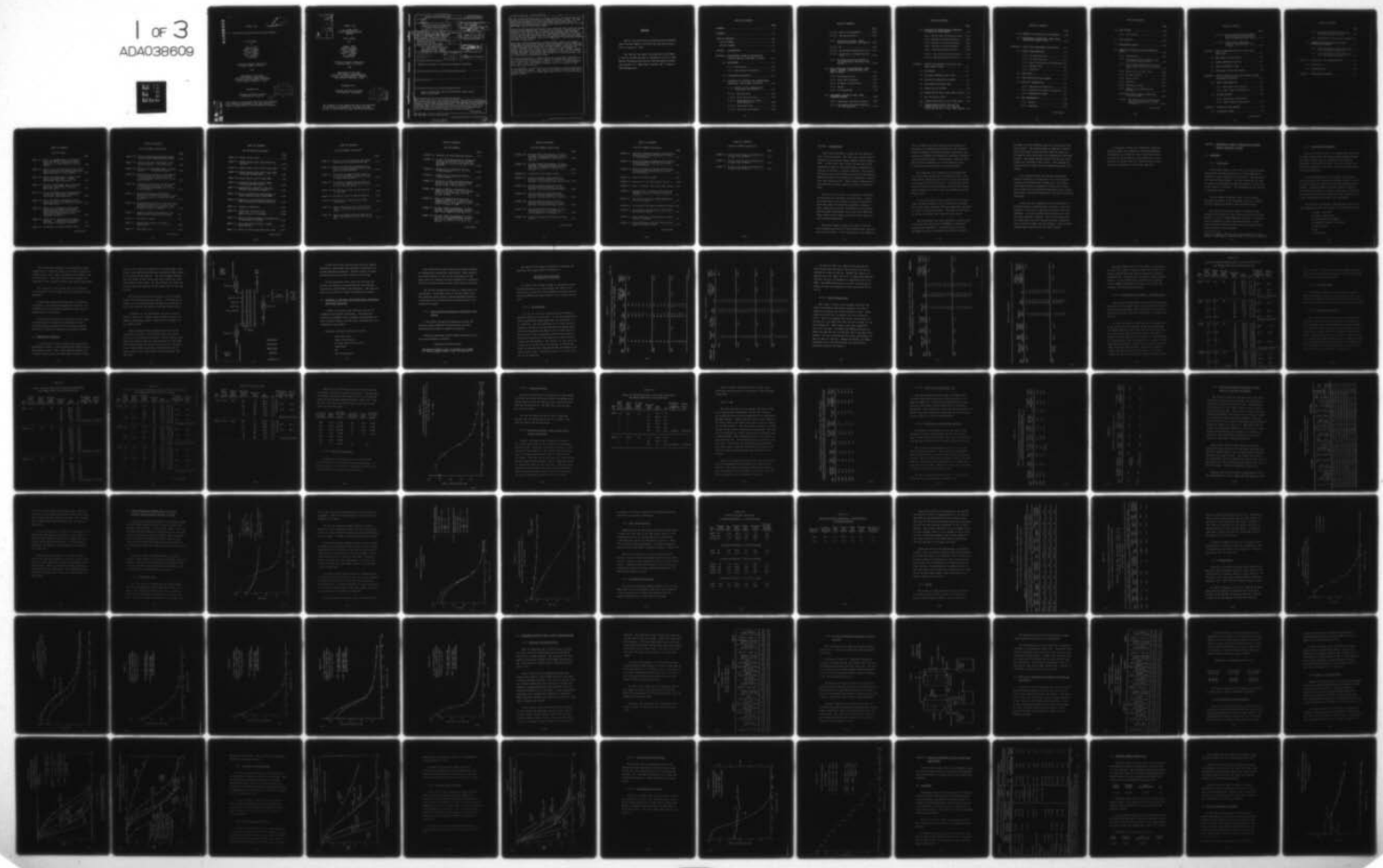
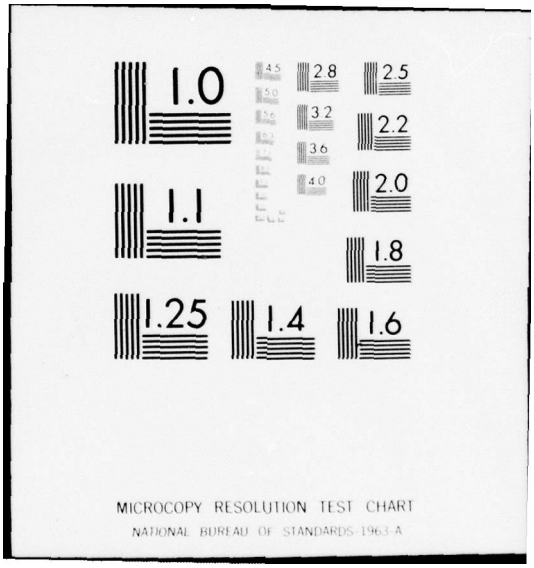
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REPORT 1602

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FINAL REPORT

BY

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RAYMOND SHUMAN
EZRA S. ALHADEFF
JEFFREY WARK
FRANK C. FARRELL
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A. FORSYTHE

WESTGATE RESEARCH CORPORATION
CONTRACT DAMD 17-75C-5013

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U.S.ARMY MEDICAL BIOENGINEERING
RESEARCH AND DEVELOPMENT LABORATORY
FORT DETRICK, MARYLAND 21301

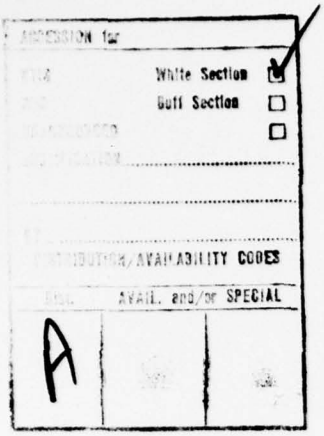
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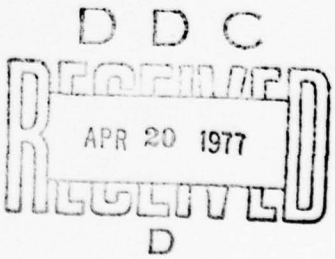
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (6)

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
UV-OZONE WATER OXIDATION/ STERILIZATION PROCESS. (9)

5. TYPE OF REPORT & PERIOD COVERED
Final Report, 1 Jul 74 - 31 Aug 76

6. PERFORMING ORG. REPORT NUMBER
~~1501~~ 1602

7. AUTHOR(s) (10)
Jack D. Zeff, Jeffrey Wark, A. Forsythe
Raymond Shuman, P.C. Farrell
Ezra S. Alhadeff, D.T. Boylan

8. CONTRACT OR GRANT NUMBER(s) (15)
DAMD 17-75-C-5013

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Westgate Research Corporation (Frank)
13478 Beach Avenue
Marina del Rey CA 90291

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Medical Research and Development Command
Washington DC 20314

12. REPORT DATE (11)
NOVEMBER 1976

13. NUMBER OF PAGES
208

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (14) 1602 (12) 214p.

15. SECURITY CLASS. (of this report)
None

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Ozone, Ultraviolet, Water Purification, Water Reuse, Water Disinfection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report describes the second and third year efforts of Westgate Research Corporation in developing UV-Ozone Systems for the Army MUST Program and for NASA Manned Spacecraft. In the first year program (Contract DADA 17-73-C-3138), the UV-ozone process was found to be more effective than either ozone or UV alone in destroying trace organic compounds and microorganisms in various waters.

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In the second and third years, process variables of importance were studied on the bench and then in a URM pilot plant system. The URM (Unit Reactor Module) is a basic building block module which is designed to be unitized into a full-scale UV-ozone system for the Army MUST Water Processing Element (WPE).

Statistically designed experiments were conducted using both the bench system and the URM system. In these tests various compositions of synthetic waste waters, which simulate the permeate from the MUST reverse osmosis system, were used. Mathematical models of the bench system and the URM system were derived. These models describe power consumption and retention time for a wide range of operating conditions and water compositions.

Using the mathematical models, minimum power, weight, and volume, UV/O_3 MUST and spacecraft systems can be designed. For the MUST WPE, a URM UV/O_3 system designed for treating hospital composite, reverse osmosis permeate will occupy 5'6" x 5'6" x 2'6", will weigh 750 pounds, and will have a total power demand of 5 KW. Volume, height, weight, and power requirements are minimized by the use of vertical 36 inch UV lamps, by operating the system at 3-5 psig pressure, and by eliminating a precontactor stage.

For manned spacecraft, a UV/O_3 system (no expendables required) can be developed which removes the organic residuals from wash water. This system will accommodate a crew of 5, will be 7 inches diameter by 8 inches long, will weigh 12 pounds, and will consume 36 watt-hours per pound of water.

A no-expendable, system can also be developed for disinfecting water in the Shuttle Orbiter. This system will weigh 9 pounds, will be 4 inches diameter by 11.5 inches long, and will use 7.9 watt-hours per pound of water.

FOREWORD

This is the final report describing work performed under Contract DAMD 17-75-C-5013 for the period July 1, 1974 to August 31, 1976.

The contract was under the direction of LTC LeRoy H. Reuter and CPT Jeremiah J. McCarthy of the U.S. Army Medical Bioengineering Research and Development Laboratory and Mr. A.L. Ingelfinger, and Mr. Dan C. Popma of NASA Headquarters.

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SECTION 1 INTRODUCTION

This report describes a study that was conducted over a two year period. The first year of the study is summarized in the Annual Report (Report 1501), December 1975. In this first year, effort was directed to the oxidation of specific individual organic compounds and mixtures of organics in aqueous solution. The organics of interest to the Army Medical Research and Development Command and NASA were hydroquinone, pyrogallol, xylenol, urea, and sodium acetate. Other organic compounds also evaluated were ethanol, glycerol, glycine, and acetic acid.

This first year effort was conducted on the bench in both batch and continuous reaction modes. Studies were undertaken on the effects of ozone concentration, ozone mass flow, UV intensity, agitation, residence time, temperature, and pH. Preliminary estimates were made for power requirements for a full-scale MUST WPE UV-O_3 system and for water re-use and water supply systems in manned spacecraft.

The annual report of this first year's work has been incorporated into this report which covers the overall two year effort. In the second year, the objectives

were to complete the bench study of the variables of importance on individual and mixtures of the selected organic compounds in aqueous solution; then define the operating variables for oxidizing a specified, synthetic reverse osmosis permeate. This permeate simulates the MUST hospital composite waste water which has been treated by ultra-filtration and reverse osmosis.

The study was to be conducted on the bench first in a batch mode and then in a continuous system. The study of the continuous operation was to be carried out in a design-of-experiment regime. A preliminary mathematical model was to be formulated to aid in the design and development of a 1/10 to 1/15 scale MUST pilot plant UV-O_3 system.

In the final phase of the second year of this program, the pilot plant was to be fabricated, assembled, and tested; again using the design-of-experiment approach to evolve a mathematical model. The model is then used to design an optimum, full scale UV-ozone system.

These objectives have been fulfilled, and the pilot system has been delivered to USAMBRDL for additional testing and evaluations. The pilot UV-O_3 system as developed consists of two Unit Reactor Modules (URM).

The URM is a basic building block for a full scale MUST UV-O_3 system. The optimum number of URMs are unitized into a full-scale system with the required number of UV lamps to treat waste waters as designated in the MUST program. The design characteristics for the full scale systems are included in this report. These designs as derived from the models are for minimum total power and volume.

It is recognized that the present mathematical models and designs are based upon tests using hospital composite RO permeate with 12 mg/l urea. The models and designs should be expanded to include other waste waters which will be encountered and waste waters spiked with organic constituents which are resistant to ordinary ozonolysis.

A study was also undertaken in the second year to determine means of removing urea from water, since this compound is resistant to ordinary ozonolysis and UV-O_3 oxidation. A study was made of the literature to seek out other methods of removal. Very little information was found other than urea removal by enzyme decomposition, activated carbon, and ion exchange. None of these methods appear practical for the MUST program.

A literature search and a laboratory study was made on aqueous urea photolysis and photo-oxidation. Preliminary tests show that urea at certain concentrations can be removed at a more rapid rate in the presence of shorter wave UV. However, more research has to be undertaken to verify this approach.

SECTION 2 EXPERIMENTAL STUDY OF OXIDATION OF SELECTED ORGANIC COMPOUNDS IN WATER

2.1 BACKGROUND

2.1.1 Theoretical

In the Final Report of the first year of this program, two possible reaction mechanisms for ozone oxidation of organics in water solution were described.* The mechanisms are ionic and free radical. In ionic oxidation, one atom of oxygen by electrophilic action participates in each step of the organic's oxidation. The by-product of the reaction is molecular oxygen.

In free radical oxidation, ozone is the reaction initiator and oxygen is the principal reactant. Examples of each reaction are given in the referenced report.

The role of ultraviolet light in conjunction with ozonolysis of organics in water solution was not discussed. Actually, little is known about this reaction; it could be either catalysis or a free-radical mechanism. In this study one of the objectives was to obtain further insight into the cause of this reaction.

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*Zeff, J.D. et al, "UV-Ozone Water Oxidation/Sterilization Process," Final Report, Contract DADA 17-73-C-3138, Sept.1974

2.1.2 Experimental Background

In the first year study, it was found that when using a column reactor with a UV lamp extending axially through the entire height, partial oxidation of hydroquinone, pyrogallol, and xylenol occurred. However, oxidation did not go to completion, since there was no detectable change in TOC concentration.

At the commencement of this program, the objective was to set up a more efficient laboratory system to attain a greater degree of oxidation of the selected organic compounds. If nearly-complete oxidation could be achieved, an assessment of process variables could then be undertaken to determine the variables which were most influential on energy requirements and reactor size and weight.

The first year experiments indicated that these variables appeared to have some effect on oxidation efficiency:

1) ozone mass flow
2) ozone concentration
3) concentration of organics
4) chemical structure of organics
5) UV intensity
6) pH
7) temperature

The experimental approach at the beginning of this program was to initially screen all of these variables to further assess their degree of influence on oxidation and UV efficiencies. Once the variables were screened for importance, more detailed testing could then be undertaken.

The compounds tested in the first year continued to be evaluated in this study, as well as mixtures of the compounds.

As the study progressed, other waste constituents of interest to the contracting agencies were also to be evaluated to provide further insight into the range of capabilities of the process.

From the data collected in the course of the study, a design analysis was made which predicted reactor sizing and energy expenditures for processing specific quantities of waters of interest to the Army and NASA.

2.2 EXPERIMENTAL APPARATUS

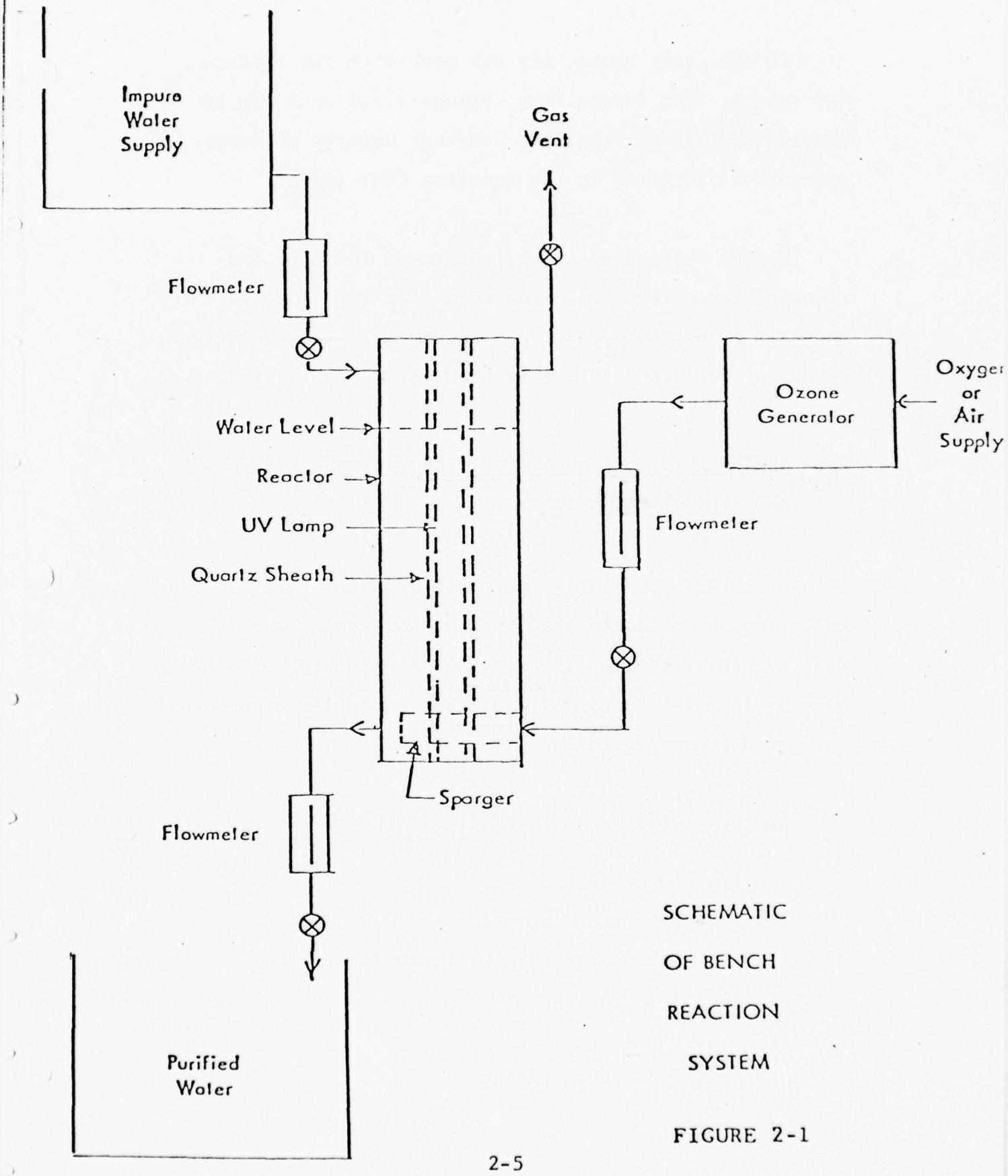
A 3 liter and a 12 liter reactor were used in the experimental studies. Both reactors were fabricated from 304 stainless steel. The 3 liter capacity reactor was 3 inches in diameter by 36 inches high, and the 12 liter

reactor was 6 inches in diameter by 36 inches high. Each reactor contained one low-pressure, mercury UV lamp located in the center of the reactor. The lamp extended through the full height of the reactor and was sheathed in a one-inch diameter quartz tube. At line voltage, the lamp drew 43 watts which was measured at the input-leads of the lamp ballast.

The ozone was diffused from the base of the reactor using a 10-30 micron pore-size sparger. The ozone gas in oxygen or air diffused upwardly through the contaminated water and exited at the outlet at the top of the reactor.

A schematic of the experimental reaction system is shown in Figure 2-1. Either reactor could be operated as either a continuous system as shown in the schematic, or as a batch system.

Three different ozone generators were used in the experimental program. In the early tests, two Sanders ozonizers were operated in parallel. These ozonizers were limited in capacity and were soon replaced by a PCI Model C2P Ozone Generator for larger scale tests and continuous tests. When further scale-up was implemented, the PCI Ozone Generator was replaced with a Welsbach Model T816 Generator.



SCHEMATIC OF BENCH REACTION SYSTEM

FIGURE 2-1

In the early tests, air was used with the Sanders Generators; then oxygen from cylinders replaced air to provide additional capacity. Further details on ozone generation are given in the sections that follow.

In the continuous tests, water was fed into the reactor by gravity at a prescribed flow rate and was measured by a Brooks Model 2001 Rotameter. The purified water was collected in a poly tank below the reactor.

2.3 SCREENING OF VARIABLES FOR HYDROQUINONE, PYROGALLOL, AND XYLENOL OXIDATION

A number of variables may influence the rate of oxidation and oxidation efficiency. Screening was designed to eliminate those variables which appeared to have a minimal effect, and the other variables were then evaluated in more detail.

Variables evaluated initially included:

Ozone mass flow
Ozone concentration
UV input power / UV intensity
Temperature
pH
TOC concentration

The assessment was made using an equal part solution of hydroquinone, pyrogallol, and xylenol. This solution was representative of some of the constituents in the waste waters of interest and was considered as a departure point in the more detailed study of the process variables.

The initial evaluation was done on a batch basis for convenience. In previous work, it had been shown that the operating levels found in batch operations served as a valid guide for establishing the operating levels for continuous systems.

2.3.1 Batch Testing, Hydroquinone, Pyrogallol, and Xylenol

In the batch testing and subsequent testing, TOC analysis using a Beckman 915 Analyzer was used for determining the degree of complete oxidation.

Oxidation efficiency and UV energy efficiency in all tests were defined as follows:

Oxidation Efficiency Index

$$\frac{\text{TOC Removed (mg/l)} \times \text{Vol. of Influent (l)} \times 100\%}{1/8 \times \text{Ozone consumed (mg/l)} \times \text{Vol. of Ozone Gas (l)}}$$

The amount of UV energy consumed for promoting the oxidation (UV energy index) is defined as:

$$\frac{\text{UV Energy (watt-minutes)}}{\text{TOC Oxidized to } CO_2 \text{ (mg)}}$$

To achieve the maximum economy in oxidizing a given contaminated water to a satisfactory TOC level, it is necessary to attain the maximum TOC/O_3 Efficiency and the minimum UV/TOC Energy Demand within a reasonable reaction time.

2.3.1.1 pH Adjustment

A series of tests were conducted where the pH was adjusted upward to 8 or greater. It has been reported by other experimenters that higher pH's increased the rate of oxidation. The test procedure was to make up the 3-component solution to 50 mg/l TOC using distilled water and increasing pH by the addition of 4 N NaOH solution. Three liters of the 3-component solution were added to the UV-O_3 reactor and 25 ml samples were taken every 15 minutes for TOC analysis. The reactor was operated as a batch system and the rate of oxidation was determined. Table 2-1 presents the reduction of TOC and change of pH with reaction time. Experiment M378 was a control where pH was not adjusted.

Table 2-1

Table 2-1

Effect of pH Adjustment on UV Energy Index and TOC/O_3 Efficiency, Batch Reactions, 3 Liter Volume, 34 mg O_3/O_2/min

Exp. No.	Reaction Time (min)	UV Lamp Input Power (watts)	TOC (mg/l)	pH	Overall UV Energy Index $\frac{\text{watt-min}}{\text{mgC}}$	Overall TOC/O_3 Effic (%)
M379	0	34.1	46.5	8.3	22.0	36.5
	15		48.6	6.9		
	30		38.3	6.0		
	45		22.8	5.9		
	60		9.8	6.6		
	75		4.1	7.3		
	90		0	7.8		
M380	0	0	54.4	8.9	-	10.3
	15		48.4	5.7		
	30		48.3	5.0		
	45		48.9	4.8		
	60		45.6	4.6		
M381	0	34.1	46.5	10.1	18.3	43.8
	15		42.5	9.0		
	30		35.2	7.5		
	45		23.9	7.3		
	60		10.3	7.6		
	75		0	8.0		

(continued)

Table 2-1 (continued)

Table 2-1 (continued) Exp. No.	Reaction Time (min)	UV Lamp Input Power (watts)	TOC (mg/l)	pH	Overall UV Energy Index watt-min / mgC	Overall TOC/O_3 Effic (%)
M382	0	0	52.4	9.4	-	26.7
	15		41.9	6.9		
	30		40.9	6.7		
	45		32.7	6.6		
	60		31.2	6.7		
	75		23.3	7.0		
	90		18.4	7.1		
M383	0	28.1	50.0	9.2	17.1	38.6
	15		43.1	7.8		
	30		34.7	6.8		
	45		23.9	6.7		
	60		12.8	7.0		
	75		5.0	7.5		
	90		0.8	8.1		
M384	0	48.3	53.4	9.3	22.6	16.7
	15		45.0	7.0		
	30		37.8	6.6		
	45		19.7	6.8		
	60		7.8	7.2		
	75		0	8.0		
M378	0	34.1	53.9	6.4	15.8	50.7
	15		43.1	3.7		
	30		26.8	3.6		
	45		17.1	3.8		
	60		4.0	4.4		
	75		0	6.0		

As shown in Table 2-1, when the UV lamp was off (Experiments M380 and M382), TOC oxidation was slow in comparison to when UV was on. Without the lamp on, it appeared that the higher pH of 9.2 in Experiment M382 did increase the rate of oxidation as compared to pH 8.9 in M380. The TOC/O_3 Efficiencies in these two experiments without UV were low compared to those runs where the UV was on.

2.3.1.2 Ozone Concentration

This series of tests were designed to measure the effect on oxidation efficiency, UV index, and rate of reaction by varying the concentrations of ozone. Either compressed dried air, or oxygen, was used to generate ozone. Table 2-2 compares the results using either 5.75 mg O_3/l or 8.3 mg O_3/l plus 34.1 watt UV to using 5.75 mg O_3/l without UV. These results were then compared to using 19.5 mg O_3/l. As shown, the TOC/O_3 efficiency is about the same for the 5.75 mg O_3/l and 8.3 mg O_3/l level; however, the rate of oxidation was slower when using 5.75 mg/l O_3 than 8.3 mg/l O_3. Without UV (M386), the TOC/O_3 efficiency fell to 12.9% and only 10.4 mg/l TOC was oxidized to CO_2 in 120 minutes.

Table 2-2 Effect of O_3 Concentration in Air on UV Power Efficiency and TOC/O_3 Efficiency, Batch Reactions, 3 liter Volume

Table 2-2

Exp. No.	Ozone Conc in Air (mg/l)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	Overall UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	Overall TOC/O_3 Effic. (%)
M385	5.75	16.1	34.1	0	50.3	6.5	27.2	62.2
				15	42.1	4.1		
				30	43.2	3.8		
				45	36.2	3.8		
				60	24.7	3.8		
				75	17.5	4.1		
				90	10.0	4.3		
				105	4.0	4.4		
				120	0.2	4.7		
M387	8.3	23.3	34.1	0	54.8	6.2	19.5	60.0
				15	48.9	4.1		
				30	45.0	3.9		
				45	35.7	3.9		
				60	22.2	3.9		
				75	11.2	4.1		
				90	2.3	4.1		

(continued)

Table 2-1 (continued)

Exp. No.	Ozone Conc in Air (mg/l)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	Overall UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	Overall TOC/O_3 Effic. (%)
M386	5.75	16.1	0	0	46.6	6.5	-	12.9
				15	42.1	4.3		
				30	42.6	3.9		
				45	40.7	3.9		
				60	39.0	3.9		
				75	36.7	3.8		
				90	34.2	3.9		
				105	35.7	3.9		
				120	36.2	3.8		
M388	19.5 (in O_2)	54.5	34.1	0	50.9	6.1	13.9	36.0
				15	42.6	4.0		
				30	29.2	3.7		
				45	13.2	4.2		
				60	1.9	4.7		

Experiment M388 shows that the higher concentration of ozone (19.5 mg/l) in oxygen reduces the amount of UV energy required since the rate of oxidation increases significantly. The efficient utilization of O_3, however, suffers. It was obvious that trade-offs are required between TOC/O_3 efficiency, UV energy utilization, and reaction time with O_3 concentration.

2.3.1.3 Programming of O_3 Input -- Batch Reactions

This series of experiments were designed to determine the effect of varying the ozone concentration with time as the oxidation proceeded. This information was useful in determining whether there was an advantage in staging the process.

As shown in Table 2-3, M395 was run at a higher level of O_3 concentration through the entire reaction period. The TOC/O_3 efficiency was higher and the UV energy index was lower in the first 60 minutes than in the last 15 minutes when the TOC level fell below 6.4. Decreasing the O_3 concentration at the beginning of the reaction in M398 and M399 had an adverse effect on the amount of UV energy /mgC required in this interval. There was a lower UV energy index when the O_3 concentration was decreased towards the end of the reaction as shown in M1301 in com-

Table 2-3

Effect of Programming O_3 Input on UV Power Efficiency and TOC/O_3 Efficiency, Batch Operation

Exp. No.	Ozone conc in O_2 (mg/l)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	UV Energy Index (watt-min / mgC)	TOC/O_3 Effic. (%)
M395	25.9	72.5	43	0	84.3	7.3		
				15	66.9	4.7	13.0	36.4
				30	51.3	4.5		
				45	21.7	4.8	9.6	49.5
				60	6.4	5.3		
				75	2.3	6.0	52.4	9.0
							13.1(ave)	36.2(ave)
M398	21.0	58.8	43	0	71.4	6.7		
	"	"		15	69.2	4.0	51.8	11.3
	"	"		30	63.1	3.9		
	25.9	72.5		45	42.1	4.1		
	"	"		60	21.8	4.3	10.4	45.6
	"	"		75	8.2	4.7		
	21.0	58.8		90	3.1	6.7	23.0	35.4
							18.9(ave)	28.7(ave)
M399	9.1	25.4	43	0	69.2	7.0		
	"	"		15	68.8	5.2	1075	1.3
	"	"		30	68.8	4.4		
	23.2	65.0		45	64.9	4.0	25.4	20.8
	"	"		60	51.9	4.0		
	"	"		75	38.1	4.0		
	9.1	25.4		90	27.9	4.0		
	"	"		105	17.5	4.7	20.5	60.5
	"	"		120	9.9	4.8		
	"	"		135	3.9	6.1		
							29.6(ave)	33.9(ave)
M1301	24.1	67.4	43	0	75.4	7.0		
	"	"		15	65.5	4.3	17.8	27.4
	"	"		30	52.3	3.9		
	"	"		45	33.3	4.2	10.0	48.8
	15.9	44.6		60	11.2	4.3		
	"	"		75	1.9	5.4	37.4	19.7
	"	"	(2-15)	90	0.2	6.7		
							16.4(ave)	33.5(ave

parison to M395. However, the average TOC/O_3 efficiencies were not improved when the O_3 concentration was decreased at the end of the reaction period.

2.3.1.4 Ozone Mass Flow

A preliminary comparison of mass flow is shown in Table 2-4. With an increase in mass flow of ozone, both UV index and TOC/O_3 efficiency decreased, indicating that excess ozone mass flow did not improve the rate of reaction.

2.3.1.5 UV Energy Programming

After assessing the effects of O_3 concentration and mass flow, the next step was to determine the impact of programming UV energy input on TOC/O_3 efficiency and UV/mgC. This assessment was made by operating the reactor on a batch basis using 3 liters of 3-component mixture per batch. Results of this series of tests are shown in Table 2-5. Minimum UV energy with the greatest TOC/O_3 efficiency was obtained by using an O_3 mass flow of 70.8 mg/min, and a UV lamp input of 43 watts for 30 minutes, then a reduction to 29 watts for 30 minutes, and then off.

Table 2-4

Effect of Ozone Mass Flow on UV Power Efficiency and TOC/O_3 Efficiency, Batch Operation

Exp. No.	Ozone conc in O_2 (% by wt)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
M394	1.9	74	43	0	84.3	7.3		
				15	66.9	4.7		
				30	51.3	4.5		
				45	21.7	4.8		
				60	6.4	5.3		
				75	2.3	6.0	13.1(ave)	36.2(ave)
M1339	2.5	124	43	0	83.5	5.8		
				15	83.0	3.2		
				30	77.5	3.2		
				45	47.5	3.0		
				60	20.5	3.5		
				75	14.0	3.8		
				90	8.0	4.2		
				105	4.5	5.0		
				120	3.0	5.5		
				135	2.0	5.8	19.0(ave)	14.6(ave
M1338	2.7	171	43	0	90.0	5.1		
				15	-	-		
				30	67.5	3.5		
				45	25.0	3.8		
				60	13.3	4.0		
				75	6.5	5.0		
				90	4.5	6.0		
				105	2.5	6.0		
				120	1.5	6.0	15.1(ave)	13.3(ave

Table 2-5

Effect of Programming UV Energy Input on UV Power Efficiency and TOC/O_3 Efficiency, Batch Operation

Exp. No.	Ozone conc in O_2 (mg/l)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
M1302	27.2	76.3	41.2	0	76.3	6.9		
	"	"	"	15	73.3	4.2	22.1	19.5
	"	"	34.1	30	57.7	3.9		
	"	"	34.1	45	34.3	4.1	8.5	42.0
	15.9	44.6	41.2	60	17.6	4.3		
	"	"	"	75	4.8	5.2	25.4	29.1
	"	"	"	90	1.4	6.0		
							15.5(ave)	33.4(ave)
M1303	24.1	67.4	41.2	0	80.0	6.8		
	"	"	"	15	72.8	4.2	19.5	25.0
	"	"	28.1	30	58.9	3.9		
	"	"	"	45	36.2	4.2	6.1	54.2
	15.9	44.6	41.2	60	13.2	4.5		
	"	"	"	75	3.9	5.4	34.3	21.5
				90	1.2	6.1		
							14.0(ave)	35.1(ave)
M1304	24.1	67.4	41.2	0	82.9	7.0		
	"	"	"	15	80.1	4.3	18.1	25.9
	"	"	0	30	60.2	4.1		
	"	"	"	45	47.0	3.8	0	20.4
	15.9	44.6	41.2	60	43.0	4.1		
	"	"	"	75	35.2	4.1	15.4	47.9
	"	"	"	90	16.3	4.4		
	"	"	"	105	4.8	5.1	27.3	27.1
	"	"	"	120	1.2	6.7		
							15.1(ave)	29.2(ave)

(continued)

Table 2-5 (continued)

Exp. No.	Ozone conc in O_2 (mg/l)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
'1312	25.3	70.8	43	0	68.6	7.4		
			"	15	59.4	4.1	12.5	39.0
			29	30	34.1	4.4		
			"	45	9.8	4.9	8.8	37.4
			0	60	1.0	6.6		
			0	75	0.2	5.7		
							10.5(ave)	30.9(av
M1313	25.3	70.8	43	0	86.8	6.5		
			"	15	72.0	4.8	10.7	45.2
			29	30	46.8	3.6		
			"	45	16.7	4.1	6.8	48.4
			0	60	4.0	4.4		
			0	75	3.0	5.1		
			0	90	1.9	4.9		
							8.5(ave)	32.0(av

Input power to the UV lamp was varied by the use of a 110 volt, laboratory variable transformer. Measurements of UV power intensity of the lamp at 253.7 nm was made by using an Ultra-Violet Products UV Meter, Model J225. The distance from the center of the lamp to the face of the meter cell was 7/8 inches.

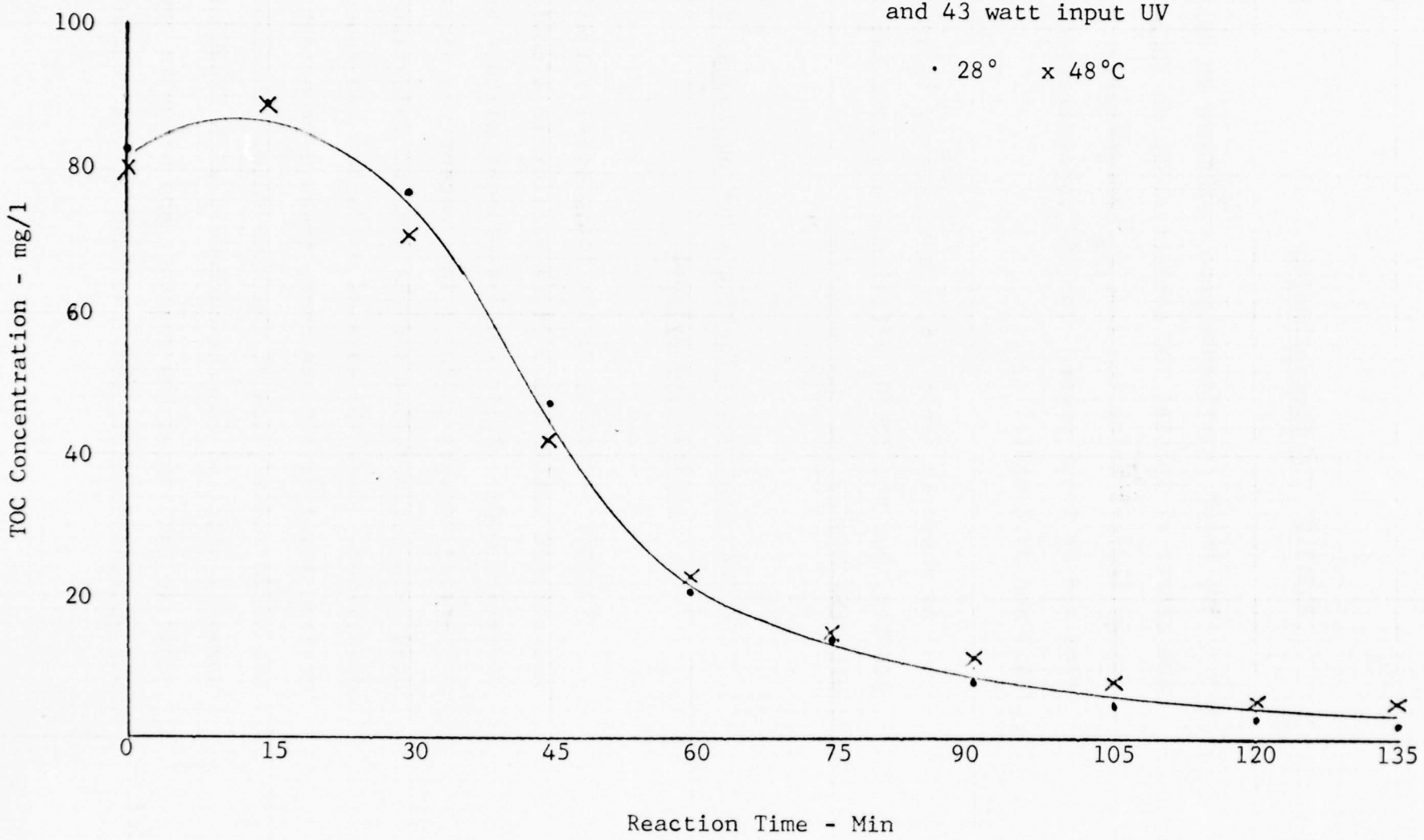
Variable Transformer Setting	Power Input Watts	UV Power Intensity uw/cm^2	Variable Transformer Setting	Power Input Watts	UV Power Intensity uw/cm^2
140	48.3	11,100	70	34.1	7,500
130	45.3	10,800	60	32.5	6,800
120	43.3	10,320	50	29.9	5,900
110	41.2	9,800	45	28.1	5,400
100	39.9	9,300			
90	38.2	8,800			
80	35.3	8,200	40	OFF	

2.3.1.6 Effect of Temperature

A comparison of oxidation rates at 48°C and 28°C were made for 3 liter batches of 3-component mixture. As shown in Figure 2-2, the rate of oxidation of this mixture was unaffected by an increase in temperature.

Figure 2-2

3 Liter Batch Oxidation of 3-Component Mixtures
at 28°C and 48°C using 124 mg O_3/min @ 2.5% O_3 in O_2
and 43 watt input UV



2.3.1.7 TOC Concentration

Two batch experiments were conducted on determining the effect of initial TOC concentration on TOC/O_3 and UV energy indices using the same O_3 concentration and mass flow and UV input power. The TOC concentrations were 84.3 and 39.2 mg/l.

As shown in Table 2-6, the UV energy index was greater, but the TOC/O_3 efficiency was somewhat lower with the higher TOC concentration.

2.3.2 Continuous Testing - Hydroquinone, Pyrogallol, and Xylenol

Further screening of the independent variables was carried out in the 3 liter reactor in a continuous operating mode. Again the 3-component mixture was used at various concentrations. The reactor was first operated as a batch system and the rate of oxidation was determined. Once the rate of oxidation was found and the desired level of TOC achieved, fresh 3-component mixture was added and removed at the same rate. The reactor was normally operated counter-currently with fresh mixture added at the top of the reactor, and ozone in oxygen or air sparged upwardly from the base of the reactor.

Table 2-6

Effect of TOC Concentrations on UV Power Efficiency and TOC/O_3 Efficiency, Batch Operation

Exp. No.	Ozone conc in O_2 (w+%)	Ozone Mass Flow (mg/min)	UV Lamp Input Power (watts)	Reaction Time (min)	TOC (mg/l)	pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
M394	1.8	72.5	43	0	84.3	7.3		
	"	"		15	66.9	4.7		
	"	"		30	51.3	4.5		
	"	"		45	21.7	4.8		
	"	"		60	6.4	5.3		
	"	"		75	2.3	6.0	7.3(ave)	36.2(ave)
M1315	1.7	70.8	43	0	39.2	6.6		
	"	"		15	10.2	4.6		
	"	"		30	0	6.6	13.1(ave)	44.3(ave)

Those variables which have been examined in the continuous operating mode are described in the following subsections.

2.3.2.1 pH

The test procedure for the upward adjustment of pH was to make up the 3-component, 50 mg/l TOC solution, using distilled water and increasing pH by the addition of 4N NaOH solution. Three liters of solution were added to the UV-O_3 reactor and samples were taken every 15 minutes for the TOC analysis. The reactor was operated as a batch system and the rate of oxidation was determined. Once the rate of oxidation was found, and the desired minimum level of TOC achieved, fresh 3-component mixture was added at a predetermined rate. Processed mixture was removed at the same rate. The reactor was operated counter-currently with fresh mixture added at the top of the reactor, and ozone-in-oxygen sparged upwardly from the base of the reactor.

Table 2-7 presents the results after the reactor was operated continuously and steady-state conditions were achieved. The upward adjustment of pH did not appear to have any profound effect on TOC/O_3 efficiency, nor on the UV energy index for the 3-component solution.

Table 2-7

Effect of pH Adjustment on UV Power Efficiency and TOC/O_3 Efficiency, Continuous Operation at Various Flow Rates and UV Input Power, 34 mg O_3/O_2/min (0.8% O_3)

Exp. No.	Influent TOC conc (mg/l)	Flow Rate (ml/min)	Res Time (min)	Influent pH	UV Lamp Input Power (watts)	Effluent TOC conc (mg/l)	Effluent pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
M379	46.5	33	91	8.3	34.1	2.9	7.5	23.7	33.8
M381	46.5	40	75	10.1	34.1	0	8.0	18.3	43.8
M383	50.0	33	91	9.2	28.1	4.5	7.8	18.7	35.3
M384	53.4	40	75	9.3	48.3	3.7	7.6	24.4	50.2
M378	53.9	40	75	6.4	34.1	2.7	4.7	16.6	48.2

2.3.2.2 O_3 Concentration/O_3 Mass Flow

The batch oxidations, M385, M387, and M388, where the ozone concentration and mass flow were varied, are shown in Table 2-2. Each of these experiments were operated in a batch mode, and then converted to continuous operations. The steady-state values are shown in Table 2-8. The UV energy utilization increased with O_3 concentrations and mass flow as it did in the batch mode.

2.3.2.3 Co-Current vs. Counter-Current Flow

A preliminary continuous test was run where fresh 3-component mixture was introduced to the base of the 3 liter reactor instead of the top. The ozone-in-oxygen was then sparged from the base co-currently with the influent.

The reactor start-up procedure was the same as the counter-current operation. Three liters of 3-component mix were placed in the reactor, and UV and O_3 sparging was started. After the TOC level was below 5 mg/l, continuous flow was started; then flow continued until steady-state conditions were reached. Table 2-9 compares the co-current run with a previous counter-current run.

For the same operating levels, there is very little difference in efficiencies or residence time.

Table 2-8

Effect of O_3 Concentration in Air on UV Power Efficiency and TOC/O_3 Efficiency, Continuous Operation

Exp. No.	Influent TOC conc (mg/l)	Flow Rate (ml/min)	Res Time (min)	O_3 conc in Air (mg/l)	O_3 Mass Flow (mg/min)	UV Lamp Input Power (watts)	Effluent TOC conc (mg/l)	pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
M385	50.3	25	120	5.75	16.1	34.1	3.0	4.3	28.8	58.8
M387	54.8	33	91	8.3	23.3	34.1	1.3	4.0	19.3	36.4
M388	50.9	50	60	19.5 (in O_2)	54.5	34.1	0.7	5.4	13.6	36.8

Table 2-9

Co-Current Vs. Counter-Current Flow

Exp. No.	Influent TOC Conc (mg/l)	Influent Flow Rate (ml/min)	Res. Time	O_3 Conc in O_2 (mg/l)[2]	O_3 Mass Flow (mg/min)	UV Lamp Input Power (watts)	Effluent TOC Conc (mg/l)	pH	UV Energy Index $\left(\frac{\text{watt-min}}{\text{mgC}}\right)$	TOC/O_3 Effic. (%)
M388	50.9	50 (counter-current)	60	19.5	54.5	34.1	0.7	5.4	13.6	36.0
M1308	46.0	50 (co-current)	60	15.9	44.6	34.1	6.4	5.3	17.2	35.5

2.3.3 Two-Stage Continuous Oxidation of Hydroquinone, Pyrogallol and Xylenol

The effect of using less UV input power once the 3-component mix was partially oxidized, was examined by a simulated, two-stage continuous system. The procedure was carried out in the 3 liter reactor using a counter-current operating mode. Three liters of the 3-component mixture were added to the reactor, the UV lamp was turned on, and ozone-in-oxygen sparging commenced. Once the desired TOC level was reached, additional fresh 3-component mixture was added at a fixed rate. Continuous flow was started by draining the effluent at the same rate. After steady-state conditions were reached, the effluent was collected. After sufficient effluent was saved, the reactor was shut down, drained and cleaned.

Three liters of first stage effluent were then returned to the reactor, the UV lamp power and ozone mass flow set, and the reactor run as a batch system until the TOC level was 5 mg/l or less. The reactor was then run as a continuous system by additng more first-stage effluent. The flow rate of the simulated second stage was the same as the first stage. Table 2-10 summarizes these tests.

Influent, TOC concentrations of approximately 20, 40, 60, and 80 mg/l were used. Higher UV input power was used

Table 2-10

Simulated Two-Stage Continuous Operation
Three - Part Simulated Waste Water

	1st Stage									2nd Stage								
Experiment No.	Influent conc TOC mg/l	Flow Rate ml/min	Res Time min	Effluent conc TOC mg/l	O_3 Input mg/min	O_3 Output mg/min	$\frac{TOC}{O_3}$ Effic.(%)	Lamp Watts	UV Energy Index $\frac{W\text{-}m}{mgC}$	Influent conc TOC mg/l	Flow Rate ml/min	Res Time (min)	Effluent conc TOC mg/l	O_3 Input mg/min	O_3 Output mg/min	$\frac{TOC}{O_3}$ Effic. (%)	Lamp Watts	UV Energy Index $\frac{W\text{-}m}{mgC}$	Ave $\frac{TOC}{O_3}$ Effic.% Supplied	Ave UV Energy Index $\frac{W\text{-}m}{mgC}$
M1321	84.2	100	30	23.8	70.8	23.0	68.2	43	7.2	23.8	100	30	8.4	70.8	32.1	17.4	29	17.5	42.7	9.4
M1322	56.3	100	30	16.0	70.8	25.1	45.5	43	10.7	16.1	100	30	4.5	70.8	31.7	13.1	29	25.0	29.3	13.9
M1323	86.0	100	30	47.3	70.8	21.8	43.7	43	11.1	46.0	100	30	9.1	70.8	43.9	41.7	29	8.8	43.4	9.4
M1329	65.0	100	30	33.7	75.6	21.6	33.1	43	13.7	33.1	100	30	7.5	75.6	29.0	27.1	29	12.5	30.4	12.5
M1324	40.4	200	15	22.9	70.8	27.1	39.5	43	12.3	22.9	200	15	5.4	70.8	37.4	39.5	43	12.3	39.5	12.3
M1325	43.3	200	15	20.0	70.8	27.8	52.6	43	9.2	19.0	200	15	5.4	70.8	35.5	30.7	29	10.7	42.8	9.5
M1326	19.5	200	15	7.1	70.8	26.4	28.0	43	17.3	7.5	200	15	4.5	70.8	70.6	6.8	0	0	16.9	14.3
M1327	19.5	200	15	9.3	75.6	32.4	21.6	29	14.2	8.0	200	15	4.9	75.6	67.9	6.6	0	0	15.4	9.9
M1328	19.5	200	15	7.1	75.6	31.2	26.2	29	11.7	6.3	200	15	5.8	54.7	46.3	1.7	0	0	16.8	10.6

in the first stage than in the second stage. The same mass flow rate of O_3 was used in the second stage as the first stage, with the exception of M1328. The residence time for the 60-80 mg/l TOC influent was 30 minutes in both stages.

It was the objective of these tests to obtain a less than 5 mg/l TOC second-stage effluent. This TOC was achieved with influents in the 20 to 60 mg/l TOC range, but not the 80 mg/l concentrations. A slight upward adjustment in residence time is required to accomplish the 5 mg/l TOC.

Average UV energy indices of less than 10 watt-minutes per mgC were achieved at all three concentrations using two-stage operations and less UV lamp power in the second stage. However, the average TOC/O_3 efficiency decreased with lower TOC inputs. This efficiency could possibly be increased if a lower mass flow was used in both stages.

2.4 BATCH OXIDATION OF HYDROQUINONE, PYROGALLOL, XYLENOL, SODIUM ACETATE, AND UREA IN WATER

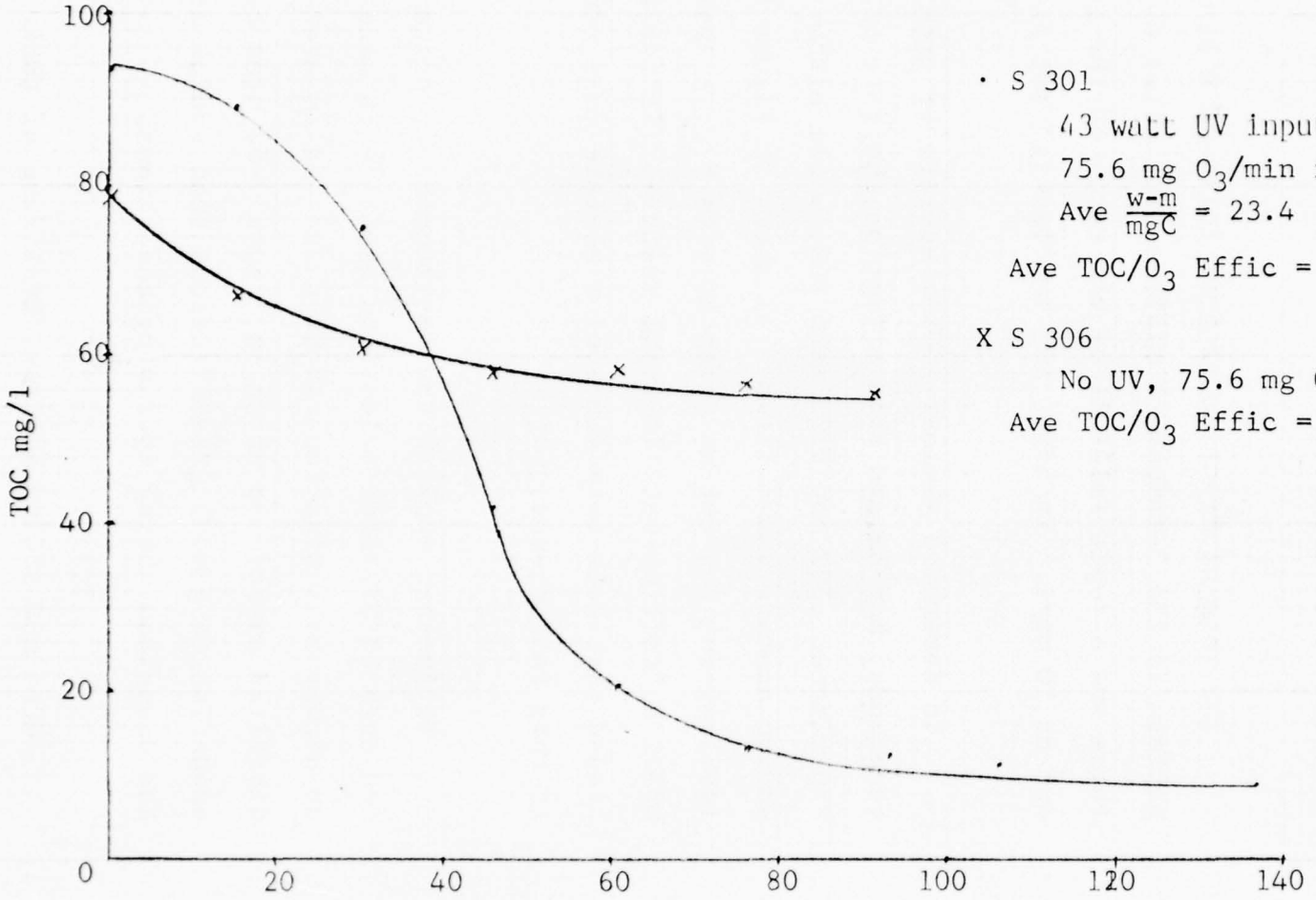
After the screening of variables was completed, those variables which appeared to have a greater impact were studied in more detail. To aid in this study, a new reactor with twice the diameter (6 inches) and four times the volume (12 liters) was used to study UV power intensity. The 3 inch and 6 inch diameter reactors were of equal height and the same 36 inch long, 43 watt UV lamp in a one-inch quartz sheath was used in the center of both reactors.

Water with equal parts hydroquinone, pyrogallol, xylenol, sodium acetate, and urea was evaluated, using both reactors. The latter two ingredients are found in waste waters generated on long-term manned space flight. Urea is also found in field hsopital waste waters.

2.4.1 Preliminary Tests

The first series of experiments determined TOC/O_3 efficiency and UV/mgC for 80-90 mg/l TOC solutions composed of an equal-part mixture of the five components: hydroquinone, pyrogallol, xylenol, sodium acetate, and urea. Figure 2-3 depicts the reduction of TOC with time

Oxidation of 5-Component Mixture Figure 2-3
3 liter Batches



· S 301
43 watt UV input
75.6 mg O_3/min in O_2
Ave $\frac{w-m}{mgC}$ = 23.4
Ave TOC/O_3 Effic = 29.6%

X S 306
No UV, 75.6 mg O_3/min in O_2
Ave TOC/O_3 Effic = 8.5%

for 3 liter batch reactions which were sparged with 75.6 mg O_3/min. S301 had a steady input of 43 watts UV, and S306 had no UV input.

The rate of reaction of S301 followed a similar pattern to the 3-component mixture, but after 60 minutes there was a rapid fall-off of the rate and the TOC leveled out at 10 mg/l. In S306, the TOC leveled out at 55 mg/l.

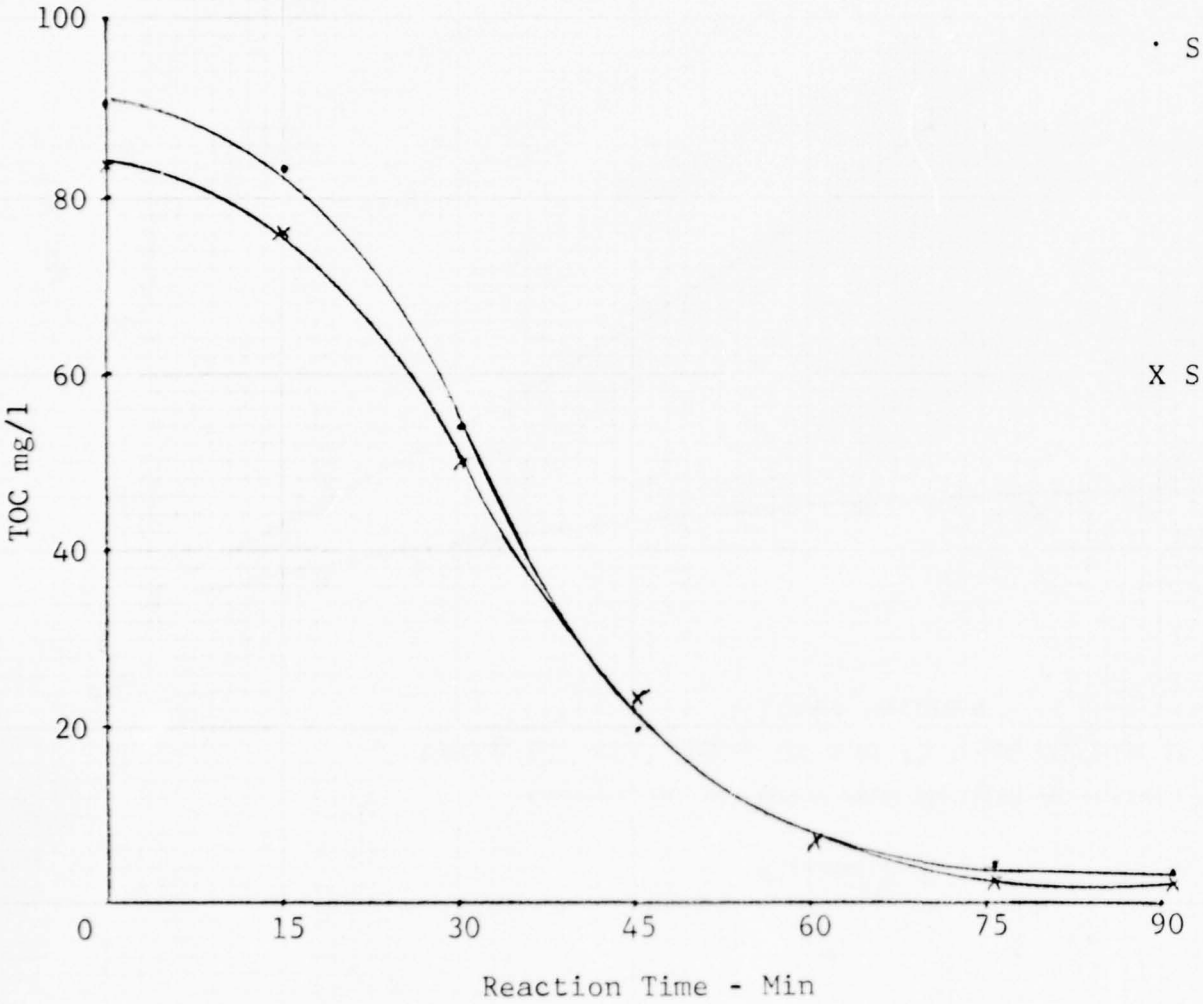
To determine whether sodium acetate or urea, or both compounds, had caused this effect on the rate of reaction, Experiments S302 and S303 were run, where either urea or sodium acetate was omitted. As shown in Figure 2-4, the leveling-out was not as great as with S301. There was still a "tailing-out" for each mixture. It can be concluded that both urea and sodium acetate must contribute to this tailing-out.

To further explore the resistance of sodium acetate and urea to UV-ozone oxidation, experiments were conducted on higher concentrations of urea and sodium acetate in distilled water. As shown in Figure 2-5, urea resists UV-ozonation to a much greater extent than sodium acetate for the described set of operating conditions.

Urea and sodium acetate, by virtue of their greater

Figure 2-4

Oxidation of 4-Component Mixture
3 liter Batches

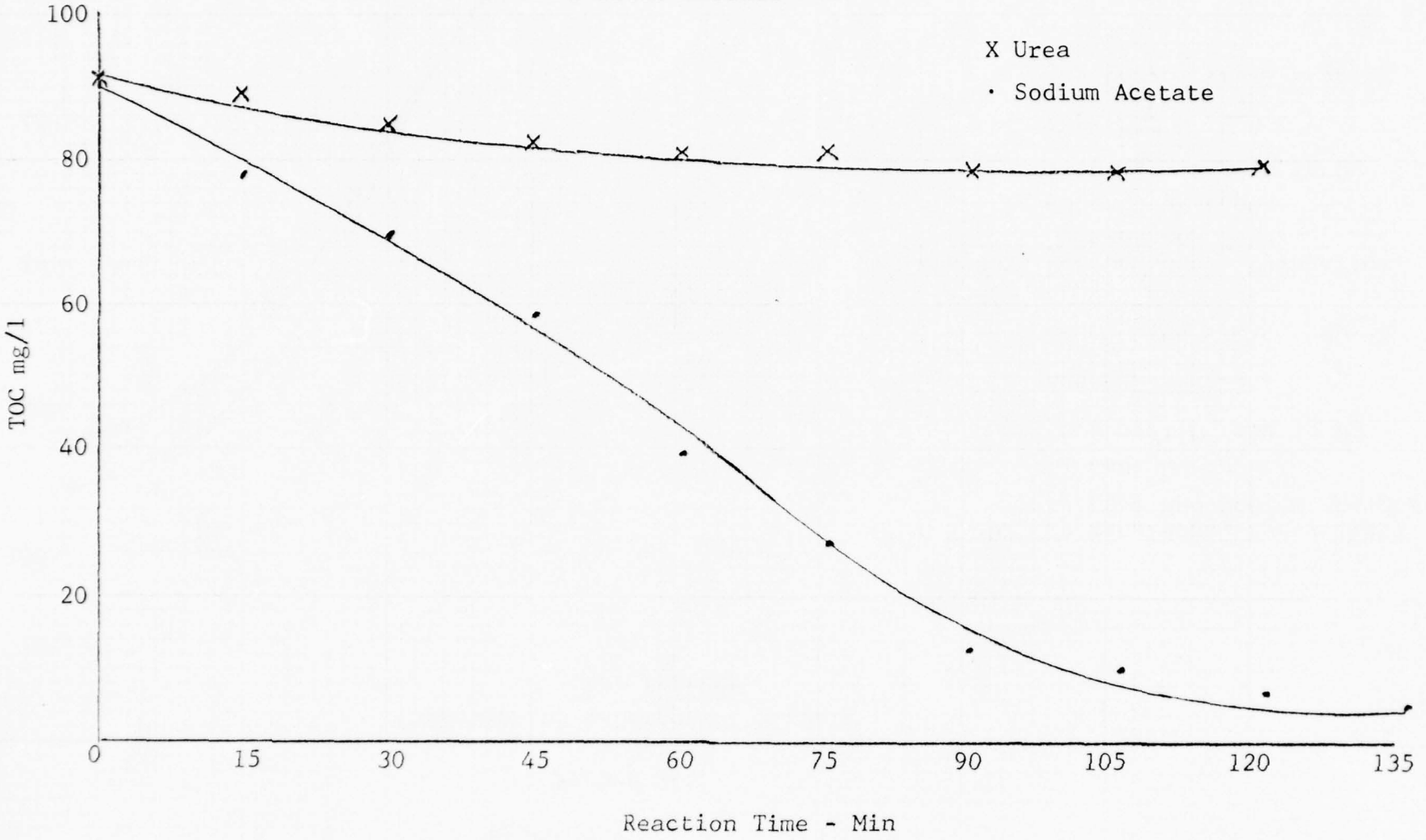


· S 302 Hydroquinone, Pyrogallol, Xylenol and Sodium Acetate
43 watt UV input
75.6 mg/l O_3/min in O_2
Ave $\frac{w-m}{mgC}$ = 15.2
Ave TOC/O_3 Effic = 30.7%

X S 303 Hydroquinone, Pyrogallol, Xylenol and Urea
43 watt UV input
75.6 mg/l O_3/min in O_2
Ave $\frac{w-m}{mgC}$ = 16.3
Ave TOC/O_3 Effic = 28.6%

Figure 2-5

Oxidation of Urea and Sodium Acetate
Using 43 watt Input UV and 75.6 mg O_3/min in O_2
3 liter Batches



resistance to UV-ozone oxidation, will therefore increase the UV and ozone power requirements.

2.4.2 Ozone Mass Flow Rate

Comparisons in the batch mode were made on the effect of ozone mass flow rate on the TOC removal rate of 3 and 5 component mixtures at 80 mg/l TOC levels in both the 3 inch diameter and the 6 inch diameter reactors. Table 2-11 summarizes these comparisons. A similar comparison was made for 20 mg/l TOC, 5 component mixtures, Table 2-12.

Referring to Table 2-11, it was observed that an increase in mass flow of ozone improved the rate of oxidation of 3 component and 5 component mixtures in the 12 liter reactor. Apparently the water in the 3 liter reactor was sufficiently ozonated at these operating conditions, but the 12 liter reactor was not.

2.4.3 UV Depth of Penetration

To ascertain if UV was equally effective for a 3 inch light path as a 1.5 inch path, batch tests were conducted in the 6 inch diameter reactor and compared with the results obtained in the 3 inch diameter reactor.

Table 2-11

Effect of O_3 Mass Flow Rate

3 Component Mixture - 3 liter Reactor

Exp. No.	O_3 Mass Flow (mg/min)	O_3 Conc (%)	Initial TOC (mg/l)	Final TOC (mg/l)	Reaction Time (min)	Ave Rate of TOC Removal (mg/min)
M394	74	1.9	84.3	2.3	75	3.3
M1339	124	2.5	83.5	3.0	120	2.0
M1338	171	2.7	90.0	2.0	105	2.5
			5 Component Mixture - 3 liter Reactor			
S305	74	1.9	82.8	4.1	135	1.75
S325	146	2.3	86.2	4.5	150	1.6
			3 Component Mixture - 12 liter Reactor			
M1332	74	1.9	83.1	4.7	180	5.2
M1341	124	2.5	80.5	5.0	135	6.7
M1348	146	2.3	79.0	5.0	135	6.6
M1342	171	2.7	82.0	4.0	105	8.9
			5 Component Mixture - 12 liter Reactor			
S328	146	2.3	80.5	7.0	315	2.8
S326	171	2.7	78.0	7.0	240	3.5

Table 2-12

Effect of O_3 Mass Flow Rate - 3 liter Reactor

5 - Component Mixture

Experiment Number	Ozone Mass Flow (mg/min)	Ozone Conc (%)	Initial TOC (mg/l)	Final TOC (mg/l)	Reaction Time (min)	Ave Rate of TOC Removal (mg/min)
S335	124	2.5	19.0	2.0	60	3.4
S336	171	2.7	23.0	1.5	45	5.7

Equal-part mixtures of hydroquinone, pyrogallol, and xylenol in water at approximately 20, 40, and 80 mg/l TOC were batch-oxidized in the 6 inch reactor. The rates of TOC removal were then compared to previous runs at the same operating conditions in the 3 liter reactor. The average rate was 5.0 to 5.2 mg/min in the 12 liter reactor, and 2.1 to 3.9 mg/min in the 3 liter reactor, indicating a greater rate of TOC removal in the larger reactor for all three TOC concentrations, and the same input of UV power and ozone.

Equal-part mixtures of hydroquinone, pyrogallol, xylenol, urea, and sodium acetate at TOC concentrations of 80 and 40-50 mg/l were oxidized in the 12 liter reactor and compared to oxidations in the 3 liter reactor. The average rate of removal was 2.3 mg/min in the 12 liter reactor, in comparison to 1.6 mg/min for the 80 mg/l TOC range, and 4.4 mg/min in comparison to 1.3 mg/min in the 40-50 mg/l range. These differences are shown in Tables 2-13 and 2-14.

2.4.4 Mixing

The effect of using mechanical and air agitation was studied in the 12 liter reactor. In M1334, an Eastern Propeller Mixer, Model 5, with a rotational

Table 2-13

Comparison of the Rate of TOC Removal in 3 inch Diameter Reactor to the 6 inch Diameter Reactor, using 3-Component Mixture

Conditions: 74 mg O_3/min at 1.9% O_3 conc (by wt) in O_2, 43 watts UV Input Power

1.5 inch UV Light Path (3 liter batch)						3 inch UV Light Path (12 liter batch)					
Exp. No.	Initial TOC (mg/l)	Final TOC (mg/l)	$-\Delta$TOC (mg/l)	Reaction Time (min)	Ave Rate of Removal (mg/min)	Exp. No.	Initial TOC (mg/l)	Final TOC (mg/l)	$-\Delta$TOC (mg/l)	Reaction Time (min)	Ave Rate of Removal (mg/min)
M394	84.3	2.3	82.0	75	3.3	M1332	83.1	4.7	78.4	180	5.2
M1315	39.2	0	39.2	30	3.9	M1330	43.3	4.8	38.5	90	5.1
M1319	22.3	1.0	21.3	30	2.1	M1331	20.7	1.8	18.9	45	5.0

Table 2-14

Comparison of the Rate of TOC Removal in 3 inch Diameter Reactor to the 6 inch Diameter Reactor, using 5-Component Mixture

Conditions: 80 mg/l TOC: 146 mg O_3/min, 2.3% O_3 in O_2
40-50 mg/l TOC: 124 mg O_3/min, 2.5% O_3 in O_2
UV Input Power: 43 watts

1.5 inch UV Light Path (3 liter batch)						3 inch UV Light Path (12 liter batch)					
Exp. No.	Initial TOC (mg/l)	Final TOC (mg/l)	$-\Delta$TOC (mg/l)	Reaction Time (min)	Ave Rate of Removal (mg/min)	Exp. No.	Initial TOC (mg/l)	Final TOC (mg/l)	$-\Delta$TOC (mg/l)	Reac Time (min)	Ave Rate of Removal (mg/min)
S325	86.2	4.5	81.7	150	1.6	S328	80.5	5.0	75.5	390	2.3
S330	50.5	5.0	45.5	105	1.3	S329	43.5	5.0	38.5	105	4.4

speed of approximately 300 rpm, was used. The agitator shaft extended about halfway down into the reactor and was offset 1 3/4 inches from the center. In M1333, a glass tube was inserted into the reactor from the top and extended to 1/2 inch from the bottom. A diaphragm pump with a capacity of 430 cubic inches/min provided the compressed air for mixing.

As shown in Figures 2-6 and 2-7, no change in oxidation rate was noted for either the 3-component or the 5-component mixtures when 74.2 mg O_3/min at 1.9% O_3 in O_2, and 43 watts UV were used.

2.4.5 UV Programming

The effect of reducing UV power after partial oxidation of the 5-component mixture at three levels of TOC concentration was further studied in batch testing. If the power to the lamp can be reduced without affecting oxidation rate, there can be a savings of process power.

As shown in Figures 2-8 to 2-11, reducing UV input power does not affect the oxidation rate of 20 mg/l, 40 mg/l or 80 mg/l TOC, 5-component mixtures, once 70% or more of the TOC content is completely oxidized.

Figure 2-6

Effect of Mixing on Oxidation
of 3-Component Mixture in 12 liter Reactor
Using 1-43 watt UV lamp, 74.2 mg O_3/min, 1.9% O_3

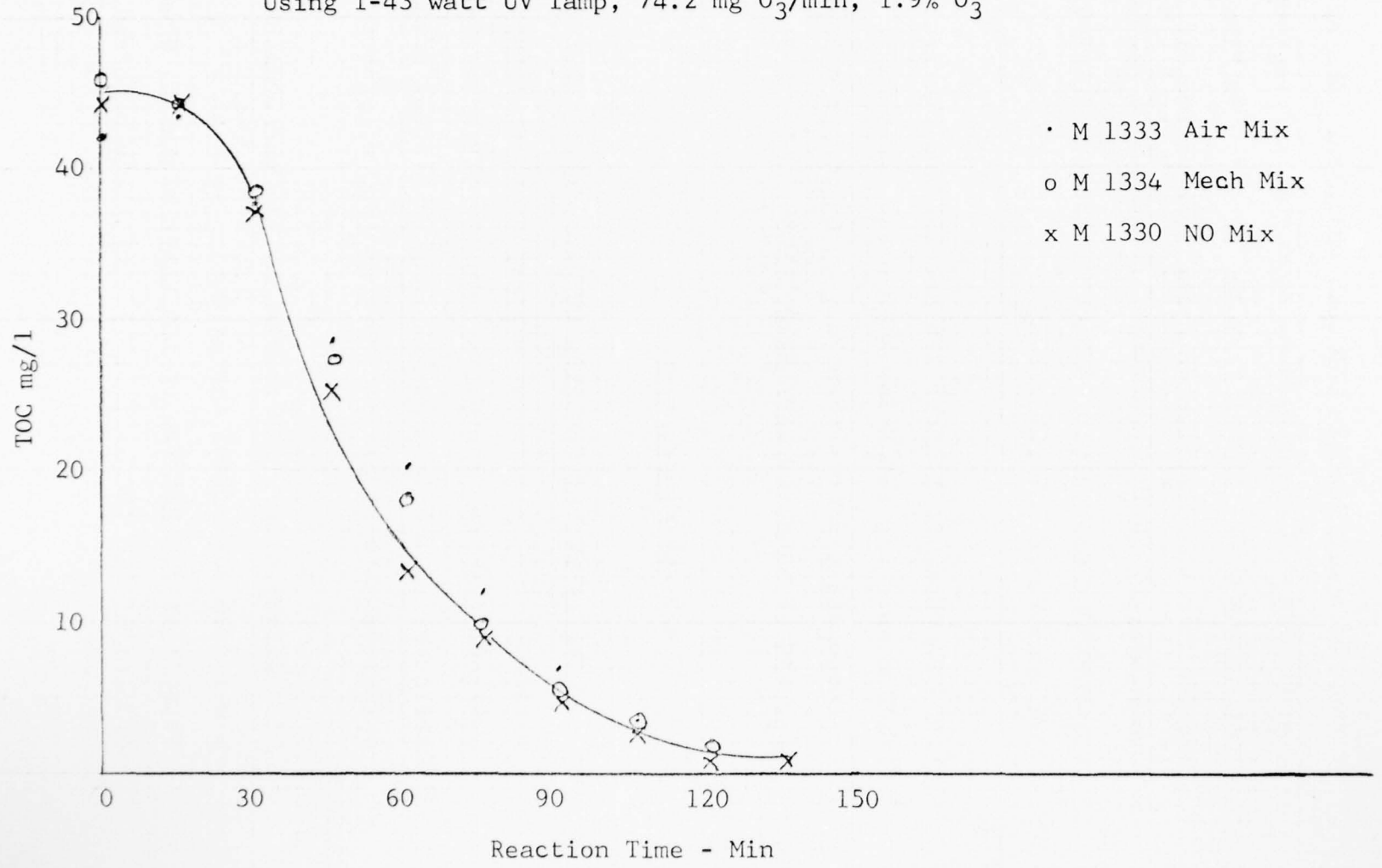


Figure 2-7

Effect of Mechanical Mixing
on 5-Component Mixture in 12 liter Reactor
O_3 Mass Flow of 74.2 mg/min. O_3 Conc 1.9%
1-43 watt UV lamp

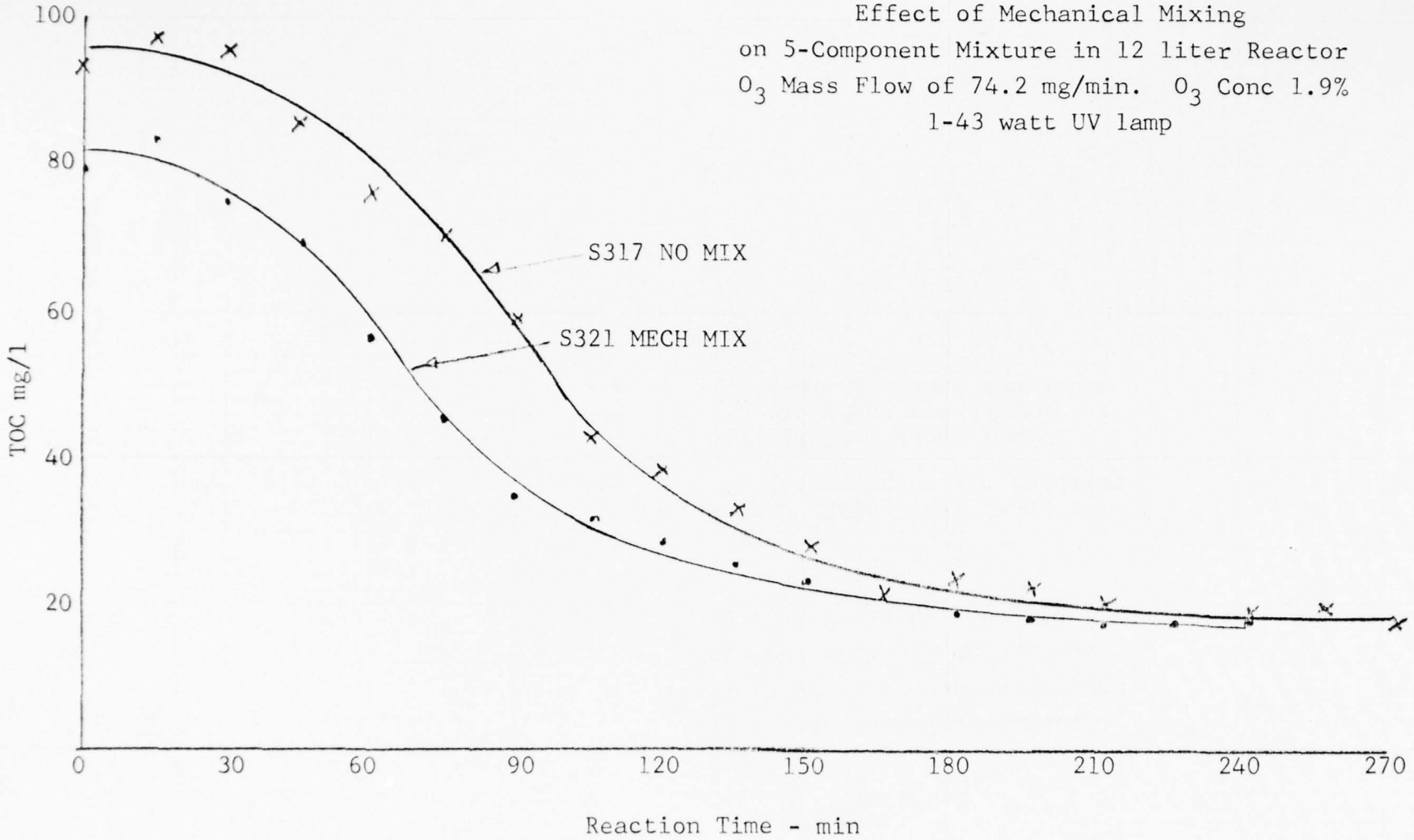


Figure 2-8

UV Input Power Programming
12 ℓ Reactor 5 Component Mixture
Oxidized with 124 mg O_3 / min
@ 2.5% O_3 in O_2 (by wt)

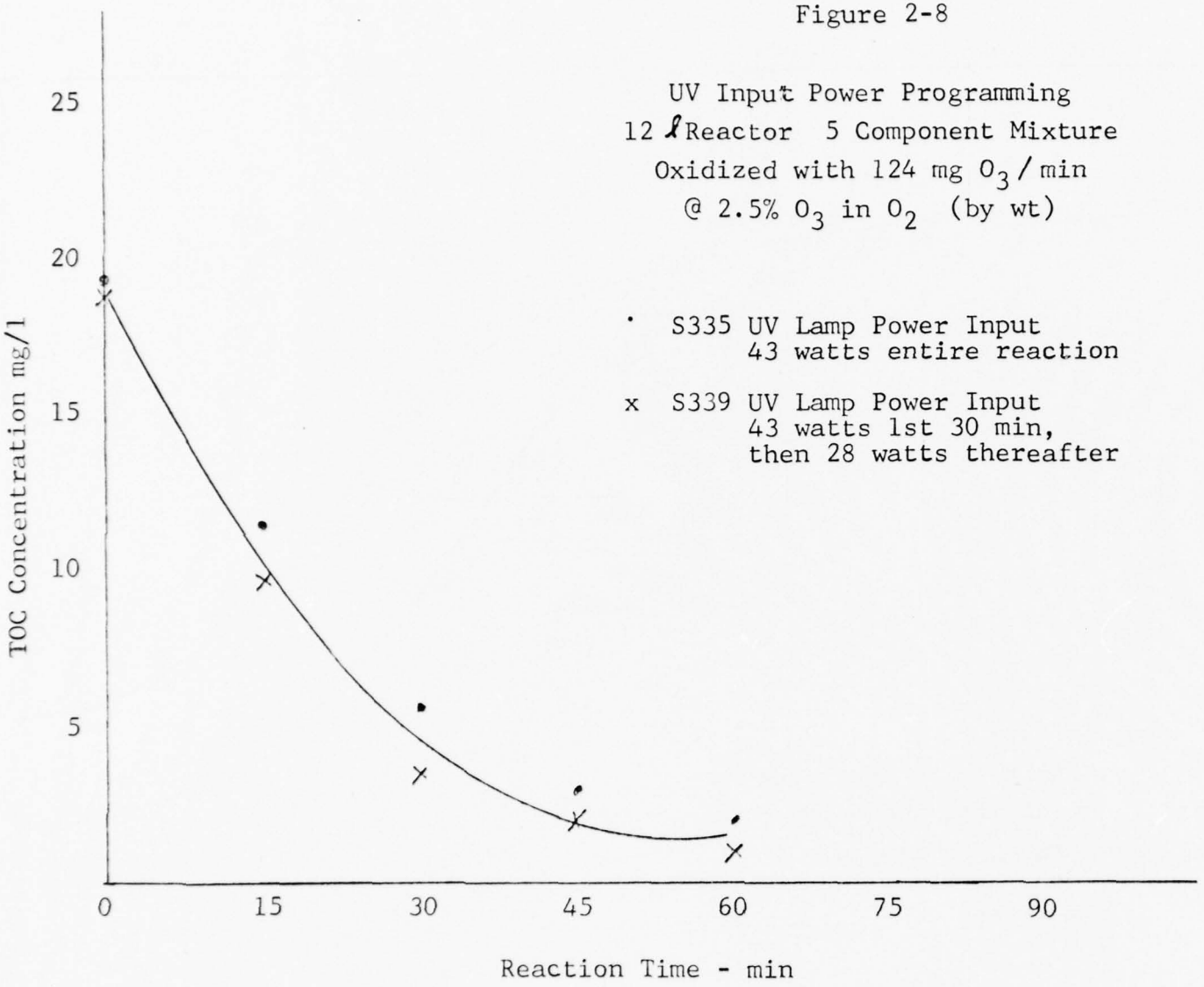


Figure 2-9

UV Input Power Programming
12 ℓ Reactor 5 Component Mixture
Oxidized with 171 mg O_3/min
@ 2.7% O_3 in O_2 (by wt)

• S336 UV Lamp Power Input
43 watts entire reaction

x S338 UV Lamp Power Input
43 watts 1st 30 min,
then 28 watts thereafter

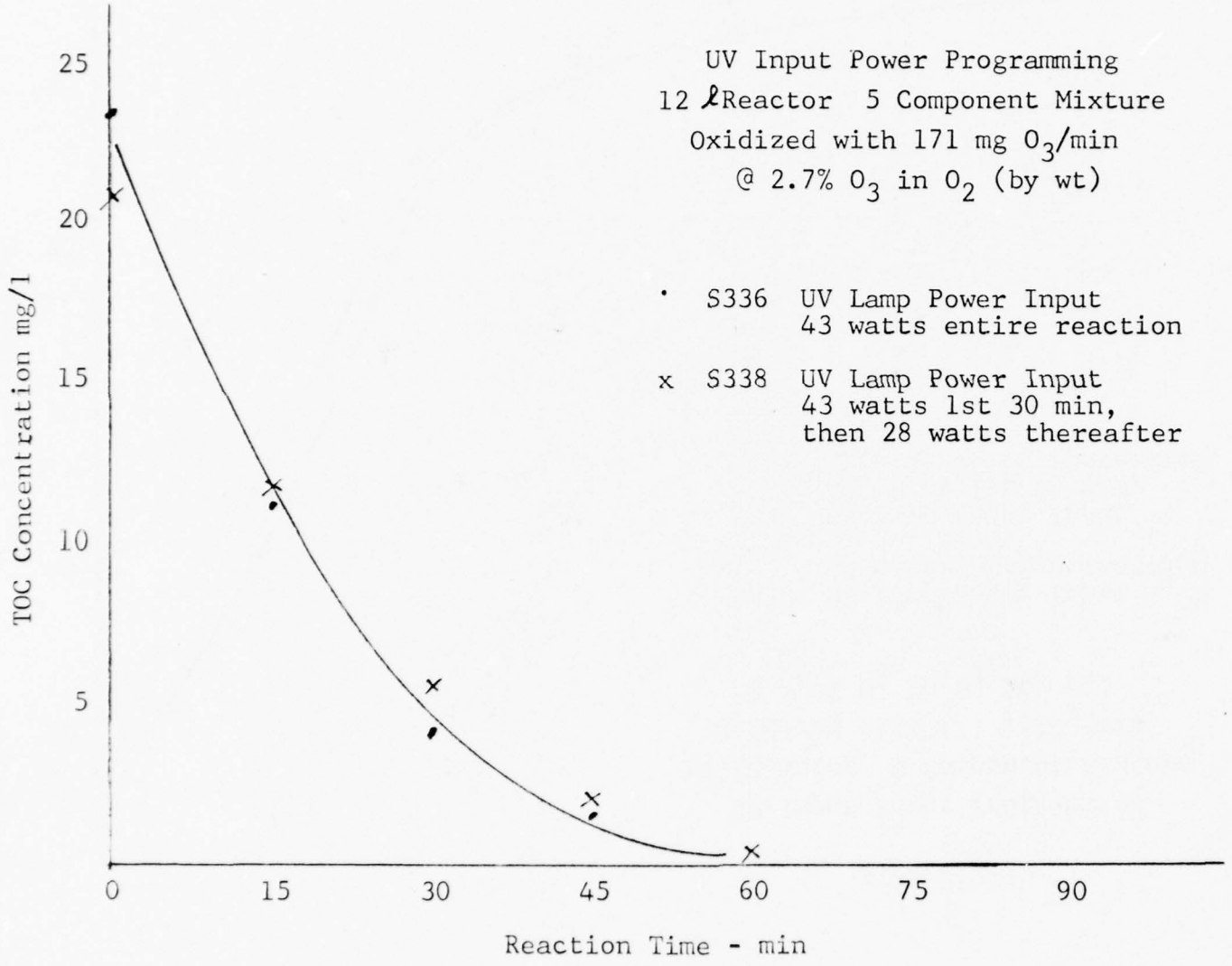


Figure 2-10

UV Input Power Programming
12 ℓ Reactor 5 Component Mixture
Oxidized with 171 mg/O_3 min
@ 2.7% O_3 in O_2 (by wt)

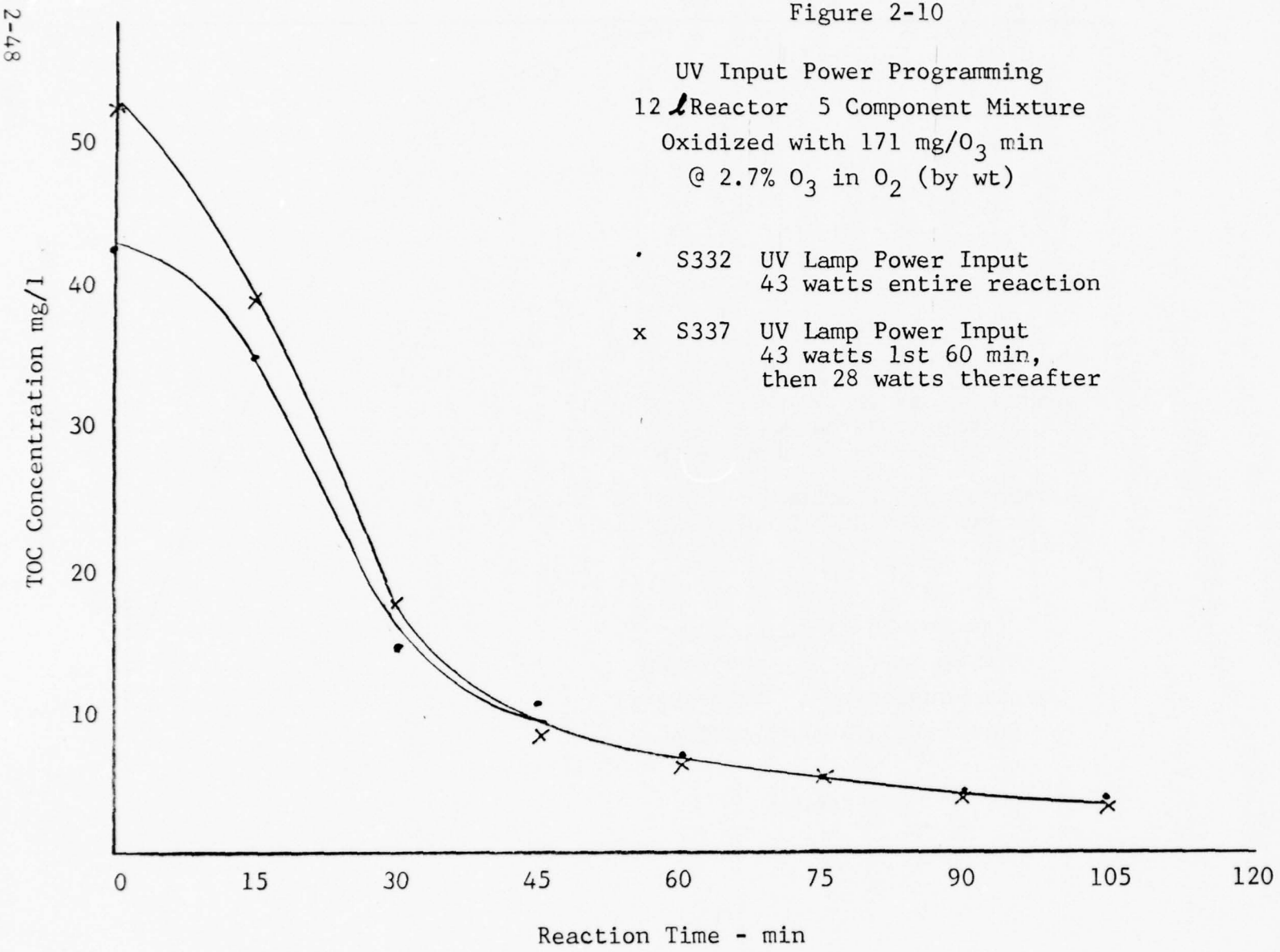
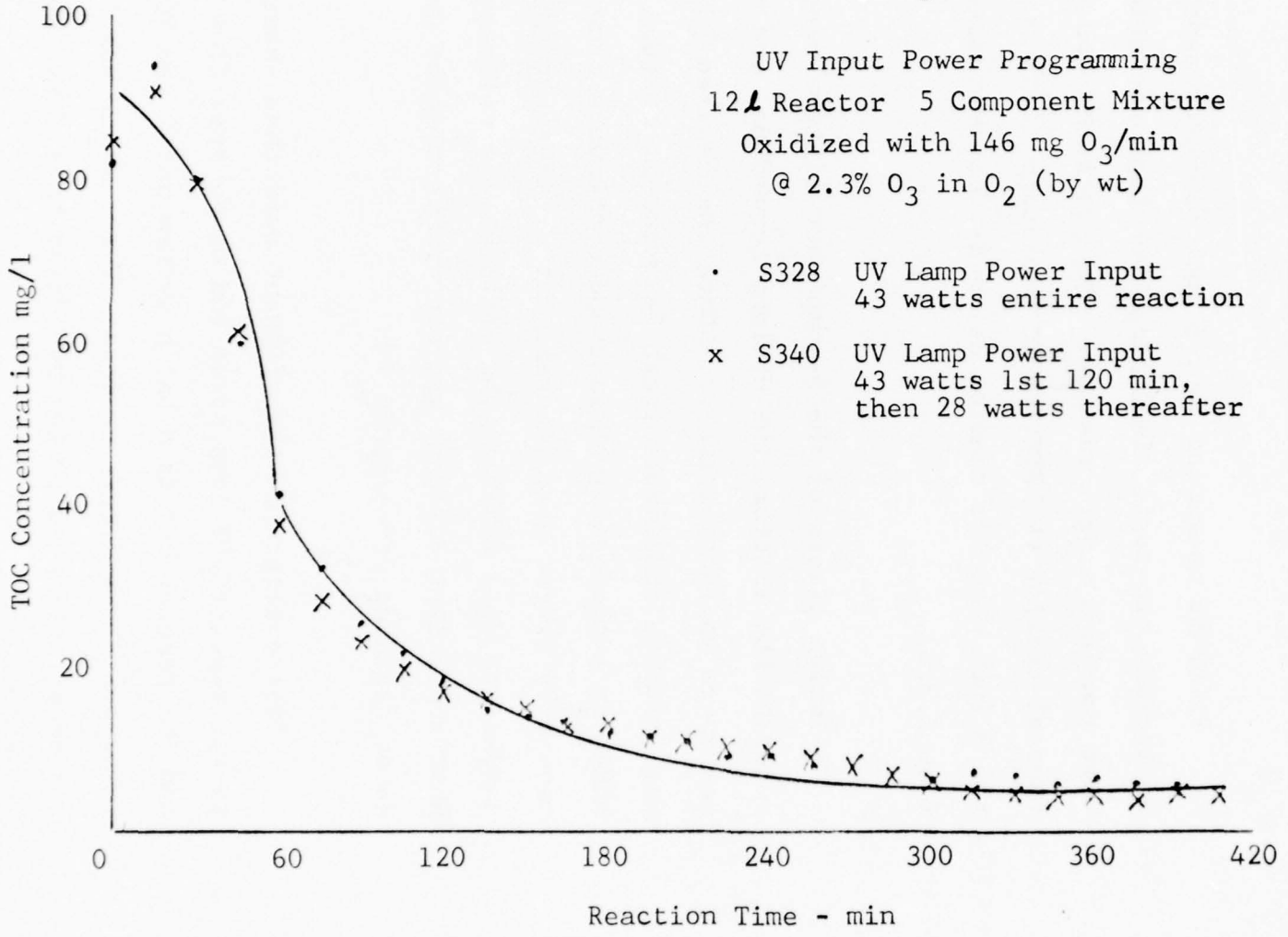


Figure 2-11

UV Input Power Programming
12 ℓ Reactor 5 Component Mixture
Oxidized with 146 mg O_3/min
@ 2.3% O_3 in O_2 (by wt)

· S328 UV Lamp Power Input
43 watts entire reaction

x S340 UV Lamp Power Input
43 watts 1st 120 min,
then 28 watts thereafter



2.5 CONTINUOUS TESTING IN THE 6 INCH DIAMETER REACTOR

2.5.1 Simulated, Two-Stage Testing

Prior to operating two, 6 inch diameter reactors in series, two tests simulating two-stage operation were run in a single reactor. The procedure for this type of testing was similar to two-stage tests run in the 3 inch diameter reactor using 3-component mixture (See 2.3.2).

Twelve liters of the 5-component mixture were added to the reactor, the UV lamp turned on, and ozone-in-oxygen sparging actuated. Once the desired TOC level was reached, additional fresh 5-component mixture was added at a predetermined rate and continuous flow commenced by draining at the same rate. After steady-state conditions were reached, the effluent was collected. When sufficient effluent was saved, the reactor was shut down, drained, and cleaned.

Twelve liters of the effluent were then returned to the reactor, UV lamp power and ozone mass flow set, and the reactor run as a batch system until the TOC level was about 5 mg/l or less. The reactor was then run as a continuous system by adding more first stage

effluent. The flow rate of the second stage operation was the same as the first stage. Table 2-15 summarizes the two tests. Full lamp input power of 43 watts was used in the first stage, and the lamp power was reduced to 28 watts in the second stage. The same ozone mass flow rate and ozone concentration was used in both stages.

In S341, 124 mg O_3/min at 2.5% O_3 concentration in O_3 was used in both stages to oxidize 39 mg/l TOC of the 5-component mix. A residence time of 80 minutes in each stage reduced the TOC to 5 mg/l TOC. The overall UV efficiency was 56.3 watt-minutes per mgC and the overall TOC/O_3 efficiency was 16.4%.

In S342, 171 mg O_3/min at 2.7% O_3/O_2 was used in two stages to oxidize 75.5 mg/l TOC to 6 mg/l TOC. Overall UV efficiency was 10.6 watt-minutes per mgC and TOC/O_3 efficiency was 40.6%.

These two runs were useful in establishing operating variables in the actual two-stage, continuous tests.

TABLE 2-15

Simulated Two Stage Continuous Operation

5 Component Mix

43 watt UV Input Reactor 1

28 watt UV Input Reactor 2

	REACTOR 1											REACTOR 2						OVERALL		
Experiment Number	Influent Conc TOC mg/l	Res Time/Real min	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc mg/l	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc mg/l	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %
S341	39.0	80	2.5	124	1.3	65	9.0	4.5	9.6	29.0	2.5	124	1.5	74	5.0	0.6	46.7	3.9	2.5	13.9	16.4
S342	75.5	48	2.7	171	1.8	113	21.0	13.6	3.2	63.7	2.7	171	1.9	120	6.0	3.7	7.5	17.5	8.7	4.1	40.6

2.5.2 Two-Stage Continuous Oxidation, 12 liter Reactors

The staged process is shown in schematic form in Figure 2-12. Start-up procedure for this system was as follows:

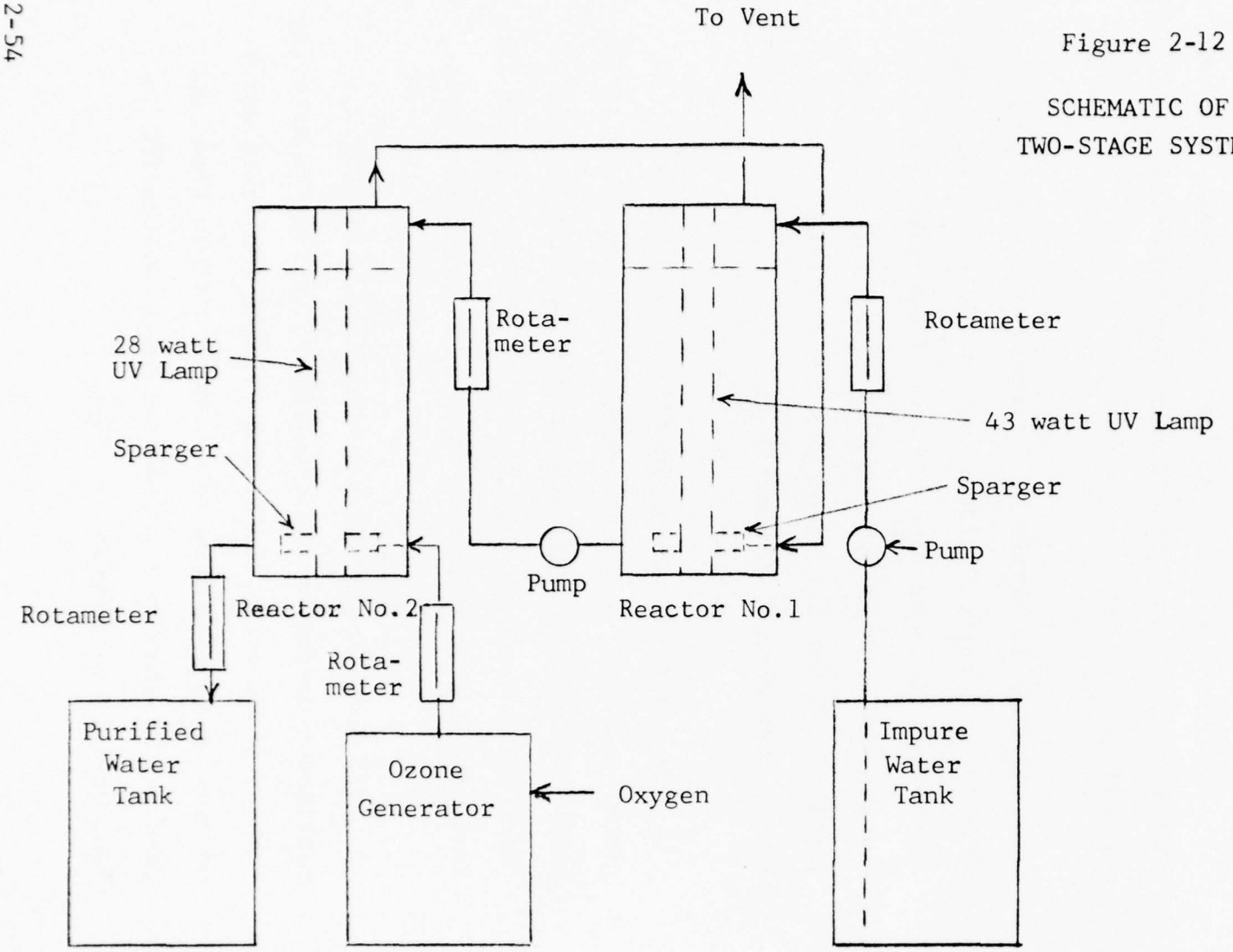
(1) Pump 12 liters of 5 component solution to Reactor 1, actuate UV lamp, and sparge ozone at a predetermined concentration and mass flow rate. The reactor was then run as a batch system until the desired level of TOC was attained, and the contents of Reactor 1 were then pumped to Reactor 2.

(2) Reactor 1 was again filled with fresh 5-component solution, and both reactors were operated in the batch mode until 5 mg/l TOC was obtained in Reactor 2. Ozone was introduced into Reactor 2 and then passed into Reactor 1 during this part of the start-up procedure.

(3) Once 5 mg/l TOC was achieved in Reactor 2, continuous operating commenced by actuating the metering pumps to Reactors 1 and 2, and opening the drain valve on Reactor 2. The flow rate (and residence time) was then established by the time required for the TOC in Reactor 2 to be reduced to 5 mg/l.

Figure 2-12

SCHEMATIC OF
TWO-STAGE SYSTEM



The continuous operation proceeded until steady-state operating conditions were established.

Two preliminary tests on 80 mg/l TOC, 5 component solution are summarized in Table 2-16. Ozone mass flows and UV input power were the same in both tests, but the residence time was varied. In S343, the residence time per reactor was 240 minutes and in S345 residence time was 120 minutes. The effluent from Reactor 2 was 5.1 mg/l TOC for S343 and 11 mg/l TOC for S345. Overall UV and TOC/O_3 efficiencies were less for S343.

2.6 OXIDATION OF OTHER ORGANIC COMPOUNDS IN WATER AND LAB PERMEATE

A series of tests were made in the 12 liter reactor with and without agitation on individual solutions of acetic acid, ethanol, glycerol, and glycine. The objective of this test series was to make a rough comparison of the results of the Westgate Reaction System to the results of Houston Research, Inc. in their Final Report No. 7184, entitled "Oxidation of Refractory Organic Materials by Ozone and Ultraviolet Light," Contract DAAK 01-74-C-0239.

TABLE 2-16

Varying Residence Time

5 Component Mix Continuous Operation - 2-Stage

43 watt UV Input Reactor 1

28 watt UV Input Reactor 2

O_3 Flow Introduced to Reactor 2 then to Reactor 1

	REACTOR 1										REACTOR 2								OVERALL		
Experiment Number	Influent Conc TOC mg/l	Res Time/Real min	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc mg/l	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc mg/l	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %	Ave Rate of TOC Removal mg/min	UV Index w-m/mgC	Supplied TOC/O_3 Effic %
S343	78.0	240	2.6	166	1.1	72	10	3.4	12.6	16.4	2.7	171	2.6	166	5.1	0.24	114	1.1	1.8	19.5	17.0
S345	77.5	120	1.7	108	.08	50	16	6.1	7.0	45.5	2.7	171	1.7	108	11.	0.5	56	2.3	3.3	10.7	31.1

It was difficult to simulate Houston's process conditions, since Westgate was working with a 6 inch diameter x 36 inch high reactor, with one 43 watt UV lamp in a quartz sheath extending through the entire reactor, while Houston had used a reactor with an L/D of 1 with one 15 watt UV lamp two-thirds submerged, without being enclosed in a quartz sheath.

Comparison of operating variables were:

$\frac{O_3 \text{ Mass Flow}}{\text{Vol of } H_2O}$	$\frac{4.5 \text{ mg } O_3/\text{min}}{\text{liter } H_2O}$	$\frac{3.95 \text{ mg } O_3/\text{min}}{\text{liter } H_2O}$
$\frac{\text{UV Power}}{\text{Vol of } H_2O}$	$\frac{1.5 \text{ watts}}{\text{liter } H_2O}$	$\frac{3.58 \text{ watts}}{\text{liter } H_2O}$

The concentrations of each compound were identical to those used in Houston Research's experiments.

2.6.1 Acetic Acid in Distilled Water

Acetic acid in distilled water at 106 mg/l concentration was oxidized (1) with and without agitation and (2) with and without UV in the 12 liter reactor. The concentration of acetic acid was the same as used by Houston Research in their tests, using a 9.92 liter

stirred reactor with an equivalent mixing power of 20 HP/1000 gallons, and an O_3 mass flow of 45.64 mg O_3/min at an O_3 concentration of 2%.

As shown in Figure 2-13, the results are superimposed on Houston Research's graph. The UV-ozone oxidation rate without agitation was slightly better than Houston's with agitation at 50°C. There appeared to be little difference between Westgate's results with and without agitation, except in V303 where O_3 mass flow was reduced to 47.4 mg O_3 min.

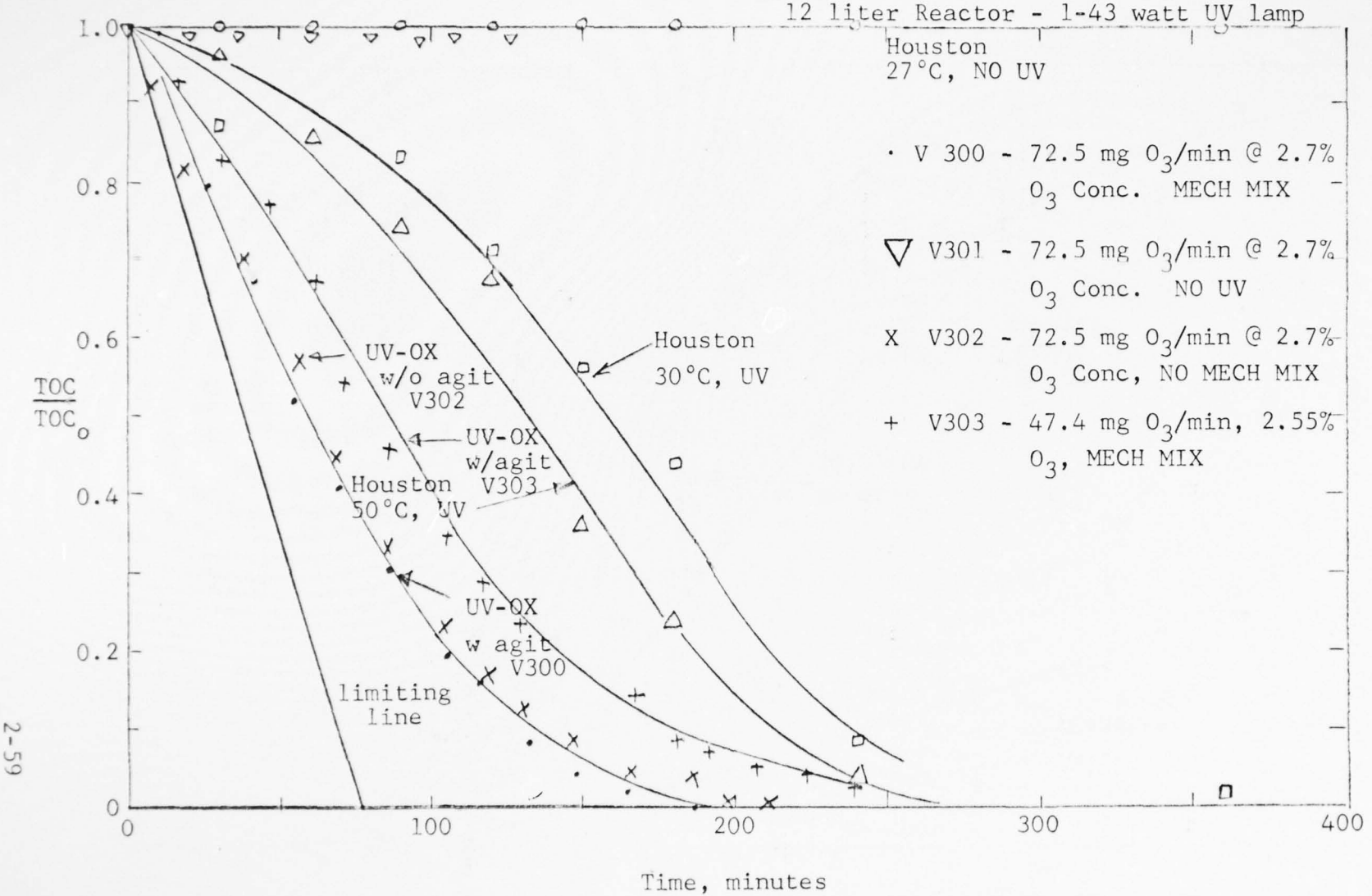
2.6.2 Ethanol in Distilled Water

Ethanol in distilled water at 115 mg/l was oxidized (1) with and without agitation and (2) with and without UV in the 12 liter reactor. The concentration of ethanol was the same as used by Houston Research in their tests using a 9.92 liter, stirred reactor with the equivalent mixing power of 20.6 HP/1000 gallons, and an O_3 mass flow of 43.26 mg/min at a concentration of 3%.

As shown in Figure 2-14, the rate of oxidation of Et300 was slightly greater than Houston's 30°C plus UV run, but less than Houston's 50°C UV test. The oxidation rate was about the same with or without agitation for

Figure 2-13

Westgate Results Superimposed
on Houston Research Results
12 liter Reactor - 1-43 watt UV lamp

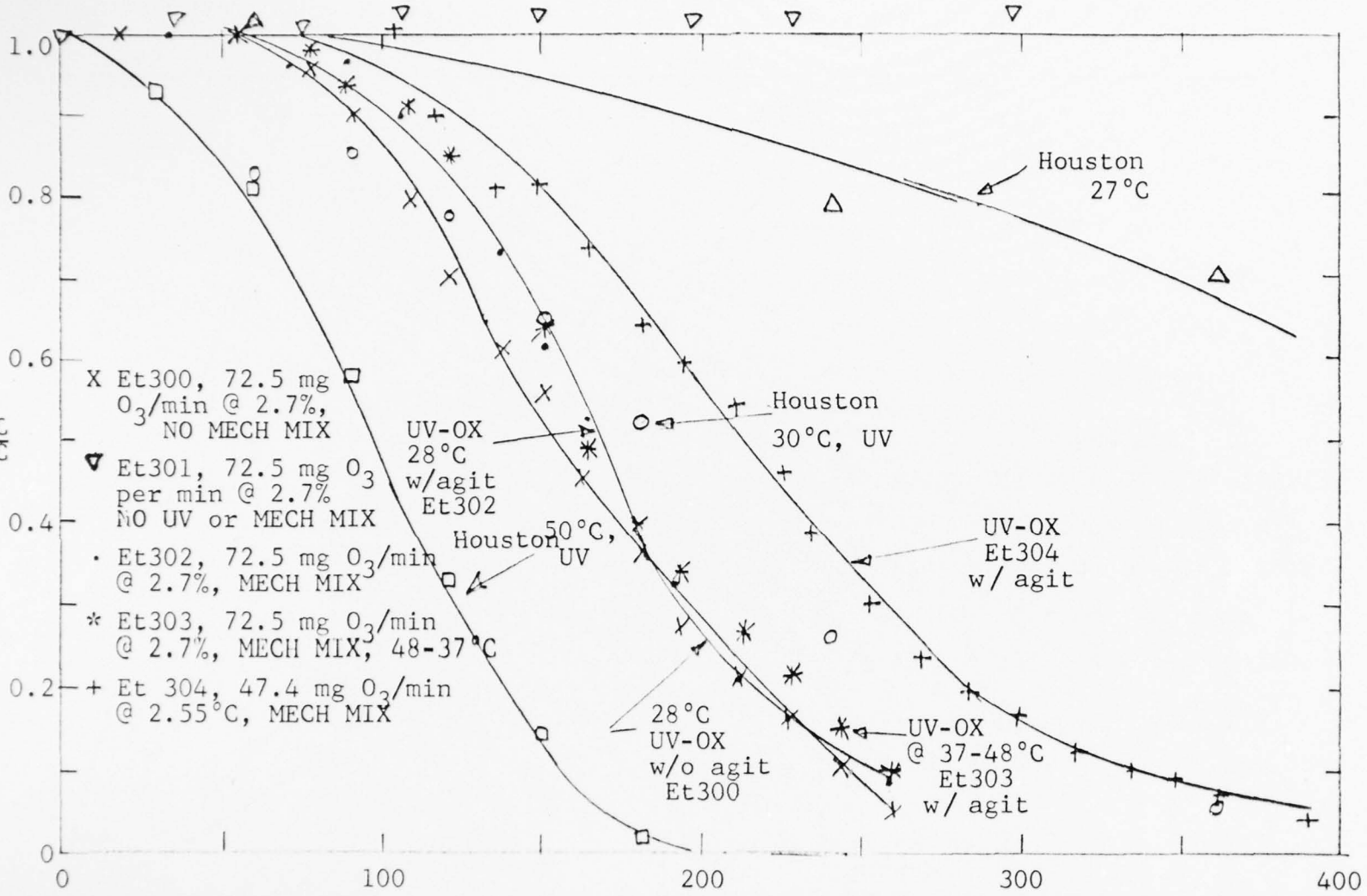


Ozone Oxidation of Acetic Acid, Effect of UV and Temperature
(Initial CH_3COOH = 105 mg/l, O_3(1) = 3.5 mg/l)

Figure 2-14

Westgate Results Superimposed on Houston Research Results

12 liter Reactor, 1-43 watt UV lamp



Ozone Oxidation of Ethanol, Effect of UV and Temperature
(Initial C_2H_5OH = 116 mg/l, O_3(1) = 2-4 mg/l)

Westgate's test at 28°C. The elevation of temperature (Et303) did not have an effect.

2.6.3 Glycerol in Distilled Water

Glycerol in distilled water at a concentration of 106 mg/l was oxidized in the 12 liter reactor. This concentration of glycerol was the same as used by Houston Research in their tests using a 9.92 liter, stirred reactor with the equivalent agitation power of 20 HP/1000 gallons, and an O_3 mass flow of 49.58 mg/min at a concentration of 2.3%.

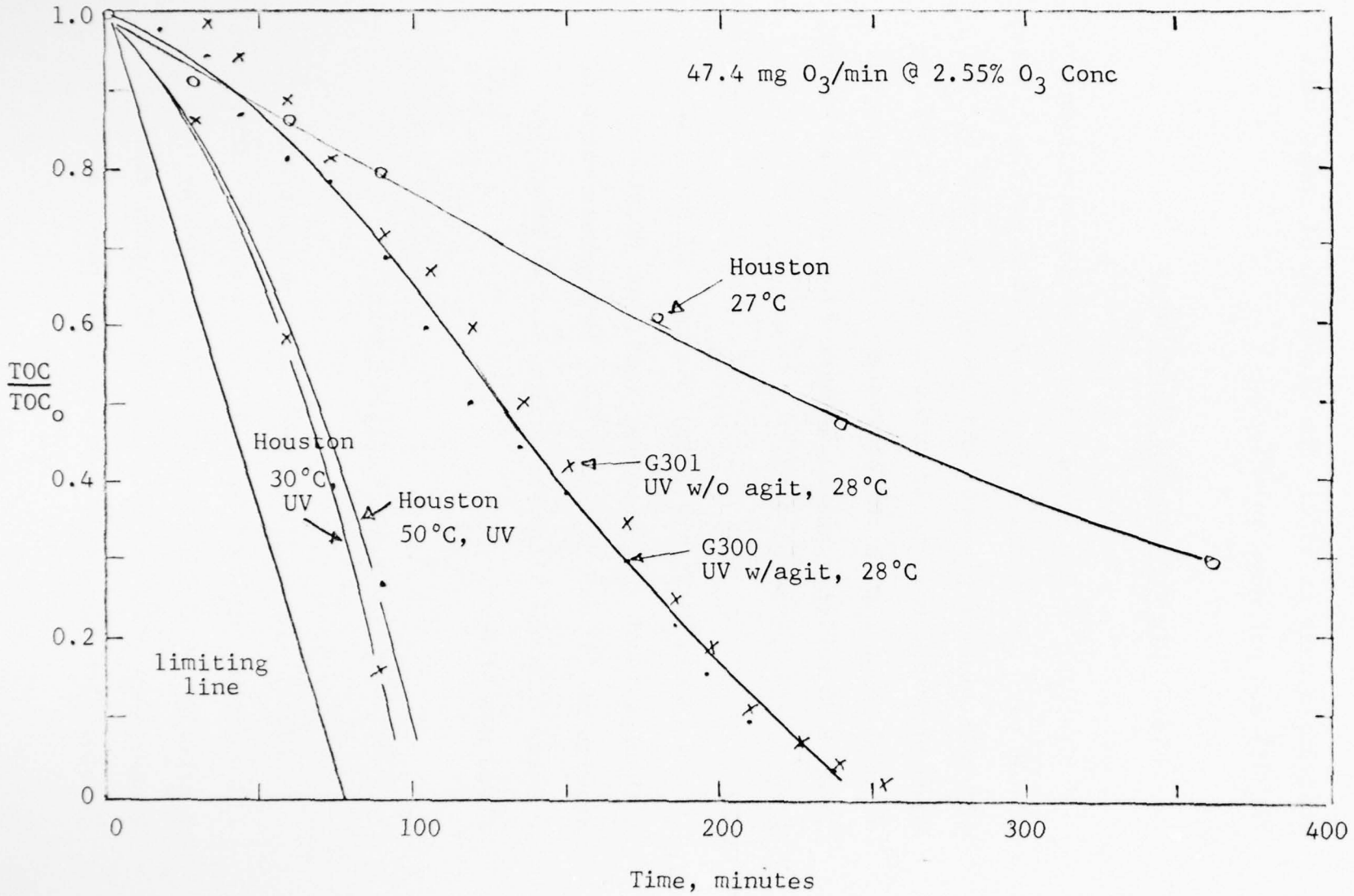
As shown in Figure 2-15, the rate of oxidation with or without agitation was less than Houston's results at 30° and 50°C with UV. Westgate's ratio of O_3 mass flow per liter was lower, but UV power per liter was higher.

2.6.4 Glycine in Distilled Water

Glycine in distilled water at a concentration of 117 mg/l was oxidized in a 12 liter reactor. This concentration of glycine was the same as used by Houston Research in their tests using a 9.92 liter, stirred reactor with the equivalent agitation power of 20 HP/

Figure 2-15

Westgate Results Superimposed on Houston Research Results
12 liter Reactor, 1-43 watt UV lamp



Ozone Oxidation of Glycerol, Effect of UV and Temperature
(Initial $CH_2OHCHOHCH_2OH$ = 106 mg/l, O_3(l) = 1.4 mg/l)

1000 gallons, and an O_3 mass flow of 45.84 mg/min at a concentration of 2.1%.

As shown in Figure 2-16, there was little difference in oxidation rate between Westgate's runs with and without agitation; also Westgate's rate of oxidation coincided fairly close to Houston's results.

2.6.5 Laboratory Waste Permeate

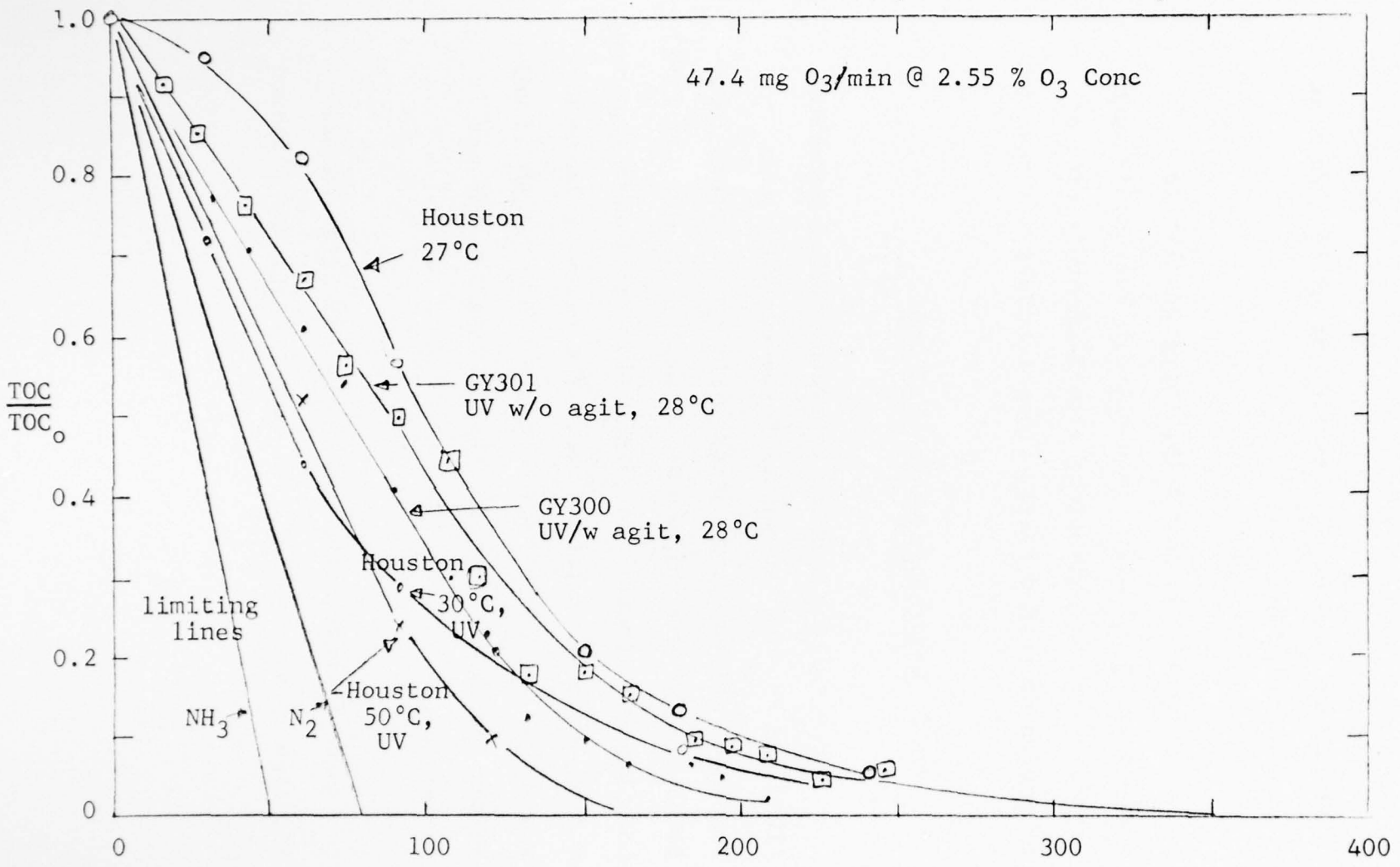
Fifty gallons each of Laboratory Waste Permeate (LWP) and Hospital Composite Permeate (HCP) were received from Walden Research Division of Abcor, Inc. Each permeate was shipped in 55 gallon steel drums with polyethylene liners. Unfortunately, the liners ruptured during shipment in both drums. The permeate being at a pH of 3, picked up iron contamination from the drums. Walden was able to replace the HCP but the LWP was unavailable.

Several tests were run on the LWP after pH was adjusted upward to 8 and the iron precipitate filtered out.

Figure 2-16

Westgate Results Superimposed on Houston Research Results

12 liter Reactor, 1-43 watt UV lamp



Ozone Oxidation of Glycine, Effect of UV and Temperature

(Initial NH_2CH_2COOH = 117 mg/l, $O_3(1)$ = 1.4 mg/l)

2.6.5.1 Three-Inch Diameter Reactor

The initial test was conducted in the 3 inch diameter reactor operating in the batch mode, using 43 watt UV. The results of this test are presented in Figure 2-17. The LWP was difficult to oxidize and required 240 minutes to reduce the TOC to less than 5 mg/l.

2.6.5.2 Six-Inch Diameter Reactor

Batch tests on LWP in the 6 inch diameter reactor are summarized in Figure 2-18. In the presence of UV, LW 301 and LW 304 attained <5 mg/l TOC in 420 and 450 minutes. Without UV LW 305 reached <5 mg/l TOC in about 540 minutes. The ozone efficiencies in all tests were low.

Figure 2-17

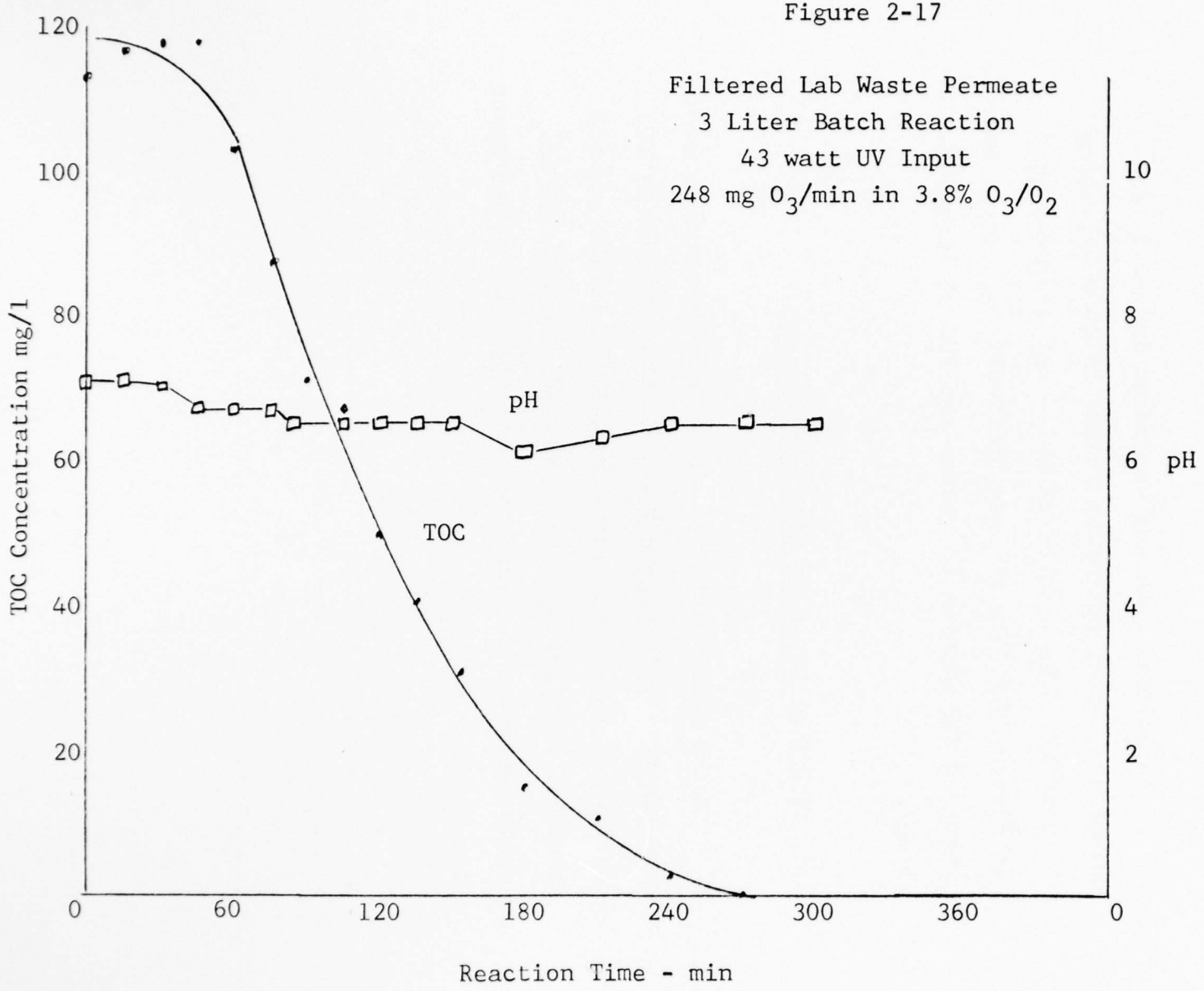
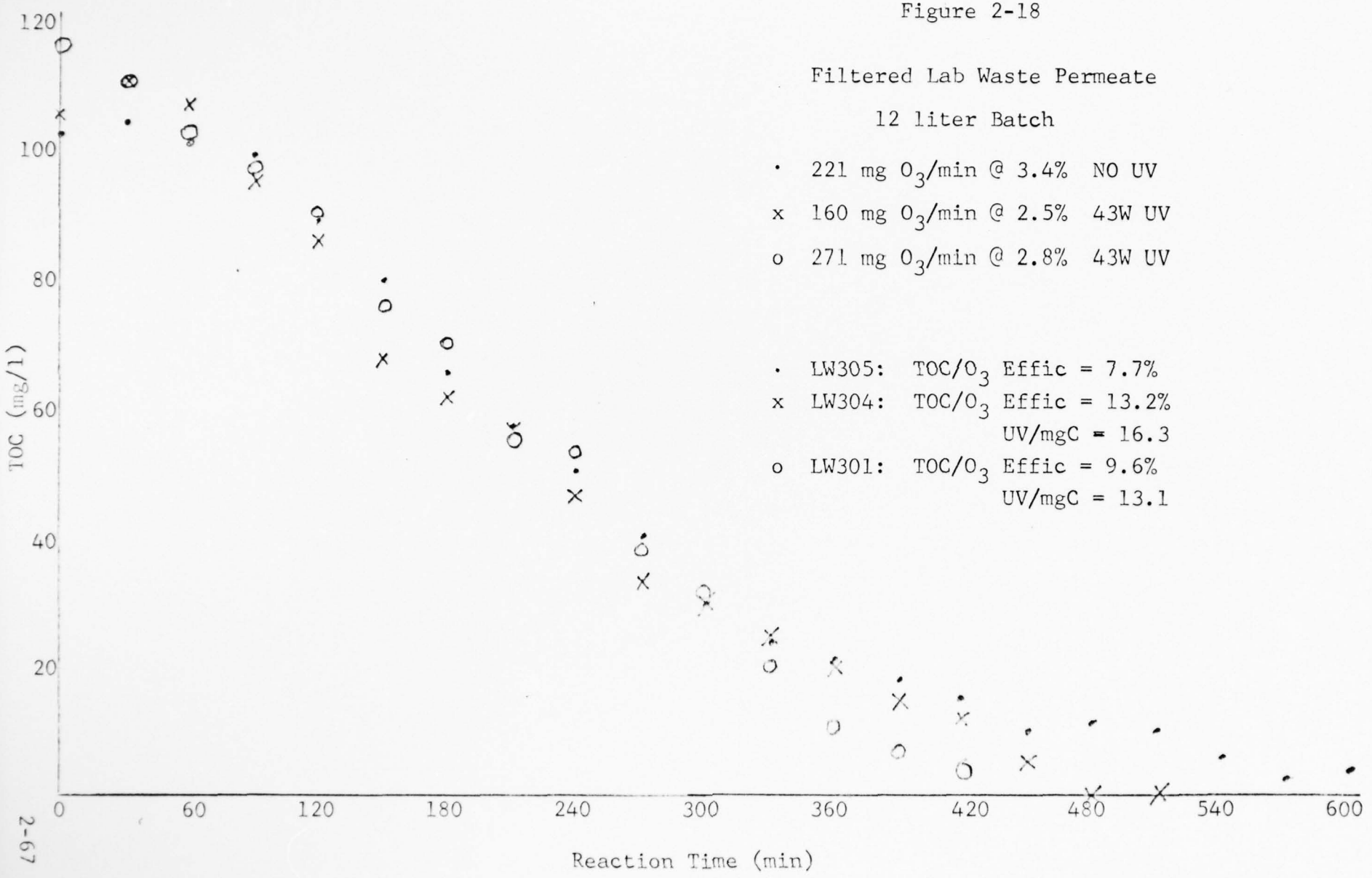

Filtered Lab Waste Permeate
3 Liter Batch Reaction
43 watt UV Input
248 mg O_3/min in 3.8% O_3/O_2
TOC Concentration mg/l
120
100
80
60
40
20
0
60
120
180
240
300
360
0
10
8
6
pH
4
2
pH
TOC
Reaction Time - min

Figure 2-18


Filtered Lab Waste Permeate
12 liter Batch
• 221 mg O_3/min @ 3.4% NO UV
x 160 mg O_3/min @ 2.5% 43W UV
o 271 mg O_3/min @ 2.8% 43W UV
• LW305: TOC/O_3 Effic = 7.7%
x LW304: TOC/O_3 Effic = 13.2%
UV/mgC = 16.3
o LW301: TOC/O_3 Effic = 9.6%
UV/mgC = 13.1
TOC (mg/l)
120
100
80
60
40
20
0
60
120
180
240
300
360
420
480
540
600
Reaction Time (min)

SECTION 3 DESIGN OF EXPERIMENT TESTING OF TWO STAGE BENCH SYSTEM

The next step in the study of the UV-Ozone Process was the two stage oxidation of synthetic MUST Hospital Composite Permeate in accord with design-of-experiment procedure.

3.1 BACKGROUND

Background information on rationale for synthetic Hospital Composite (HC) Permeate formulation, experimental procedure, and changes in contract scope are provided in Captain McCarthy's "Memorandum for Record" in the Appendix. This memorandum was drawn up as a result of a meeting on 10 October 1975 between USAMBRDL and Westgate personnel.

Table 3-1 presents detail on raw waste formulations, analyses of RO permeates, and synthetic HC, RO permeate.

As noted in the previously referenced Memorandum, the two-stage counter-current flow, UV-ozone system was used in the testing. The schematic of this system is shown in Figure 2-12.

Table 3-1

PROPOSED SYNTHETIC RO PERMEATE FROM MUST HOSPITAL COMPOSITE WASTEWATER

Compound	Synthetic Raw Waste Formulations: Walden 24-hr Composite (UF Feed)	Univ of Cincinnati Feedwater for RO Runs	Tardiff-Mullaney Report Estimated Conc. in Untreated Waste	Analyses of RO Permeates (Range): USAMBRDL Data Walden IT-Series	Synthetic RO Permeate Suggested Concentrations: mg/l or µl/l	Conversion Factors mg/l TOC / µl/l or mg/l conc.	mg/l as organic carbon
Methanol	20.2 µl/l	18 mg/l	30 µl/l	2-16 µl/l	16 µl/l	0.30	4.8
Acetone	6.3 µl/l	-	0.6 µl/l	0.7-5 µl/l	5 µl/l	0.49	2.5
Formaldehyde	0.1 µl/l	12 mg/l	230 µl/l	<5 µl/l (not detected)	0.5[1] µl/l	0.32	0.2
Ethanol	-	1.8 mg/l	458 µl/l	<1 µl/l (not detected)	0.5[1] µl/l	0.41	0.2
2-Propanol	-	-	0.02 µl/l	0.1-0.5 µl/l	0.5 µl/l	0.47	0.2
Diethyl ether	0.6 µl/l	-	0.6 µl/l	<0.1-0.1 µl/l	0.1 µl/l	0.46	0.1
Methyl ethyl ketone	-	-	-	0.1-0.2 µl/l	0.2 µl/l	0.54	0.1
Phenol	0.8 mg/l	-	0.7 mg/l	-	0.4[2] mg/l	0.76	0.3
Urea	1.8 mg/l	-	13 mg/l	-	1.8 mg/l	0.20	0.4
o-Toluidine	0.2 µl/l	0.2 mg/l	0.2 mg/l	-	0.1[2] µl/l	0.78	0.1
N,N-Diethyl-m-toluamide	0.5 mg/l	0.4 mg/l	0.4 mg/l	-	0.2[2] mg/l	0.75	0.2
Acetic Acid (x-ray)	10 mg/l[5]	38 mg/l	10.2 mg/l	-	8[3] mg/l	0.40	3.2
Acetic Acid (Lab)	3.4 mg/l	-	-	-	2.8[4] mg/l	0.40	1.1
						Total	13.4

[1] Estimates based on GC detection limits and synthetic waste concentrations

[2] A 50% rejection of these compounds by the RO membrane was assumed

[3] A 20% rejection of 10 mg/l RO feed concentration was used to obtain this value

[4] A 20% rejection of 3.4 mg/l RO feed concentration was used to obtain this value

[5] Acetic Acid was added : 942 ul/l of Kodak X-Omat Fixer which contained 1.3% Acetic Acid

3.2 SYNTHETIC PERMEATE BATCH TESTS

The first series of tests using the synthetic HC, RO Permeate were run on a batch basis in one of the 12 liter reactors. The synthetic permeate was made up to a 96 liter volume in a 30 gallon polyethylene drum. The TOC analysis of the synthetic HC permeate after make up, using the Beckman 915 Analyzer, was:

Total Carbon	Inorganic Carbon	Total Organic Carbon	pH
12 mg/l	6 mg/l	6 mg/l	7.2

The TOC was less than one-half of the theoretical organic carbon. From previous experience with the 915 Analyzer, there appeared to be an inaccuracy in the inorganic channel.

The analytical procedure was therefore modified by acidifying the TOC sample with dilute hydrochloric acid to a pH of 2 and purging the CO_2 from the sample by bubbling dry nitrogen gas through the sample for 5 minutes.

TOC analysis of the purged sample was:

Total Carbon	Inorganic Carbon	Total Organic Carbon	Original pH
8 mg/l	0 mg/l	8 mg/l	7.2

This modification in analytical procedure raised the TOC somewhat, but not to the theoretical level.*

Batch tests in the 12 liter reactor were run on this permeate to set levels for ozone mass flow, ozone concentration, and UV light input power. This information was useful for setting the levels of operating variables in the continuous testing.

Figures 3-1 to 3-3 show that there is little difference in rate of oxidation at higher mass flows of O_3 with and without UV. However, when a lower mass flow of O_3 was used (Figure 3-3), there was a significant difference in the rate of oxidation.

3.3 DESIGN OF EXPERIMENT RATIONALE

As described in Paragraph 5 in "Memorandum of Record" (Appendix), in the initial design-of-experiment testing, the two reactors were to be operated continuously in series with counter-current operation. Low-pressure mercury lamps with predominantly 254 nm wavelengths were to be operated at input power levels at 0, 28, and 43 watts. Ozone was to be generated from

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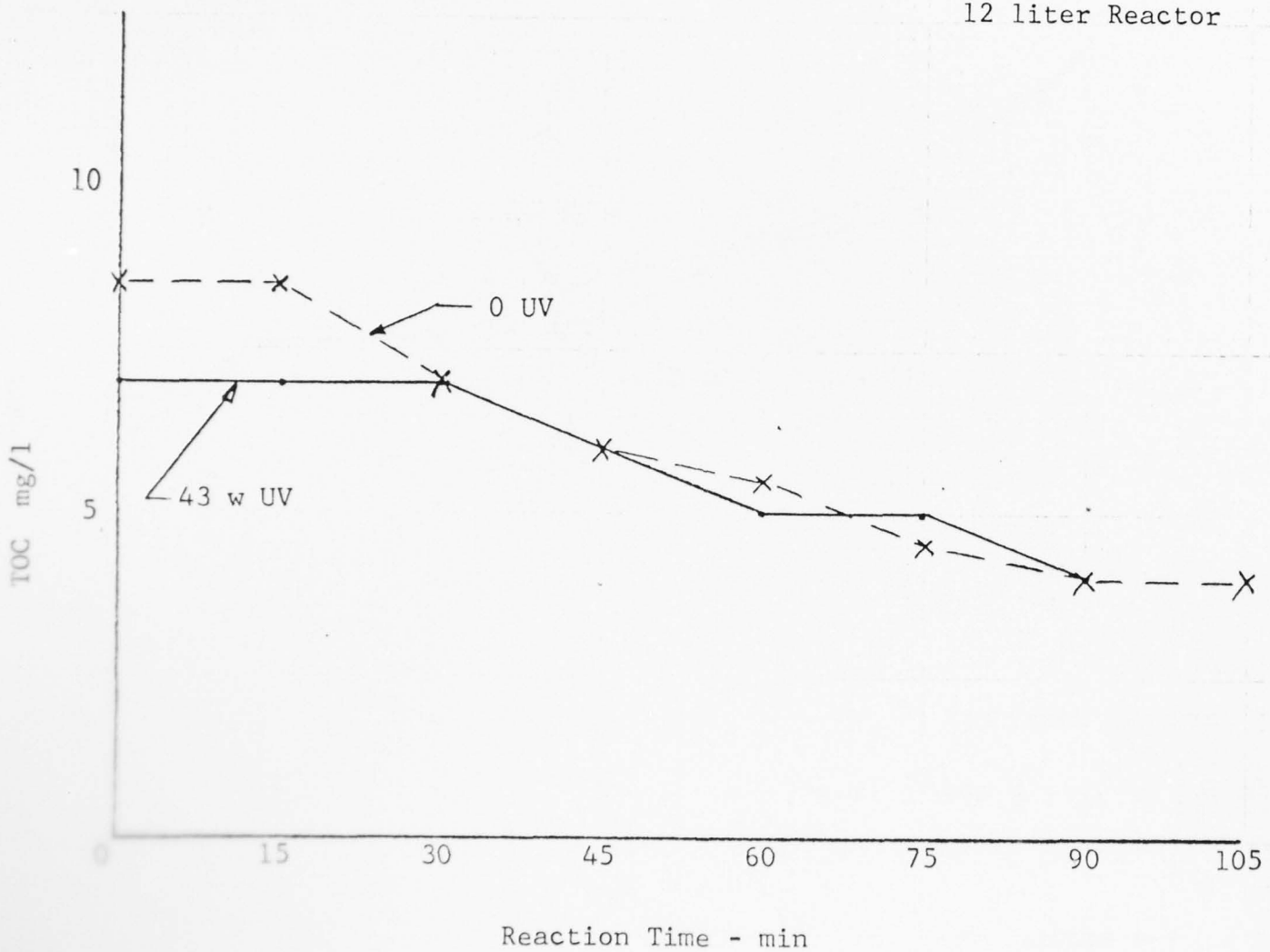
*For more discussion on TOC analysis, see Section 3.7

Figure 3-1

Synthetic Hospital Composite RO Permeate

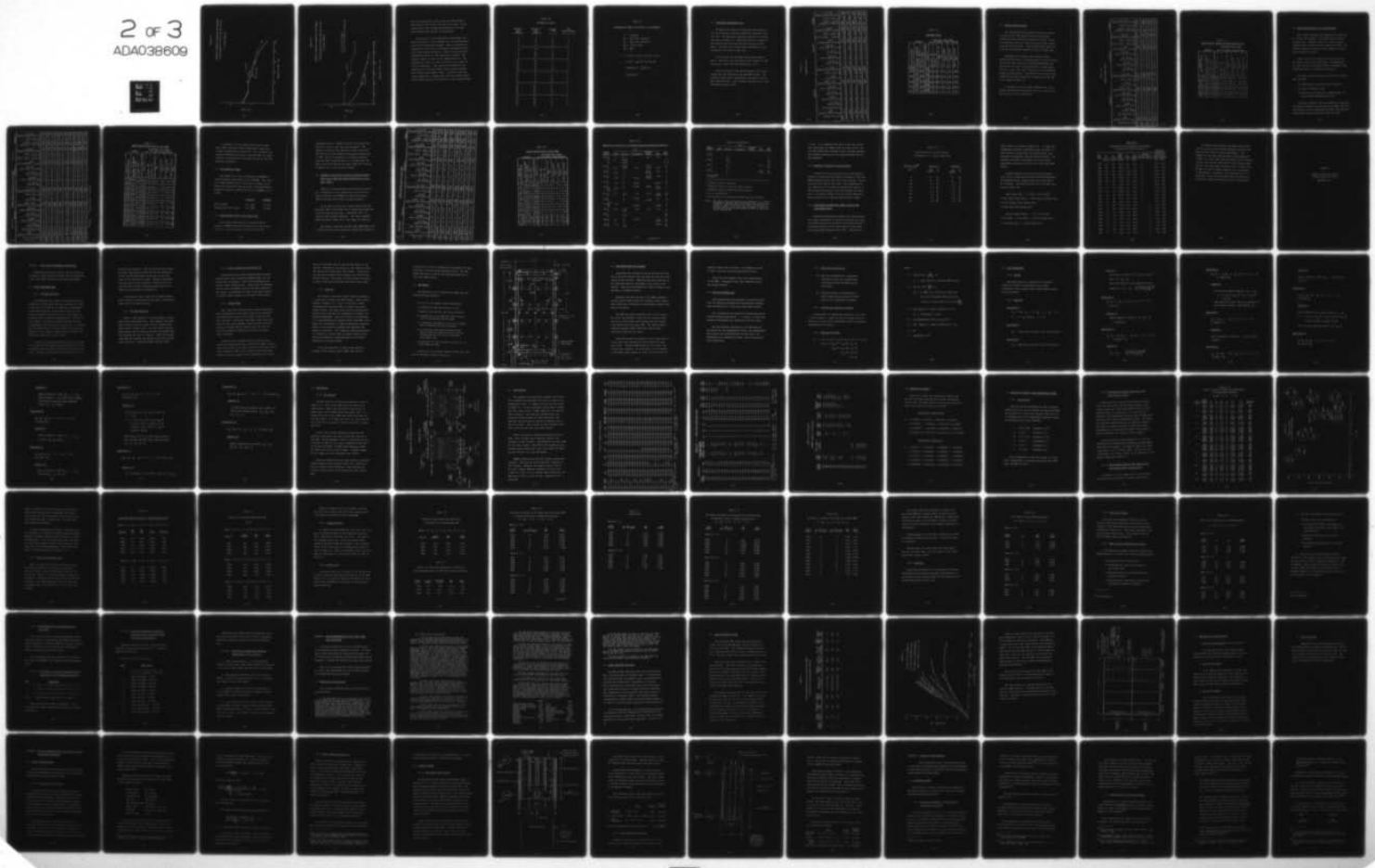
70 mg O_3/min @ 1.6% O_3 (by wt) in Air

12 liter Reactor



AD-A038 609 WESTGATE RESEARCH CORP MARINA DEL REY CALIF F/G 13/2
UV-OZONE WATER OXIDATION/STERILIZATION PROCESS.(U)
NOV 76 J D ZEFF, J WARK, R SHUMAN DAMD17-75-C-5013
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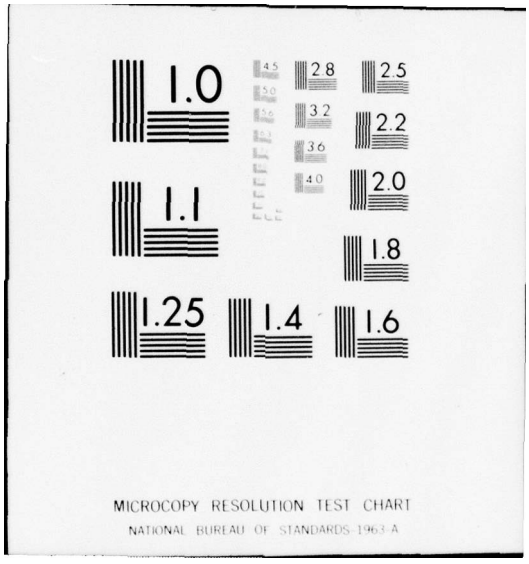

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Figure 3-2

Synthetic Hospital Composite RO Permeate

50 mg O_3/min @ 1.7% O_3 (by wt) in Air

12 liter Reactor

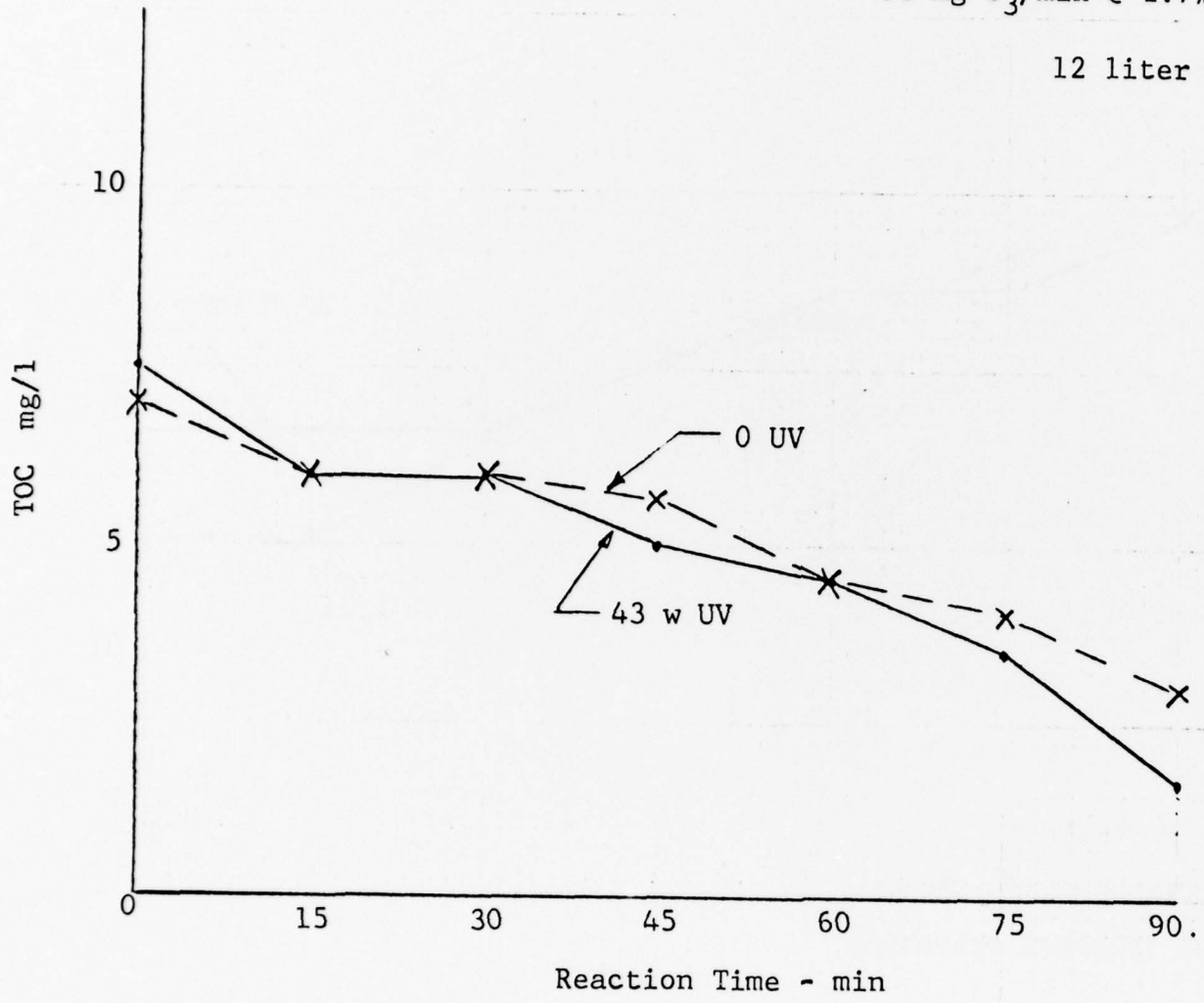
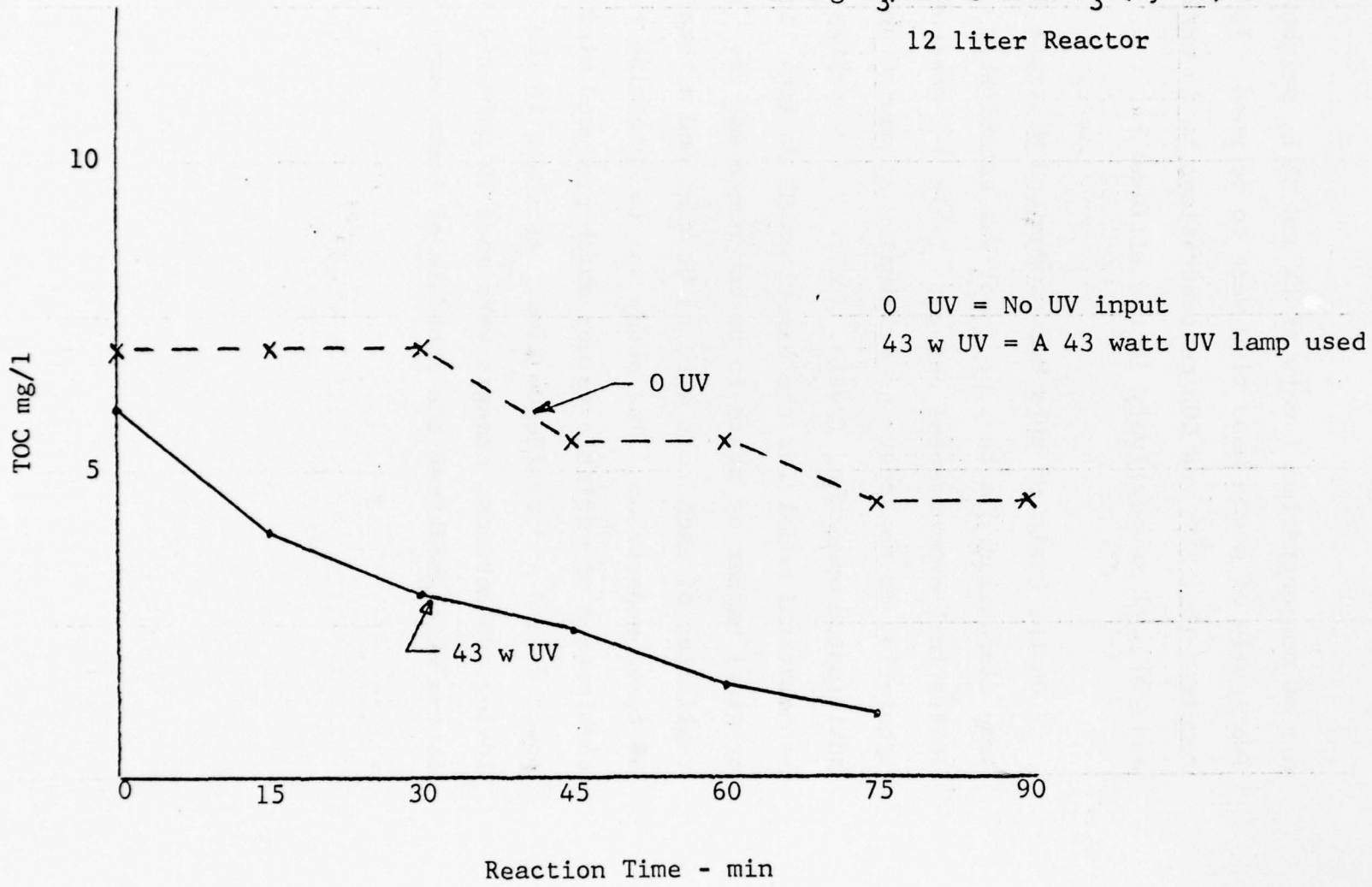


Figure 3-3

Synthetic Hospital Composite RO Permeate

29 mg O_3/min @ 2.0% O_3 (by wt) in Air

12 liter Reactor



air at concentration levels of 1% and 2% by weight. Two levels of ozone mass flow were to be used. It was required that TOC and COD concentrations be $\leq$5 mg/l and $\leq$10 mg/l respectively in the effluent.

On the basis of this Memorandum and Westgate and Army discussions, a test protocol was established using statistical experimental design. Table 3-2 presents a tabulation of the tests as originally scheduled and the anticipated operating levels. Table 3-3 describes the mathematical model for the experimental design. The original number of tests to be conducted was 24. Two replicates of each test were to be run, and a total of 48 tests undertaken. The study was to determine the combination of variable values which produced minimum power demand and residence time. As shown in the following subsections, changes were made in permeate formulation which modified the schedule of tests significantly.

Table 3-2

SCHEDULE OF TESTS

Reactor 1 UV_1 Watts	Reactor 2 UV_2 Watts	O_3 Mass Flow	O_3% Concentration
0	0	L	1
0	0	L	2
0	0	H	1
0	0	H	2
0	43	L	1
0	43	L	2
0	43	H	1
0	43	H	2
28	28	L	1
28	28	L	2
28	28	H	1
28	28	H	2
43	0	L	1
43	0	L	2
43	0	H	1
43	0	H	2
43	43	L	1
43	43	L	2
43	43	H	1
43	43	H	2
43	28	L	1
43	28	L	2
43	28	H	1
43	28	H	2

Table 3-3

MATHEMATICAL MODEL FOR DESIGN OF EXPERIMENTS

y = response

X_1 = UV_1 level, Reactor 1

X_2 = UV_2 level, Reactor 2

X_3 = O_3 mass flow

X_4 = O_3%

$$y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_1^2 + b_6 X_2^2 + b_7 (X_1 X_2) + b_8 (X_1 X_3) + b_{11} (X_2 X_4) + b_{12} (X_3 X_4)$$

3.4 CONTINUOUS SHAKEDOWN TESTS

To define the levels of ozone mass flow required for the two-stage continuous operation, shakedown tests were run. The operating variables used and the results are shown in Table 3-4. Experiment 304 was a repeat of 303 except distilled water was used in place of tap water. No difference in UV energy requirements or O_3 efficiency were noted in this test.

All effluents met the MUST TOC and COD requirements. The overall O_3 efficiencies were higher for the low O_3 mass flows than the high O_3 mass flows.

Table 3-5 presents the projected power and reactor volumes for the 4200 gallon per day MUST system. The projected total power requirements are lower as the O_3 mass flow decreases. The residence time does not lessen with higher O_3 mass flow.

Table 3-4

SHAKEDOWN TESTS

	REACTOR 1										REACTOR 2								OVERALL		
Experiment Number	Influent Conc TOC/COD mg/l	Res Time/Reac min	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC/COD-Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic	Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %
SHCP	7						7.0			0					4.0			15.6	0.3		15.6
300	10.1	60	0.5	8.2	0.4	6.7	10.5	43	215	0	1.9	30.7	0.5	8.2	5.7	28	140	9.4	0.44	355	8.6
301	7 / 12.4	52	1.3	54.0	0.2	9.1	6.0 / 1.2	43	187	3.4 / 14.3	2.0	84.0	1.3	54.0	3.5 / 2.0	28	122	5.5 / 0	0.5 / 1.2	309	8.9 / 8.3
302	9 / 19.6	53	1.3	55.0	0.2	10.0	8.0 / 1.6	43	191	3.3 / 10.5	2.0	85.4	1.3	55.0	5.0 / 0.4	28	124	6.3 / 0.1	0.45 / 2.2	315	8.4 / 15.5
303	9 / 15.2	54	0.5	15.4	0.2	5.8	6.0 / 11.2	43	195	34.2 / 17.1	1.3	40.0	0.5	15.4	3.0 / 6.8	28	127	13.2 / 7.3	0.7 / 0.9	323	26.4 / 13.9
304	9 / 19.6	54	0.6	20.0	0.2	5.8	6.0 / 4.0	43	195	26.4 / 51.5	1.2	39.3	0.6	20.0	3.0 / 0.4	28	127	13.4 / 6.0	0.7 / 2.1	323	26.9 / 32.2

Table 3-5

SHAKEDOWN TESTS

Experiment Number	OVERALL			PROJECTED MUST POWER NO. OF LAMPS & REAC. VOLUME					
	Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	O_3 Power KW	UV Power KW	Total Power UV + O_3 KW	No. of 43 w Lamps Reac 1	No. of 43 w Lamps Reac 2	REAC Water Volume Gals
SHCP	0.3		15.6						
300	0.44	355	8.6	2.6	4.7	7.3	66	43	210
	0.5		8.9						
301	1.2	309	8.5	6.4	4.1	10.5	58	38	183
	0.45		8.4						
302	2.2	315	15.5	6.6	4.2	10.8	59	38	185
	0.7		26.4						
303	0.9	323	13.9	3.2	4.3	7.5	60	39	189
	0.7		26.9						
304	2.1	323	32.2	3.1	4.3	7.4	60	39	189

3.5 DOUBLE RECIPE TESTING

The synthetic RO, HC permeate solute was doubled to increase the TOC content and to allow broader responses in the design-of-experiment testing. Table 3-6 summarizes four test runs at various ozone concentrations and mass flows. The UV input power levels to each reactor remained constant for all of these runs.

By doubling the recipe, the residence times doubled and there was a marked decrease in O_3 efficiency. The second stage effluent met COD specifications but TOC was 1/2 to 1 mg/l off specification in Experiments 306-308. Again, the lower level O_3 mass flow provided higher O_3 efficiencies. The effect of low O_3 mass flow on MUST total power projection in Experiments 305 and 307 is shown in Table 3-7.

It should also be noted that doubling the recipe doubles the UV power requirement and the reactor volume for this set of test conditions.

Table 3-6

DOUBLE RECIPE TESTS

	REACTOR 1										REACTOR 2							OVERALL		
Experiment Number	Influent Conc TOC/COD mg/l	Res Time/Reac min	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic	Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %
11-25 305	15.0 19.2	120	0.65	31.7	0.2	12.0	11.0 0.8	43	430	7.6 17.4	1.0	57.6	0.61	31.7	4.0 0.8	28	280	11.1 0	1.1 1.8	710	15.3 9.5
12-5 306	17.5 20.8	120	0.8	67.2	0.5	46.0	10.0 13.6	43	430	8.9 5.8	1.0	92	0.8	67.2	5.5 6.0	28	280	3.9 2.5	1.2 1.5	710	10.4 4.8
12-11 307	22 21.2	120	0.77	37.4	0.5	22.6	12.0 7.6	43	430	21.4 8.8	1.49	65.8	0.77	37.4	6.0 6.5	28	280	7.3 0.5	1.6 1.5	710	19.4 6.7
12-16 308	16.5 21.2	120	1.1	46.6	0.5	23.1	12.0 22.0	43	430	7.7 0	1.96	86.4	1.1	46.6	6.0 8.4	28	280	5.5 4.7	1.0 1.3	710	9.7 4.4

Table 3-7

DOUBLE RECIPE POWER AND VOLUME PROJECTIONS

Date and Experiment Number	OVERALL: Ave Rate of TOC/COD Removal mg/min	OVERALL: UV Index w-m/l	OVERALL: Supplied TOC/O_3/COD/O_3 Effic %	PROJECTED MUST POWER NO. OF LAMPS & REACTOR VOL.: O_3 Power KW	UV Power KW	Total Power UV + O_3 KW	No. of 43 w Lamps Reac 1	No. of 43 w Lamps Reac 2	REAC Water Volume Gals
11-25 305	1.1 / 1.8	710	15.3 / 9.5	10.1	9.4	19.5	132	86	420
12-5 306	1.2 / 1.5	710	10.4 / 4.8	16.2	9.4	25.6	132	86	420
12-11 307	1.6 / 1.5	710	19.4 / 6.7	11.5	9.4	20.9	132	86	420
12-16 308	1.0 / 1.3	710	9.7 / 4.4	15.2	9.4	24.6	132	86	420

3.6 DOUBLE RECIPE WITH 8 mg/l UREA TESTING

The original synthetic HC, RO permeate called for a 1.8 mg/l urea content. The double recipe contains 3.6 mg/l urea. Walden's analysis of their permeate indicated that the urea content should be 8 mg/l. The synthetic permeate recipe was then changed to reflect these analytical results.

Tables 3-8 and 3-9 show the results when using the double recipe with 8 mg/l urea. The additional 4.4 mg/l urea has a profound effect on residence time, projected UV power, and projected O_3 power.

The lowest projected power was obtained in Experiment 316 with:

1) reduced power in the UV lamp in Reactor 2,
2) no UV in Reactor 1, and
3) ozone mass flow input at 42 mg/min with a 1% O_3 by weight concentration in air.

A shorter residence time was achieved in Experiment 314 with an increase of ozone mass flow input (117 mg/min) and the same UV conditions; however, the projected total power increases from 14.7 KW to 24.1 KW.

Table 3-8 DOUBLE RECIPE TESTS with 8 mg/l UREA Table 3-8

Date and Experiment Number	REACTOR 1 Influent Conc TOC/COD mg/l	Res Time/Reac min	Input O_3 Conc % by O_3 wt	Input O_3 Mass Flow mg/O_3 min	Output O_3 Conc % by O_3 wt	Output O_3 Mass Flow mg/O_3 min	Effluent TOC Conc/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	REACTOR 2 Input O_3 Conc % by O_3 wt	Input O_3 Mass Flow mg/O_3 min	Output O_3 Conc % by O_3 wt	Output O_3 Mass Flow mg/O_3 min	Effluent TOC/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	OVERALL Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l -	Supplied TOC/O_3/COD/O_3 Effic %
12-19 & 22 309	22.0 / 16.3	240	0.94	41.3	0.5	25.0	8.5 / 7.5	43	860	13.1 / 3.2	1.3	59.0	0.94	41.3	3.0 / 2.6	28	560	3.7 / 1.2	0.95 / 0.7	1420	12.9 / 3.5
12-23 & 24 310	22.0 / 14.1	240	0.4	18.2	0.2	8.6	11.0 / 11.0	43	860	24.2 / 2.5	1.2	52.8	0.4	18.2	4.0 / 5.3	43	860	5.3 / 1.6	0.90 / 0.4	1720	13.6 / 2.5
1-5-76 311	20.5 / 45.0	240	1.2	35.5	0.7	21.2	12.0 / 26.2	0	0	9.6 / 7.9	1.8	52.8	1.2	35.5	5.0 / 4.6	43	860	5.3 / 6.1	0.78 / 2.0	860	11.7 / 11.5
1-7-76 312	20.5 / 31.3	240	0.6	26.4	0.25	11.0	11.5 / 26.0	0	0	13.6 / 3.0	1.4	60.5	0.6	26.4	4.5 / 2.5	43	860	4.6 / 5.8	0.8 / 1.44	860	10.6 / 7.1
1-12 313	19 / 46	240	1.4	107	1.0	74.9	5.5 / 6.4	43	860	4.6 / 5.5	1.6	117	1.4	107	5.0 / 7.6	0	0	0.2 / 0	0.7 / 1.92	860	4.8 / 4.9
1-12 & 13 314	19 / 46	120	1.5	111	1.0	71.0	11.0 / 16.8	0	0	5.8 / 7.9	1.6	117	1.5	111	4.0 / 8.0	28	280	4.8 / 2.3	1.5 / 3.8	280	10.3 / 9.7
1-15 & 16 315	18.0 / 16.7	160	1.2	34.6	0.9	27.8	15.5 / 7.5	0	0	4.3 / 6.0	1.8	55.2	1.2	34.6	6.0 / 4.8	28	373	10.3 / 1.1	0.9 / 0.9	373	13.0 / 4.8
1-16 & 21 316	18.0 / 16.7	160	0.8	34.6	0.7	31.2	11.0 / M*	0	0	12.1 / M*	1.0	42.2	0.8	34.6	5.0 / 6.2	28	373	8.5 / M*	0.97 / 0.79	373	18.5 / 5.6
1-27 ** 317	11.0 / 11.2	80	0.7	31.2	0.7	29.7	5.0 / 9.4	0	0	23.1 / 2.6	1.0	44.0	0.7	31.2	2.0 / 4.2	28	187	8.2 / 5.3	1.35 / 1.05	187	24.5 / 7.2

*Missing **Single Recipe + 8 mg/Urea

TABLE 3-9

DOUBLE RECIPE TESTS with 8 mg/l UREA

	OVERALL			PROJECTED MUST POWER NO. OF LAMPS & REACTOR VOL.					
Date and Experiment Number	Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	O_3 Power KW	UV Power KW	Total Power UV + O_3 KW	No. of 43 w Lamps Reac 1	No. of 43 w Lamps Reac 2	REAC Water Volume Gals
12-19 & 22 309	0.95 / 0.7	1420	12.9 / 3.5	20.6	18.8	39.4	264	172	840
12-23 & 24 310	0.90 / 0.4	1720	13.6 / 2.5	18.5	22.8	41.3	264	264	840
1-5-(76) 311	0.78 / 2.0	860	11.7 / 11.5	18.5	11.4	29.9	0	264	840
1-7-(76) 312	0.8 / 1.44	860	10.6 / 7.1	21.1	11.4	32.5	0	264	840
1-12 313	0.7 / 1.92	860	4.8 / 4.9	40.8	11.4	52.2	264	0	840
1-12 & 13 314	1.5 / 3.8	280	10.3 / 9.7	20.4	3.7	24.1	0	86	420
1-15 & 16 315	0.9 / 0.9	373	13.0 / 4.8	12.9	4.9	17.8	0	115	560
1-16 & 21 316	0.97 / 0.79	373	18.5 / 5.6	9.8	4.9	14.7	0	115	560
1-27 317	1.35 / 1.05	187	24.5 / 7.2	5.1	2.5	7.6	0	58	280

A comparison of the oxidation of double recipe plus 8 mg/l urea with single recipe plus 8 mg/l urea is made in Experiments 316 and 317. The residence time and the projected total power is halved when the single recipe is substituted for the double recipe at the same operating conditions.

3.7 TOC ANALYTICAL CHECK

Two samples were sent to Westgate by USAMBRDL to compare Westgate TOC analysis with USAMBRDL. One sample was a TOCA Standard and the other was a sample of synthetic HC, RO permeate made up by Drs. Cowen and Cooper. Westgate's analysis compared closely to USAMBRDL as seen below:

	Westgate	USAMBRDL
TOCA Standard	29 mg/l	30 mg/l
Synthetic HC, RO Permeate	13.5 mg/l	14 mg/l

3.8 SINGLE RECIPE WITH 18 mg/l UREA TESTS

Upon further examination of the Walden RO-HC permeate, AMBRDL found that 18 mg/l urea in the single recipe was a more realistic formulation than the

preceding recipes. Tables 3-10 and 3-11 present the results of 8 test runs using this permeate. The shortest residence time achieved in this series was 120 minutes and the minimum total projected power was 7.9 KW. The best combination of minimum residence time and total projected power was in Experiment 321 where no UV was used and the input ozone mass flow was 53 mg/min at 1.8% O_3 in air by weight.

3.9 USAMBRDL QUANTITATIVE ANALYSIS OF DOUBLE RECIPE PLUS 8 mg/l UREA AND SINGLE RECIPE PLUS 18 mg/l UREA SAMPLES

Samples of feed permeates and effluents from Reactor 1 and Reactor 2 were submitted to Environmental Quality Division of USAMBRDL for detailed analysis. Table 3-12 shows the results of these analyses.

In the double recipe plus 8 mg/l urea series (Experiments 309 to 316) there was no significant reduction of urea in any of the tests. Experiment 309-1 is a sample of the original permeate. The other compounds showed decreases after one or two stages of oxidation.

The single recipe plus 18 mg/l urea (Experiments 318 to 325) test series also showed no significant reduction

Table 3-10

SINGLE RECIPE WITH 18 mg/l UREA

Date and Experiment Number	REACTOR 1										REACTOR 2								OVERALL		
	Influent Conc TOC/COD mg/l	Res Time/Reac min	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC Conc/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	Input O_3 Conc % by wt	Input O_3 Mass Flow mg/min	Output O_3 Conc % by wt	Output O_3 Mass Flow mg/min	Effluent TOC/COD Conc mg/l	UV Input Power watts	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %
1-29 318	14.5 21	120	0.8	36	0.7	31.2	13 16.8	0	0	3.3 3.5	1.0	46	0.8	36	5 5.6	28	280	13.9 7.3	0.95 1.54	280	16.5 10.0
1-30 319	14.5 21	240	1.0	47	1.0	43	8 13.7	0	0	5.5 2.3	1.0	46	1.0	47	6.5 6.5	0	0	1.3 2.3	0.4 0.72	0	7.0 4.7
2-4 320	12.5 20.2	120	0.8	23	0.4	12	9 14	0	0	12.2 8.1	1.0	53	0.8	23	5 6.1	28	280	6.0 4.5	0.75 1.4	280	11.3 8.0
2-5 321	12.5 20.2	120	1.6	47	1.2	36	6 14.8	0	0	11.1 3.4	1.8	53	1.6	47	5 9.7	0	0	1.5 2.9	0.75 1.05	0	11.3 5.9
2-11 322	15.5 21.6	120	0.8	11	0.6	8.6	9 9.5	0	0	47.3 33.0	2.4	34.6	0.8	11	5 4.2	28	280	9.2 4.6	1.05 1.74	280	24.2 15.1
2-13 323	15.5 21.6	160	2.0	29	1.5	21.0	6 8.7	0	0	19.7 10.0	2.4	34.6	2.0	29	6 6.5	0	0	0 1.4	0.71 1.13	0	16.5 9.8
2-23 324	13 22.1	240	0.7	10.1	0.6	8.2	10.5 11.0	0	0	9.8 16.5	1.6	22.6	0.7	10.1	5.0 7.7	28	560	9.7 2.2	0.4 0.7	560	14.2 9.6
2-24 325	13 22.1	240	0.8	11.5	0.7	10.1	8.0 9.1	0	0	17.4 17.0	1.6	22.6	0.8	11.5	6.0 7.7	0	0	3.5 0.9	0.35 0.7	0	12.4 9.6

Table 3-11

SINGLE RECIPE WITH 18 mg/l UREA

	OVERALL			PROJECTED MUST POWER NO. OF LAMPS & REACTOR VOL.					
Date and Experiment Number	Ave Rate of TOC/COD Removal mg/min	UV Index w-m/l	Supplied TOC/O_3/COD/O_3 Effic %	O_3 Power KW	UV Power KW	Total Power UV + O_3 KW	No. of 43 w Lamps Reac 1	No. of 43 w Lamps Reac 2	REAC Water Volume Gals
1-29 318	0.95 1.54	280	16.5 10.0	8.1	3.7	11.8	0	86	420
1-30 319	0.4 0.72	0	7.0 4.7	16	0	16	0	0	840
2-4 320	0.75 1.4	280	11.3 8.0	9.3	3.7	13.0	0	86	420
2-5 321	0.75 1.05	0	11.3 5.9	9.3	0	9.3	0	0	420
2-11 322	1.05 1.74	280	24.2 15.1	6.1	3.7	9.8	0	86	420
2-13 323	0.71 1.13	0	16.5 9.8	8.1	0	8.1	0	0	560
2-23 324	0.4 0.7	560	14.2 9.6	7.9	7.4	15.3	0	172	840
2-24 325	0.35 0.7	0	12.4 9.6	7.9	0	7.9	0	0	840

Table 3-12

Quantitative Analysis of Westgate Research Corporation Samples

Sample Number	ul/l					mg/l
	MeOH	Acetone	2-propanol	Diethyl ether	MEK	Urea
309-1[1]	1	11		0.1	0.3	8
-2[2]	<1	<0.05				6
-3[3]		<0.05				n.a.[4]
310-2		<0.05		<0.05		6
-3	n.a.	n.a.	n.a.	n.a.	n.a.	6
311-2	5	7		<0.1	0.2	7
-3	0.2	2		<0.05		7
312-2	3	4		<0.05	0.05	7
-3	0.8	1	<0.05	<0.05		7
313-2		2				6
-3	0.5	3	<0.05		<0.05	8
314-2	4	6	<0.05	<0.05	0.2	7
-3A	0.3	1			<0.05	7
-3B	1					
315-2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
-3		2			<0.05	6
316-2		5	<0.05		0.1	6
-3		2		<0.05		7
317-2A[5]	0.4					7
-2B			<0.05		<0.05	6
318-2	n.a.	n.a.	n.a.	n.a.	n.a.	-
-3		0.6				15
319-2		2				16
-3		0.5				16
320-2	4	3	<0.05		0.1	16
-3	2	2			<0.05	15
321-2	0.5	2			<0.05	15
-3		0.6				15

(continued)

Table 3-12 (continued)

Sample Number	ul/l MeOH	Acetone	2-propanol	Diethyl ether	MEK	mg/l Urea
322-2						
-3		0.7				14
323-2		0.8				14
-3		0.6				16
324-2		2			0.1	16
-3		0.1				16
325-2		2			0.1	16
-3		1			< .05	16
Initial Feed 2-23-76		6				

[1] indicates feed to ozonator

[2] indicates effluent from 1st stage ozonator

[3] indicates effluent from 2nd stage ozonator

[4] n.a. = not analyzed

[5] 317 arrived with two bottles having the same labeling

Note: The lower limit of detection for methanol is 1, acetone, 2-propanol, diethyl ether and methyl ethyl ketone are all 0.05. Where values are not given, no peak was observed. Where a less than value is given, a peak was observed which was either below the limit of detection or was background.

of urea. It is apparent that urea is the most refractory constituent to either ozone or ozone and UV, and the most significant residual in the oxidized permeate. All oxidized permeates met the specified MUST TOC and COD standards.

3.10 REMOVAL OF VOLATILES BY AIR PURGING

A batch test was run in the two 6 inch diameter reactors to determine the degree of removal of TOC from HCRO permeate with 18 mg/l urea by air purging. UV and ozone were not used in this test. Dry compressed air at a flow rate of 2.5 slpm was sparged into Reactor 2. The off-gas from Reactor 2 was then sparged into Reactor 1. As shown in Table 3-13, the initial TOC was 11 mg/l, and the loss in TOC was approximately 2 mg/l.

3.11 PRELIMINARY MATHEMATICAL MODEL BASED ON TWO-STAGE BENCH TESTS

Preliminary mathematical models for relating power and volume requirements to process variables for a full-scale MUST System were derived by using multi-variable regression analysis of the data from 21 of the bench tests (Experiment Numbers 305 to 325). Tabulation of

Table 3-13

Loss of Volatiles by Air Purging
of HC-RO Permeate with 18 mg/l Urea

Reaction Time (min)	Reactor 1		Reactor 2	
	TOC (mg/l)	pH	TOC (mg/l)	pH
0	11	6.6	11	6.6
30	10		10	
60	9.5		9.5	
90	8.5		8.5	
120	8.5		8.5	
150	8.5		8.5	
180	8.5		8.5	
210	9.0		9.0	

these results are shown in Table 3-14. As shown, the independent variables (predictors) were UV power in each reactor, O_3 mass flow, O_3 concentration, urea starting concentration, and the recipe multiple. The dependent variables (responses) were total power requirement and reactor volume for a full-scale MUST System.

Computer programs for the regression analysis were set up, tested and refined at the UCLA Department of Bio/Mathematical Sciences under the direction of Dr. Forsythe. The models derived for total power and reactor volume are:

$$\text{Total Power (KW)} = -7.408 + 0.014\ (UV_2)^2$$
$$+ 0.047\ (UV_1)\ (\text{Conc Urea}) - 0.007\ (UV_2)\ (O_3 \text{ Mass Flow})$$
$$+ 0.144\ (O_3 \text{ Mass Flow})\ (\text{Recipe No.})$$
$$+ 0.631\ (\text{Conc Urea (Recipe No.)}$$

$$\text{Reactor Volume (gals)} = 75.4 + \text{Conc Urea}$$
$$0.572\ (UV_1) - 0.305\ (UV_2) - 0.497\ (O_3 \text{ Mass Flow})$$
$$- 6.496\ (\text{Conc } O_3) + 62.594\ (\text{Recipe No.})$$

Table 3-14

Tabulation of Experimental Results/Power and Reactor Volume Projections

Exp. No.	UV_1	UV_2	O_3 Mass Flow	O_3 Conc	Urea Level	RECIPE		RESPONSE Projected Total Power	RESPONSE Projected React. Volume
						Double	Single		
	watts	watts	mg/min	%	mg/l			KW	Gals.
305	43	28	57.6	1.0	3.6	x		19.5	420
306	43	28	92.0	1.0	3.6	x		25.6	420
307	43	28	65.8	1.49	3.6	x		20.9	420
308	43	28	86.4	1.96	3.6	x		24.6	420
309	43	28	59.0	1.3	8.0	x		39.4	840
310	43	43	52.8	1.2	8.0	x		41.3	840
311	0	43	52.8	1.8	8.0	x		29.9	840
312	0	43	60.5	1.4	8.0	x		32.5	840
313	43	0	117.0	1.6	8.0	x		52.2	840
314	0	28	117.0	1.6	8.0	x		24.1	420
315	0	28	55.2	1.8	8.0	x		17.8	560
316	0	28	42.2	1.0	8.0	x		14.7	560
317	0	28	44.0	1.0	8.0		x	7.6	280
318	0	28	46.0	1.0	18.0		x	11.8	420
319	0	0	46.0	1.0	18.0		x	16.0	840
320	0	28	53.0	1.0	18.0		x	13.0	420
321	0	0	53.0	1.8	18.0		x	9.3	420
322	0	28	34.6	2.4	18.0		x	9.8	420
323	0	0	34.6	2.4	18.0		x	8.1	560
324	0	28	22.6	1.6	18.0		x	15.3	840
325	0	0	22.6	1.6	18.0		x	7.9	840

As shown by these models, increasing the concentration of urea and the recipe multiple increases the power and the reactor volume requirements. For example, if the urea concentration is increased from 12 mg/l to 24 mg/l when using 50 mg/min O_3 at 1% concentration, with 28 watt input power to the second stage reactor, the total power increases from 8.5 KW to 16.1 KW and the reactor volume increases from 348 gallons to 620 gallons. Conversely, the residence time in a 350 gallon reactor will increase from 100 minutes to 177 minutes with this doubling of urea concentration.

APPENDIX

EXCERPTS FROM FINAL REPORT
CONTRACT DAMD 17-75C-5013

NOVEMBER 1976

SECTION 4 PILOT PLANT DEVELOPMENT AND TESTING

Based upon bench test results, the next step was to develop a pilot plant unit which can be scaled up to a full scale MUST System with the least difficulty.

4.1 DESIGN CONSIDERATIONS

4.1.1 UV Lamp Selection

In translating the results of the bench tests to designing of larger scale UV-ozone systems, the state-of-the-art of UV lamps is an important consideration. In the bench reactors, low-pressure, 39 to 43 watt mercury germicidal lamps were used. These lamps are available from a number of manufacturers. The life of these lamps is one year or longer, and the UV power output/input power efficiency is about 35%. In scaling up the system, either a larger number of low pressure lamps or a fewer number of high wattage UV lamps with greater UV output power can be used.

A survey of lamp manufacturers was made to determine if high wattage lamps were available with the same efficiency and life characteristics as the low-pressure lamps. Sylvania, Westinghouse, General Electric, and

Hanovia were contacted. None had off-the-shelf higher UV output lamps which matched the spectral characteristics, the UV power/input efficiency, or the life spans of the low-pressure lamps. Hanovia stated that research projects were underway to improve the life and efficiency of their medium pressure lamps but no samples were available for evaluation.

At the present time, there are no higher powered lamps available which match the low-power, low-pressure lamps used in our bench testing.

4.1.2 UV Lamp Placement

Either 3 inch diameter or 6 inch diameter reactors were used in the bench tests. The length of the light path in these tests was either 1.5 or 3 inches from lamp center to reactor wall. At this time it was not known whether the UV light path could be extended without affecting the rate of reaction. Since the optimum light path was unknown, the design of the pilot system would allow for a variable distance between lamps.

4.1.3 Ozone Introduction and Diffusion

Several bench tests were conducted where various spargers were used to determine whether pore size affected rate of reaction. Very little difference was noted in these limited tests. Since point of introduction of ozone and bubble size has not been studied to any extent, accommodation is made in the pilot systems to readily change spargers to determine their effect.

4.1.4 Mixing State

The 3 inch and 6 inch diameter reactors when operated continuously on the bench could not be considered to produce either ideal stirred tank or tubular-flow flow reactions. Deviations from these ideal forms were caused by the ozone sparging, which created sufficient mixing to disrupt plug or tubular flow, but may not have been enough for sufficient ozone or activated oxygen transfer.

Further study of mixing state on reaction rate, ozone utilization efficiency, and UV power input requirements can be made if the water velocity within the reactor can be varied as well as gas velocity and UV intensity. Change in water velocity can be accomplished by varying

the cross-sectional area in each of the stages in the reactor. Widening or narrowing the flow channels within the reactor will bring about this change. The reactor was therefore designed with a square cross-section and movable baffles. The number of stages could be changed as well as the cross-sectional area within each stage.

4.1.5 Scale-Up

The design of the pilot system should be amenable to scale-up to a full-scale MUST System. From a photochemical viewpoint, it is best to develop a module containing the required number of lamps, the proper reactor volume, the right ozone sparging configuration and pore size, and the best arrangement of baffles for optimum performance. Once all of this is established, it is straightforward to design a full-scale MUST system which will accommodate 3.5 gpm by placing the required number of these modules together and operating the modules in parallel. This approach avoids the problems of scaling up a system where at present there are no clear-cut methods for applying physical and kinetic principles to reactor design.

It was the objective in this design effort to develop a unit reactor module (URM) with built-in

flexibility in ozone introduction and sparging, UV lamp placement, and flow-mixing characteristics. The URM would then serve as one of the building blocks for a full-scale MUST system.

4.2 URM DESIGN

The objective was to fabricate two URMs with the following design features:

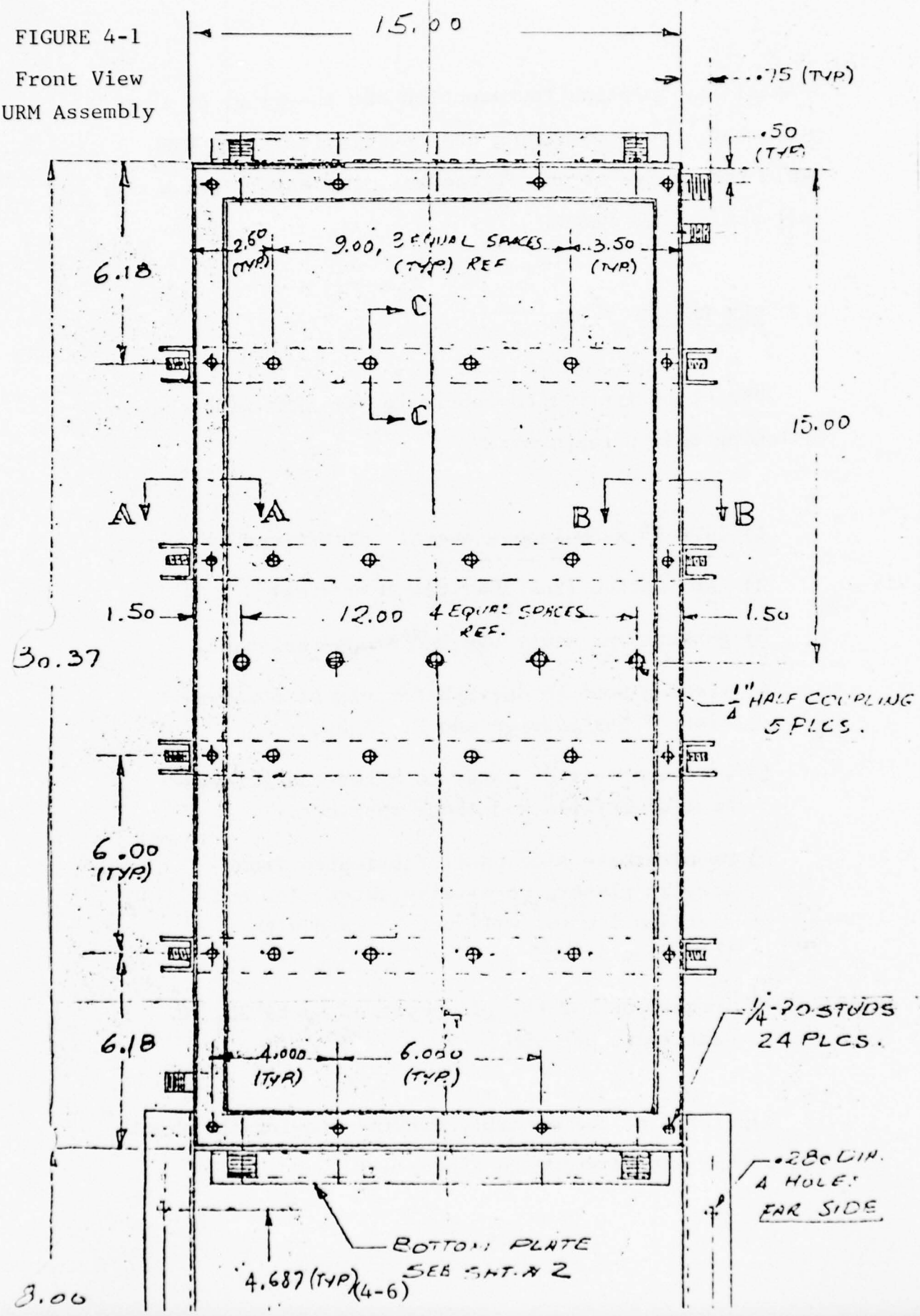
1) 15 x 15 x 30 inches overall dimensions,
2) fabrication from 304 stainless steel,
3) gaskets and seals UV- and ozone-resistant,
4) viewing port in one URM for visual observation of gas bubbles and UV light,
5) a removable side panel to alter the arrangement of baffles and ozone spargers,
6) an alternate side panel fabricated from acrylic plastic to observe water flow and distribution (UV will not be used with this panel), and
7) provisions for the placement of up to 25, 39 watt lamps per URM.

A portion of the assembly drawing showing the front view of the URM is shown in Figure 4-1.

FIGURE 4-1

Front View

URM Assembly



4.3 URM FABRICATION AND ASSEMBLY

Difficulty was encountered in the fitting and sealing of the flow baffles into the back wall and the front covers of the reactors. Modifications were necessary in the technique used for fastening of the studs to the baffles. This was accomplished by using a floating stud instead of a welded fastener.

Hydraulic pressure testing of the URMs indicated several gasket leaks around the removable front covers. These leaks were corrected by using thicker gaskets with greater durometer.

The URMs were then assembled into a total system. The system was plumbed so that the two reactors would operate in series with ozone flowing from the second stage URM to the first stage URM. The input hospital composite permeate (HCP) would then flow countercurrently to the flow of ozone.

After the system was plumbed, it was found that at 3 psig there were significant leaks around the front cover seals. Further modification of the gaskets and flanges were required. To avoid delay, it was decided to introduce equal amounts of ozone to each reactor in

parallel rather than in series. An internal pressure of only 1 psig was required with parallel flow.

After the test program, there was refurbishment of the URMs. The gasket seals were modified to hold the design pressure.

4.4 URM TEST PROGRAM PLAN

This experimental plan provided a practical guideline for obtaining minimum power and minimum residence time information for a full-scale MUST UV/O_3 System.

This information was obtained by conducting statistically designed experiments. 1 x recipe + 12 mg/l urea synthetic RO permeate was selected as the test water.

The test protocol consisted of (1) defining the objectives for the experimental series, (2) establishing the criteria for success/failure of the tests, (3) formulating the mathematical model, and (4) setting up test methodology.

4.4.1 Experimental Objectives

(1) Find the combination of independent variables to give the minimum power requirement within the MUST design constraints.

(2) Estimate values of coefficients to better understand the inter-relationships of the independent variables.

4.4.2 Criteria for Success or Failure

An experiment is considered successful if the TOC of the effluent is 5 mg/l or less at steady-state conditions at a flow rate of 800 ml/min (120 min residence time/reactor) or greater.

4.4.3 Mathematical Model

$$\begin{aligned} Z = {} & a + b_1 U + b_2 V + b_3 W + b_4 X + b_5 S + S + b_6 T \\ & + b_{11} U^2 + b_{22} V^2 + b_{33} W^2 + b_{44} X^2 \\ & + b_{12} UV + b_{13} UW + b_{14} UX \\ & + b_{23} VW + b_{24} VX \\ & + b_{34} WX \end{aligned}$$

where:

Z = Total Power $\frac{KW}{1/\,min}$ K_1

K_1 = Scale factor to full-size MUST System

U = O_3 mass flow $\frac{mgO_3}{min}$ K_2

K_2 = $\overline{A}$ KWH/ 454 x 10^3 mg O_3 x 60/1 /min

Value of $\overline{A}$ dependent upon O_3 concentration, can vary from 10.1 to 13.0 $\frac{KWH}{lbO_3}$

V = UV_2 (banks of 3 lamps in Reactor 2) x K_3

K_3 = 50 w/lamp / 1 / min

W = O_3 concentration (% O_3 in O_2 by wt)

X = UV_1 (banks of 3 lamps in Reactor 1) x K_4

S = pH

T = temperature (°C)

4.5 TEST METHODOLOGY

4.5.1 Method

The method used is a combination of Newton's method for systems of equations using secants estimated by least squares with a Gauss-Seidel method for acceleration.

4.5.2 Approach

Experiment 1:

$U_0 = 400$, $V_0 = 9$, $W_0 = 1$, $X_0 = 0$,

$S = 9$ (at intake), $T = 25$

Experiment 2:

$U_0 = 200$; Other variables same as Experiment 1

Experiment 3:

$U_0 = 600$; Other variables same as Experiment 2

Analysis 1

Fit by least squares: $z = a + b_1 U + b_{11} U^2$

using z_1, z_2, z_3

Solve for value of U that improves results.

Solution is $U_1 = U_0 - \dfrac{a + b_1 U_0 + b_{11} U_0^2}{b_1 + 2 b_{11} U_0}$

Experiment 4:

U_1, $V_0 = 9$, $W_0 = 1$, $X_0 = 0$, $S = 9$, $T = 25$

to obtain z_4

Analysis 2

Repeat Analysis 1 with z_1, z_2, z_3, z_4

to obtain U_2

Experiment 5:

U_2, $V_1 = 15$, $W_0 = 1$, $X_0 = 0$, $S = 9$, $T = 25$

to obtain z_5

Analysis 3

$$U_3 = U_2 - \frac{a + b_1 U_2 + b_{11} U_2^2}{b_1 + 2 b_{11} U_2}$$

Experiment 6

U_3, V_2 = 3, W_0 = 1, X_0 = 0, S = 9, T = 25
to obtain z_6

Analysis 4

Fit by least squares with z_1, z_2, ... z_6

$$z = a + b_1 U + b_{11} U^2 + b_2 V + b_{22} V^2 + b_{12} UV$$

Find values of U and V that are predicted to most improve results. Call them U_4, V_1.

Experiment 7

U_4, V_1, W_0 = 1, X_0 = 0, S = 9, T = 25
to obtain z_7

Analysis 5

Same as Analysis 4 with z_1,....., z_7 to yield U_5 and V_2

Experiment 8

U_5, V_2, W_0 = 1 1/2, X_0 = 0, S = 9, T = 25
to obtain z_8

Analysis 6

Same as Analysis 4 with $z_1, \ldots, z_8$ to yield U_6 and V_3

Experiment 9

U_6, V_3, $W_0 = 1/2$, $X_0 = 0$, $S = 9$, $T = 25$
to obtain z_9

Analysis 7:

Fit by stepwise least squares with $z_1, \ldots, z_9$

$$z = a + b_1 U + b_{11} U^2 + b_2 V + b_{22} V^2 + b_{12} UV + b_3 W + b_{33} W^2 + b_{13} UW + b_{23} VW$$

Solve for most improved values: U_7, V_4, W_1

Experiment 10

U_7, V_4, W_1, $X_0 = 0$, $S = 9$, $T = 25$
to obtain z_{10}

Analysis 8

Same as Analysis 7 with $z_1, \ldots\ldots, z_{10}$. Final values of U, V, and W that minimize this function and call these improved values U_8, V_5, and W_2.

Experiment 11

$U_8, V_5, W_2, X_0 = 0, S = 9, T = 25$
to obtain z_{11}

Analysis 9

Same as Analysis 7 with $z_1, \ldots\ldots, z_{11}$ to yield U_9, V_6, and W_3

Experiment 12

$U_9, V_6, W_3, X_0 = 3, S = 9, T = 25$
to obtain z_{12}

Analysis 10

Same as Analysis 7 with $z_1, \ldots\ldots, z_{12}$ to yield U_{10}, V_7, and W_4

Experiment 13

U_{10}, V_7, W_4, X_0 = 6, S = 9, T = 25
to obtain z_{13}

Analysis 11

Fit by stepwise least squares with z_1,
....., z_{13}

$$z = a + b_1 U + b_{11} U^2 + b_2 V + b_{22} V^2 + b_{12} UV + b_3 W + b_{33} W^2 + b_{13} UV + b_{23} VW + b_4 X + b_{44} X^2 + b_{14} UX + b_{24} VX + b_{34} WX$$

Find values of U, V, W, and X that minimize this function and call these improved values U_{11}, V_8, W_5, and X_1

Experiment 14

U_{11}, V_8, W_5, X_1, S = 9, T = 25 to obtain z_{14}

Analysis 12

Same as Analysis 11 to obtain U_{12}, V_9, W_6 and X_2

Experiment 15

U_{12}, V_9, W_6, X_2, S = 6.5, T = 40 to obtain z_{15}

Analysis 13

Fit full model by stepwise least squares to obtain new improved values U_{13}, V_{10}, W_7, X_3, S_1, T_1

Experiment 16

U_{13}, V_{10}, W_7, X_3, S_1, T_1 to obtain z_{16}

Analysis 14

Same as Analysis 13 to obtain U_{14}, V_{11}, W_8, X_4, S_2, and T_2

4.6 URM TESTING

4.6.1 Test Set-Up

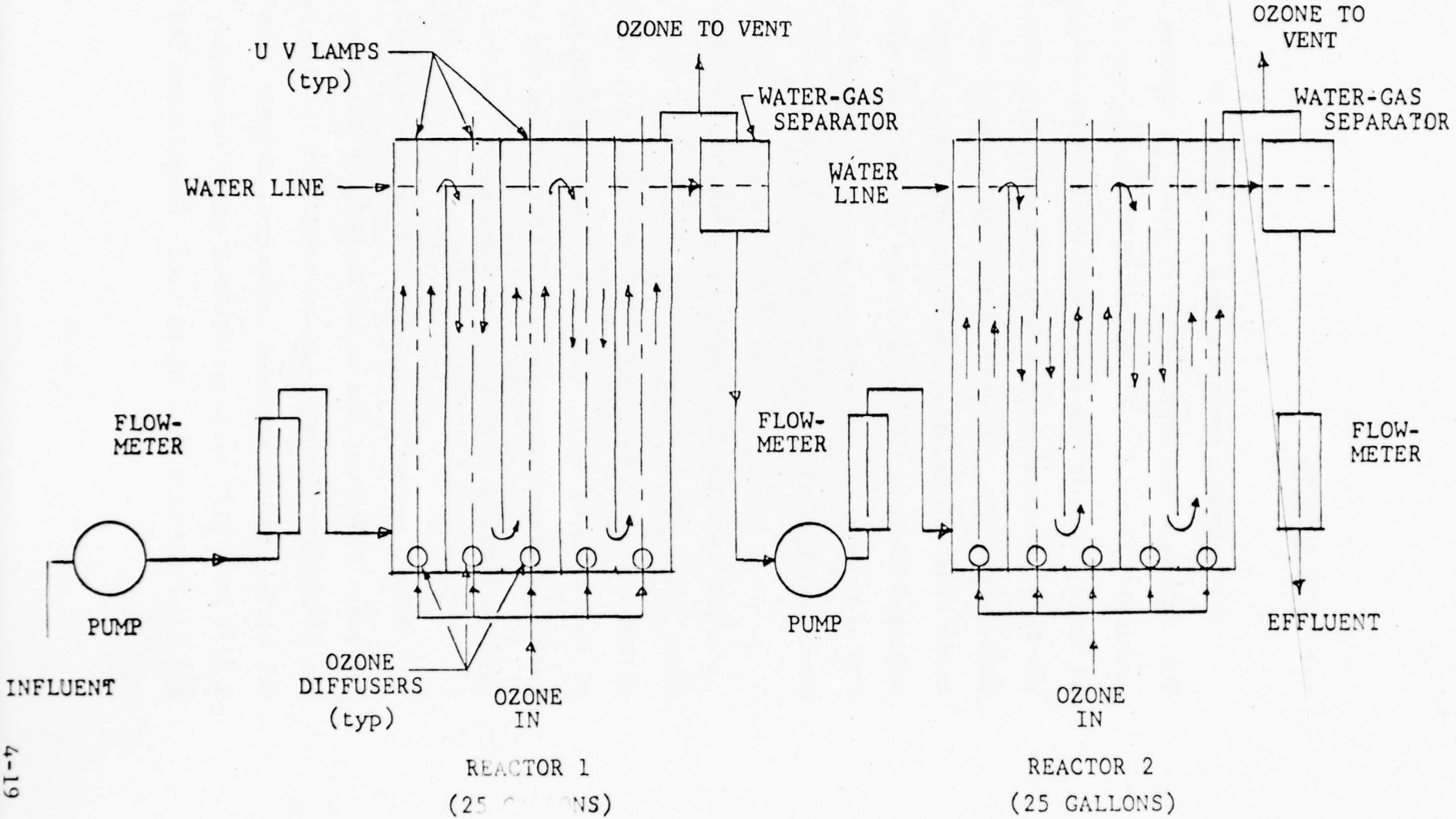
The URM system for testing was plumbed as shown in Figure 4-2. Up to 15 UV lamps could be turned on in each reactor. Each stage contained 3 lamps spaced 6 inches apart and 1½ inches from the reactor wall. If 3 lamps were to be on in a URM, they would be on only in the last stage. If 6 lamps were to be on, they would be on in the last two stages, 9 lamps in the last 3 stages, and so on.

A small size, Delrin bodied gear pump with 302 stainless steel gears was used to feed the influent to each URM. Brooks Rotameters having a measuring capacity of 150 ml to 1950 ml, were used to determine flow rates to and from each URM. An OREC Ozone Generator, Model No. 03B2-0 was used for ozone supply. Cylinder oxygen was the supply gas used throughout the testing.

Ozone was diffused into each stage through 2 spherical alumina spargers with 60 micron pore size. Bubble size was less than 2.5 mm in diameter. Each diffuser was located 6 inches apart and 4½ inches from each reactor wall.

Figure 4-2

SCHEMATIC OF TWO-STAGE PILOT SYSTEM



4.7 TEST RESULTS

The original test plan had a schedule of 16 tests. This schedule was expanded to 25 tests to improve the mathematical model. A summary of the tests are shown in Table 4-1. If the experiment failed (TOC >5 mg/l), the Fail column shows a 1.000; otherwise 0.0 indicates that it passed. The U-ADJ and FL-ADJ columns are calculated values which are flows which have been adjusted and normalized to obtain an effluent with a TOC of 5.0 mg/l. The Z column is the calculated total power value for the full-scale MUST System.

Table 4-2 provides additional analytical data on CODs, ozone off-gas, and on specific organic constituents in the effluent. All effluents run had a COD of less than 10 mg/l. Over 90% of the incoming O_3 was removed during processing in all tests where the input O_3 mass flow was less than 200 mg/min.

AMBRDL conducted the specific organic constituent analyses. Urea was the major ingredient remaining in the effluent. Methanol was reduced from 16 ul/l to < 1 ul/l, ethanol appeared unchanged, acetone from 5 ul/l to 2 ul/l or less, diethyl ether unchanged, and MEK from 0.2 ul/l to 0.01 to 0.04 (Experiment 348 excepted).

Table 1 - Summary of URM Tests

EXP	FAIL	U	V	W	X	S	T	Q	TOC-BEG	TOC-FIN	U-ADJ	FL-ADJ	Z
348	0.0	385.000	9.000	1.130	0.0	9.000	23.900	1.250	10.000	3.550	227.400	1.250	7.223
349	1.000	213.000	9.000	0.740	0.0	9.000	22.800	1.000	10.000	8.100	445.200	0.800	15.630
350	0.0	221.000	9.000	0.700	0.0	9.000	22.800	0.800	10.500	4.100	221.000	0.990	8.658
351	0.0	579.000	9.000	1.300	0.0	9.000	23.000	1.200	9.600	3.100	371.000	1.200	9.982
352	0.0	113.400	9.000	1.000	0.0	9.000	23.200	0.800	8.600	5.050	118.500	0.800	8.653
353	1.000	119.200	15.000	1.050	0.0	9.000	23.000	1.100	10.000	6.600	119.200	0.770	13.150
354	0.0	119.000	13.000	1.040	0.0	9.000	25.700	0.900	9.650	5.050	124.100	0.900	10.173
355	1.000	150.500	3.000	1.060	0.0	9.000	24.300	0.900	9.750	7.100	170.000	0.500	9.471
356	0.0	149.400	3.000	1.050	0.0	9.000	24.400	0.800	11.000	4.750	149.400	0.850	5.116
357	0.0	161.200	6.000	1.060	0.0	9.000	24.100	0.900	10.750	4.900	149.900	0.900	6.608
358	1.000	346.940	9.000	1.280	0.0	9.000	25.280	1.200	10.050	7.800	346.900	0.620	18.518
359	0.0	345.310	9.000	1.280	0.0	9.000	24.400	0.900	14.250	4.950	339.000	0.900	12.586
360	1.000	138.440	6.000	1.640	0.0	9.000	23.800	1.025	15.750	6.100	138.400	0.800	7.584
361	0.0	146.960	3.000	1.030	6.000	9.000	23.600	0.800	14.750	4.300	146.900	0.940	7.935
362	1.000	129.670	3.000	1.530	3.000	9.000	23.230	0.900	15.000	8.500	380.000	0.700	15.630
363	1.000	126.380	3.000	1.498	3.000	9.000	24.150	0.800	13.730	6.000	226.000	0.800	9.699
364	1.000	147.630	0.0	1.040	9.000	9.000	25.000	0.800	13.200	7.060	298.000	0.700	14.649
365	0.0	154.590	0.0	1.970	9.000	9.000	24.020	0.800	12.750	5.300	185.000	0.800	11.149
366	0.0	255.000	6.000	1.740	3.000	7.000	24.130	0.900	13.700	4.800	235.000	0.900	10.870
367	0.0	268.700	0.0	0.730	9.000	8.000	24.050	0.800	13.700	4.200	268.700	0.960	9.814
368	1.000	119.700	0.0	1.050	15.000	9.000	24.000	0.900	13.700	6.000	220.000	0.900	13.323
369	0.0	148.100	0.0	1.100	3.000	9.000	24.100	0.800	13.700	5.000	148.100	0.800	5.440
370	0.0	336.000	3.000	1.500	6.000	9.000	42.400	1.000	12.500	4.500	286.000	1.000	10.564
371	0.0	317.000	6.000	1.400	6.000	9.000	35.500	1.200	12.500	5.500	317.000	1.200	10.535
372	1.000	186.000	0.0	1.200	0.0	8.800	32.200	0.800	12.500	6.500	336.000	0.800	8.013

U = Ozone Mass Flow mg/min V = No. of Lamps, URM #2 W = Ozone Conc % X = No. of Lamps, URM #1
S = pH T = Temperature, °C Q = Water Flow

Table 4-2 --- Additional Analytical Data

Table 4-2

Exp. Number	U	W	O_3 in Vent Gases URM #1 mg/min	O_3 in Vent Gases URM #2 mg/min	V	X	S	T	Q	TOC Feed	TOC Effl	COD Feed	COD Effl
348	385	1.13	-	-	9	0	9	23.9	1.25	10.0	3.6	10.3	1.7
349	213	0.74	-	-	9	0	9	22.8	1.00	10.0	8.1	10.5	2.2
350	221	0.70	6.7	8.2	9	0	9	22.8	0.80	10.5	4.1	10.3	-
351	579	1.3	44.1	26.1	9	0	9	23.0	1.20	9.6	3.1	12.7	-
352	111	1.0	1.3	2.6	9	0	9	23.2	0.80	8.6	5.0	12.0	-
353	119	1.05	3.0	1.5	15	0	9	23.0	1.10	10.0	6.6		Neg
354	119	1.04	6.5	2.0	13	0	9	25.7	0.90	9.6	5.0		4.0
355	150	1.06	6.2	4.9	3	0	9	24.3	0.90	9.7	7.1		1.5
356	149	1.05	-	-	3	0	9	24.4	0.80	11.0	4.7	12.0	4.6
357	161	1.06	4.3	6.6	6	0	9	24.1	0.90	10.7	4.9		-
358	347	1.28	-	-	9	0	9	25.3	1.20	10.0	7.8		5.2
359	345	1.28	31.0	15.0	9	0	9	24.4	0.90	14.2	4.9		2.4
360	138	1.64	4.1	1.6	6	0	9	23.8	1.02	15.7	6.1		Neg
361	147	1.03	3.5	4.1	3	6	9	23.6	0.80	14.7	4.3		4.7
362	130	1.53	1.6	1.4	3	3	9	23.2	0.90	15.0	8.5		5.9
363	126	1.50	-	-	3	3	9	24.1	0.80	13.7	6.0		-
364	148	1.04	2.4	4.9	0	9	9	25.0	0.80	13.2	7.1		-
365	155	1.97	1.1	1.5	0	9	9	24.0	0.80	12.7	5.3		2.0
366	255	1.74	8.6	6.5	6	3	7	24.1	0.90	13.7	4.8		-
367	269	0.73	14.2	20.3	0	9	8	24.0	0.80	13.7	4.2		7.9
368	120	1.05	-	-	0	15	9	24.0	0.90	13.7	6.0		6.9
369	148	1.10	4.2	7.3	0	3	9	24.1	0.80	13.7	5.0		2.4
370	336	1.50	-	-	3	6	9	42.4	1.00	12.5	4.5		Neg
371	317	1.40	-	-	6	6	9	35.5	1.20	12.5	5.5		Neg
372	186	1.2	-	-	0	0	8.8	32.2	0.80	12.5	6.5		4.6

U = Total O_3 Mass Flow in V = No. of Lamps, URM #2 S = pH Q = Water Flow

W = O_3 % in X = No. of Lamps, URM #1 T = Temp °C Neg = Negative

Table 4-2 (continued)

AMBRDL Analyses of Effluent

Exp. Number	UREA mg/l	NO_3^-, NO_2^-, N mg/l	MeOH ul/l	EtOH ul/l	Acetone ul/l	Diethyl Ether ul/l	MEK ul/l
348	8.3		-	1.9	-	0.10	8.3
349	8.8		1.1	1.7	2.2	0.03	0.03
350	-		-	0.4	1.1	0.01	0.03
351	10.2		-	0.6	0.6	0.02	0.03
352	11.0		0.5	1.5	2.2	0.04	0.10
353	-		-	2.5	-	0.1	0.1
354	9.4		-	1.6	2.0	0.1	0.1
355	9.1		-	0.2	2.3	-	-
356			0.3	-	0.1	-	0.04
359			-	1.0	0.7	-	0.02
361			-	2.3	2.0	-	-
365	9.4	0.53					
367	-						
369	6.4	0.62					
370	9.3	0.68					
371	11.5	0.60					
372	10.9	0.56					

4.8 MATHEMATICAL MODELS

From the 25 tests, two mathematical models were derived: one model describes total power consumption for the full scale MUST System, and the other describes water flow velocity through the two URMs.

Total Power - MUST System

$$
\begin{aligned}
Z = {} & 5.425969 + 0.313559V + 1.902463W + 0.297531X \\
& - 0.222109S - 0.171898T + 0.022370V + 0.000062U^2 \\
& + 0.024805V^2 - 2.407578W^2 + 0.013249X^2 - 0.000041UV \\
& + 0.004635\,UW + 0.0023307X - 0.511276\,VW - 0.119371WX
\end{aligned}
$$

Water Flow - URM System

$$
\begin{aligned}
Q = {} & 0.229379 + 0.025154V - 0.069001W + 0.022678X \\
& + 0.033043S + 0.010956T + 0.000256U - 0.000006U^2 \\
& + 0.033043S + 0.010956T + 0.000256U - 0.000006U^2 \\
& - 0.002221V^2 + 0.193782W^2 - 0.000893X^2 - 0.000011UV \\
& + 0.000110UW - 0.000183UX + 0.039104VW + 0.009758WX
\end{aligned}
$$

4.9 ANALYSIS OF RESULTS USING MATHEMATICAL MODELS

4.9.1 Computations

Using the derived mathematical models, machine computations were run to determine the projected MUST UV-O_3 System for total power and water flow rate for all combinations of the independent variables within the following limits and increments:

U	100 to 200	increments of 25
V	0 to 15	increments of 3
W	0.7 to 1.9	increments of 0.2
X	0 to 15	increments of 3
S	7 to 9	increments of 1
T	25 to 40	increments of 8

10,530 computations were made, using all of the above combinations to determine projected total MUST power and URM flow rate.

4.9.2 Relationship Between Total Power and Total Reactor Volume

Working with the computed total power and water flows, the total power can be plotted against total reactor volume for a full-scale MUST system as illustrated in Table 4-3 and Figure 4-3. As the plot indicates, the relationship between these two dependent variables falls within discontinuous locii. The dependent variable combinations can be grouped as shown in the table and figure according to power and volume. Extrapolation of independent variables beyond experimental conditions was avoided in this grouping.

Fixing the pH at 9 and temperature at 32°C, the combination of variables which provide a minimum power usage fall into Group 7. As shown in Table 4-3, Group 7 specifies a 1.7 to 1.9% O_3 range. If only 0.7% O_3 is available, the lowest reactor volume possible is 595 gallons (Comp 5678, Group 5).

4.9.3 Relationship Between Total Power/ Total Volume with Ozone Concentration

In Table 4-3, it was shown that reactor volume decreased with an increase in ozone concentration.

Table 4- 3

Power vs Reactor Volume for Combinations of Independent Variables

Assume S = 9 T = 32

Group	Comp Number	U	V	W	X	Z	Q	Reactor
1.	2276	125	0	0.7	0	2.16	0.872	763
	4544	150	0	0.7	0	2.28	0.839	793
2.	4922	150	3	0.7	0	3.2	0.97	686
	2654	125	3	0.7	0	3.11	1.00	665
3.	7568	175	6	0.7	0	4.8	1.02	652
	5309	150	6	0.7	3	5.12	1.06	627
	4652	150	0	1.1	0	4.87	0.957	695
4.	5030	150	3	1.1	0	5.21	1.137	585
	2762	125	3	1.1	0	5.04	1.170	569
5.	5678	150	9	0.7	0	6.47	1.117	595
	4760	150	0	1.50	0	6.69	1.138	584
	2501	125	0	1.5	3	6.50	1.204	552
	4814	150	0	1.7	0	7.31	1.251	532
6.	5192	150	3	1.7	0	6.72	1.501	443
	5246	150	3	1.9	0	6.85	1.654	402
	10052	200	6	1.5	0	7.23	1.46	455
	5570	150	6	1.7	0	6.59	1.711	398
7.	3302	125	6	1.7	0	6.40	1.74	382
	5624	150	6	1.9	0	6.40	1.887	352
	6380	150	12	1.9	0	6.85	2.234	298
	6389	150	12	1.9	3	6.90	2.27	293
8.	6326	150	12	1.7	0	7.65	2.011	331
	8648	175	12	1.9	0	7.18	2.19	304
	6758	150	15	1.9	0	7.75	2.35	283
9.	6272	150	12	1.5	0	8.26	1.804	369
	6704	150	15	1.7	0	8.86	2.101	316
10.	4796	150	0	1.5	12	8.93	1.128	589
	9404	200	0	1.9	0	8.49	1.300	512
	4787	150	0	1.5	9	8.01	1.154	576
	6056	150	12	0.7	0	8.76	1.130	588
11.	9260	200	0	1.3	6	7.98	0.915	727
	2429	125	0	1.1	15	7.94	0.946	703
12.	4697	150	0	1.1	15	8.98	0.846	807
	9269	200	0	1.3	9	9.08	0.871	763

Figure 4-3

Power vs Volume
Full Scale MUST System

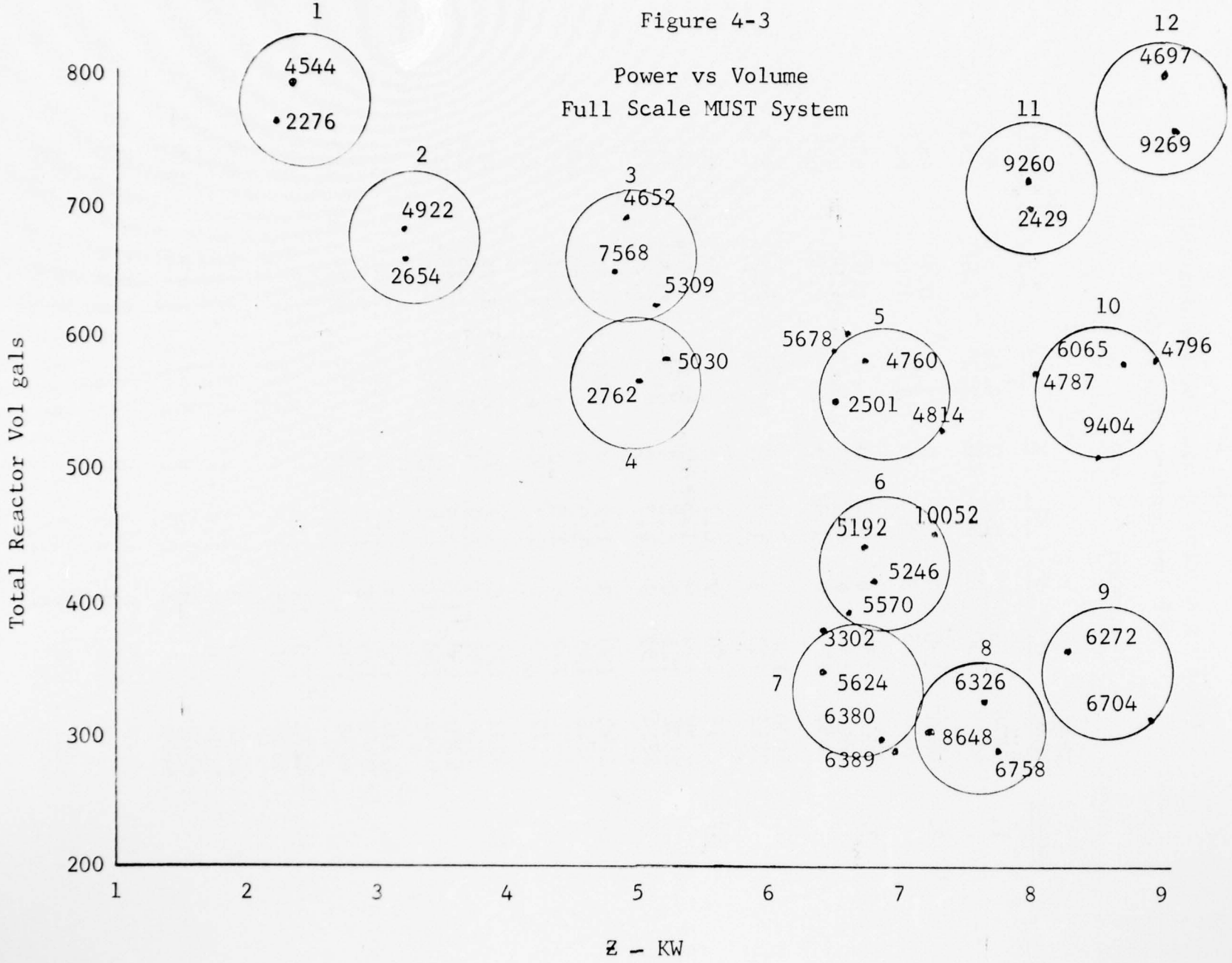


Table 4-4 shows the effect of ozone concentration on both total projected power consumption and reactor volume when no UV is on and when 3 UV lamps are on in the second stage URM. In both cases the ozone mass flow input was 150 mg/min.

As ozone concentration increases, the water flow rate increases, or conversely reactor volume decreases; however, the power increases with an increase in ozone concentration. It is also noted that with 3 UV lamps on in the second stage, reactor volume decreases for each level of ozone concentration. The effect of UV lamps is further explored in Section 4.7.6.

4.9.4 Effect of Ozone Mass Flow

Table 4-5 shows the effect of increasing ozone mass flow on URM water flow and total power when various levels of ozone concentration are used. UV was not on. There is very little change in power consumption or in water flow rate when ozone mass flow is increased. The slight negative effect on water flow is probably due to residual errors in the regression analyses.

Table 4-4

Total Power/Total Volume vs. Ozone Concentration

Where: U = 150, S = 9, T = 32, V = 0, X = 0

Comp No.	W/%	Z/KW	l/min	Vol Gals
4544	0.7	2.281	0.839	793
4652	1.1	4.87	0.957	695
4760	1.5	6.688	1.138	584
4814	1.7	7.31	1.251	532
4868	1.9	7.74	1.38	482

Where U = 150, S = 9, T = 32, V = 3, X = 0

4922	0.7	3.231	0.972	684
5030	1.1	5.21	1.137	585
5138	1.5	6.411	1.364	488
5192	1.7	6.72	1.501	443
4246	1.9	6.85	1.654	402

Table 4-5

Effect of Increasing Ozone Mass Flow

No UV

Where: W = 1.1, V = 0, X = 0, S = 9, T = 32

Comp No.	U mg/min	Z KW	Q l/min
2384	125	4.70	0.989
4652	150	4.87	0.957
6920	175	5.12	0.918
9188	200	5.44	0.871

Where: W = 1.5, V = 0, X = 0, S = 9, T = 32

2492	125	6.47	1.169
4760	150	6.69	1.138
7028	175	6.98	1.100
9296	200	7.35	1.054

Where: W = 1.9, V = 0, X = 0, S = 9, T = 32

2600	125	7.47	1.410
4868	150	7.74	1.381
7136	175	8.07	1.343
9404	200	8.49	1.300

Table 4-6 indicates that an increase in ozone mass does not increase water flow rate capacity when 3 UV lamps are turned on in the second URM.

4.9.5 Stripping Effect

It should also be pointed out that ozone mass flow rate is directly related to the volumetric gas flow rate. The greater the ozone mass flow -- the greater the volumetric gas flow. Some investigators have claimed reduction in TOC by stripping. The stripping effect is not reflected in the mathematical model as seen in Table 4-6. Also, no stripping effect was noted when the temperature is increased to 40°C as shown in Table 4-7.

4.9.6 Effect of UV

As noted in Sections 4.7.4 and 4.7.5, the presence of UV can increase the water flow capacity of the URM. Tables 4-8, 4-9, and 4-10 indicate the effect of UV on total power and URM water flow rates at various operating conditions.

Table 4-6

Effect of Increasing Ozone Mass Flow

3 UV Lamps On in Second Stage URM

Where: W = 1.1, V = 3, X = 0, S = 9, T = 32

Comp No.	U mg/min	Z KW	Q l/min
2762	125	5.04	1.170
5030	150	5.21	1.137
7298	175	5.45	1.097
9566	200	5.77	1.049

Table 4-7

Effect of Increasing Temperature to 40°C and

Increasing Mass Flow on URM Power and Flow Capacity

Comp Number	U mg/min	Gas Flow l/min	Z KW	Q l/min
2385	125	7.95	3.32	1.07
6921	175	11.1	3.74	1.01
9186	200	12.7	4.29	0.93

Table 4 - 8

The Effect of Number of UV Lamps On in the Second URM at Different Levels of Ozone Concentration

U = 150 S = 9 T = 32 X = 0

Where W = 0.7

Comp Number	V No. of lamps	$\frac{Z}{KW}$	$\frac{Q}{l/min}$
4544	0	2.28	0.839
4922	3	3.23	0.972
5300	6	4.63	1.064
5678	9	6.47	1.117
6056	12	8.76	1.130
6434	15	11.50	1.1024
Where W = 1.1			
4652	0	4.87	0.957
5030	3	5.21	1.137
5408	6	5.99	1.277
5786	9	7.22	1.376
6164	12	8.90	1.436
6542	15	11.02	1.455
Where W = 1.5			
4760	0	6.69	1.138
5138	3	6.41	1.364
5516	6	6.58	1.551
5894	9	7.20	1.698
6272	12	8.26	1.804
6650	15	9.77	1.871

continued:

Table 4 - 8
(continued)

Where W = 1.7

Comp Number	V / No. of lamps	Z / KW	Q / l/min
4814	0	7.31	1.251
5192	3	6.72	1.501
5570	6	6.59	1.711
5948	9	6.90	1.881
6326	12	7.65	2.011
6704	15	8.86	2.101

Where W = 1.9

4868	0	7.74	1.38
5246	3	6.85	1.654
5624	6	6.4	1.887
6002	9	6.4	2.081
6380	12	6.85	2.234
6758	15	7.75	2.348

Table 4 - 9

The Effect of Number of UV Lamps On in the First URM at Different Levels of Ozone Concentration

U = 150 S = 9 T = 32 V = 0

Comp Number	X No. of Lamps	Q KW	Q l/min
Where W = 1.1			
4652	0	4.87	0.957
4661	3	5.215	0.967
4670	6	5.800	0.961
4679	9	6.622	0.939
4688	12	7.68	0.900
4697	15	8.98	0.846
Where W = 1.5			
4760	0	6.69	1.138
4769	3	6.89	1.160
4778	6	7.33	1.165
4787	9	8.01	1.154
4796	12	8.93	1.128
4805	15	10.08	1.085
Where W = 1.9			
4868	0	7.74	1.381
4877	3	7.79	1.414
4886	6	8.09	1.431
4895	9	8.63	1.432
4904	12	9.40	1.417
4913	15	10.42	1.386

Table 4-10

The Effect of Number of UV Lamps On in Both URMs

U = 150 S = 9 T = 32 W = 1.5

Comp Number	X No. of Lamps	V No. of Lamps	Z KW	Q l/min
4760	0	0	6.69	1.138
5138	0	3	6.41	1.36
5147	3	3	6.61	1.39
4269	3	0	6.89	1.16
5525	3	6	6.78	1.573
5516	0	6	6.581	1.551
5894	0	9	7.198	1.698
5156	6	3	7.055	1.39
6272	0	12	8.26	1.80
5534	6	6	7.22	1.578
5903	3	9	7.40	1.72
5165	9	3	7.73	1.381

The tables show that the number of lamps on in the second URM has a strong effect on increasing the permeate flow rate through the URM system. With higher ozone concentration, more UV lamps on allow a greater increase in water flow rate and a smaller increase in total power.

Turning lamps on in the first stage does not allow an increase in the water flow rate -- only total power is increased.

Having lamps on in both stages does not improve the rate of water flow. Only the lamps in the second stage have a strong effect.

4.9.7 pH Effect

Increasing the pH from 7 to 9 decreases the power requirements and increases the water flow capacity at all levels of ozone concentration for the operating conditions described in Table 4-11.

Table 4-11

The Effect of pH on URM Performance

U = 150 T = 32 V = 3 X = 0

Where W = 0.7

Comp Number	pH	$\frac{Z}{KW}$	$\frac{Q}{l/min}$
4916	7	3.67	0.906
4919	8	3.45	0.939
4922	9	3.23	0.972
Where W = 1.1			
5024	7	5.65	1.071
5027	8	5.43	1.104
5030	9	5.21	1.137
Where W = 1.5			
5132	7	6.86	1.298
5135	8	6.63	1.331
5138	9	6.41	1.364
Where W = 1.9			
5240	7	7.29	1.588
5243	8	7.07	1.621
5246	9	6.85	1.654

4.9.8 Temperature Effect

Increasing the temperature from 24° to 40°C decreases the power requirement and increases water capacity at the indicated ozone levels and operating conditions in Table 4-12. Only three experiments were run at higher temperatures. Tests should be run at 40°C to confirm these calculations.

4.9.9 Summary of the Mathematical Analysis

1. The mathematical models show that greater flow-through capacity or smaller size URM can be achieved by:

1) Increasing ozone concentration
2) Increasing the number of UV lamps in the second stage
3) Increasing pH of the incoming Hospital Composite Permeate
4) Increasing the temperature of the incoming Hospital Composite Permeate.*

---

*To be confirmed.

Table 4-12

The Effect of Temperature on URM Performance

U = 150 S = 9 V = 3 X = 0

Where W = 0.7

Comp Number	°C	KW	$\frac{Q}{l/min}$
4921	24	4.61	0.884
4922	32	3.23	0.972
4923	40	1.86	1.059
Where W = 1.1			
5029	24	6.58	1.049
5030	32	5.21	1.137
5031	40	3.83	1.225
Where W = 1.5			
5137	24	7.79	1.277
5138	32	6.41	1.364
5139	40	5.04	1.452
Where W = 1.9			
5245	24	8.22	1.566
5246	32	6.85	1.654
5247	40	5.47	1.742

2. The power consumption can be decreased by:

1) Using lower ozone concentrations

2) Increasing the number of UV lamps in the second stage when using higher ozone concentrations

3) Increasing the pH of the incoming permeate

4) Increasing the temperature of incoming permeate*

3. The location of the UV lamps in URMs is important. The residence time is shortened when lamps are only used in the last stage(s) of URM No. 2. UV in URM No. 1 had no effect on overall residence time. In other words, UV light is not effective for 1 x Hospital Composite + 12 mg/l Urea during the first 80 to 120 minutes of the reaction.

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*To be confirmed.

4.9.10 Recommendations for Additional Tests Using URMs

The 25 tests and the resulting mathematical models provided insight in establishing the URM operating and design parameters to minimize URM size and power requirements. Additional tests should now be conducted to confirm, expand, and refine the models.

It is suggested that the following test series be run either at USAMBRDL or at Westgate Research Corporation:

4.9.10.1 The Effect of Elevated Temperature when Operating at the Following Conditions:

TEST	CONDITIONS
1	U = 125, V = 0, X = 0, W = 0.7, T = 32, S = 9
2	U = 125, V = 0, X = 0, W = 0.7, T = 40, S = 9
3	U = 125, V = 0, X = 0, W = 0.7, T = 50, S = 9
4,5,6	Repeat above, but with W = 1.1 and V = 3

Refine mathematical model accordingly. Assess and include the power and volume penalties for elevated temperatures.

4.9.10.2 Expand the Mathematical Model to Incorporate Key Ingredients Found in Hospital Waste Waters

Suggested ingredients to be studied are urea, methanol, acetic acid, and acetone in 1 x Hospital Composite RO Permeate.

Series of tests to be run are:

TEST	CONDITIONS
1	U = 125, V = 3, X = 0, W = 1.1, T = 32, S = 9, MeOH = 20 ul/l
2	Same, but MeOH = 40 ul/l
3	Same, but MeOH = 80 ul/l
4	Same, but UREA = 10 mg/l
5	Same, but UREA = 20 mg/l
6	Same, but UREA = 30 mg/l
7	Same, but HAc = 2 mg/l
8	Same, but HAc = 10 mg/l
9	Same, but HAc = 15 mg/l
10	Same, but Acetone = 10 ul/l
11	Same, but Acetone = 20 ul/l
12	Same, but Acetone = 30 ul/l

Additional tests should then be conducted to define the interaction of UV input on those ingredients which have a definite impact on power and residence time.

4.7.10.3 Other Factors Which May Influence URM Residence Time or Power

1. There are presently 2, 1.25 inch diameter spargers in each stage. This number should be increased to 3 to see if this change has an effect on the models.

2. The number of UV lamps in the last stage of URM No. 2 should be decreased from 3 to 2 to determine the impact if any on the models.

3. Samples should be taken from each stage of the two URMs to determine the actual number of stages required for a given waste water.

4. Tests should be run with only 1 center baffle in each URM to provide 4 stages overall (with the two URMs connected in series). Two or 3 lamps should be used in the last stage. Any effect can then be incorporated into the models.

SECTION 5 DESIGN CHARACTERISTICS OF A FULL SCALE MUST URM SYSTEM

An accurate design for a full scale URM system can be derived from the mathematical models. If waste waters other than hospital composite RO permeate are to be processed, the present mathematical models can be expanded to include the influence of these waste waters.

This section describes the design characteristics of a full scale MUST URM UV-O_3 system which conforms to the MUST WPE design constraints.

5.1 WPE Design Specifications

For reference, MUST WPE design specifications are reproduced here.

a) The MUST WPE will be an equipment item used in direct support of certain Army field hospitals. It is anticipated that the MUST WPE will be composed of two units: (1) the Water Treatment Unit (WTU) which, when operated alone, will treat specified waste waters for discharge to the environment, and (2) the Water Purification Unit (WPU) which, when operated alone, will treat fresh and brackish natural waters to drinking water quality for potable uses. The WTU and WPU, when operating in series, comprise the WPE which will treat specified waste waters to drinking water quality.

(b) Water Processing Element

(1) The WTU and the WPU shall provide the capability of treating and processing all hospital waste waters, except human waste, from the toilet and sanitizer, for disposal or purification of water for reuse.

(2) The units shall be housed in standard MUST Ward Containers. The units shall incorporate suitable lighting, electrical, and plumbing accessories. The MUST Ward Container is a rigid paneled metal unit which can be expanded on one side and adjacent ends by insulated fabric panels. In the nonexpanded mode the container is used as a shipping container. In the expanded mode the container serves as a utility shelter which, depending on auxiliary kit equipment used, may serve as a shower, toilet, or lavatory facility, as an office, as a storeroom, or for other uses as required by the hospital system plan. Each container includes provisions for attaching air conditioning ducts, electrical service panels, water service boxes, and so forth, so that the associated service may be supplied by the container. The MUST Ward Container is Federal Stock Number Item 5410-809-6634; length 12 ft; width 10 ft (expanded) and 7 ft (during transport); height 7 ft 3 in; and weight 1,840 lbs empty.

(3) The units shall be designed to interconnect with all waste water producing units within the MUST for the collection of waste water and with the utility element for the distribution of purified water to the using facilities. The WPE is not intended to contain prime movers for collecting waste waters from other hospital elements nor prime movers for redistribution of purified water to user elements.

(4) The units shall be designed to operate on electrical power as supplied by standard US Army 60 Hz, 3-phase, 208v engine-powered field generator sets, reference MILSTD-633-D listed in Section C, paragraph 3.

(5) Materials used in the construction of the units shall be capable of resisting deteriorating by water and chemicals used in operation.

(6) The units shall be designed and constructed to assure easy accessibility of parts and assembly. Repair and/or replacement shall be possible with a minimum of disturbance to other components of the units and without the need for special tools.

(7) The units when installed in the Ward Container shall be capable of withstanding operational, storage and transit conditions of climatic categories 1,2,4,5,6, and 7 outlined in AR 70-38. If Reverse Osmosis (RO) modules are used, provisions will be made for maintaining temperatures of the RO modules above 32° F at all times.

(8) The WTU shall be capable of processing all MUST waste waters, except human. It shall be capable of producing not less than 3900 gallons of treated water per day at 77° F (+5° F), with an effluent maximum turbidity of ten (10) Jackson Turbidity Units (JTU). The amount of treated water produced shall not be less than 94 percent of the total daily influent waste water to the WTU. As a guide, WTU effluent is to conform to industrially accepted effluent standards consistent with "secondary treatment."

(9) The WTU shall be designed for the disposal of treated water into existing open drainage channels or environment. Under this condition, the residual free chlorine content of the effluent to be discharged shall not be less than two (2) milligrams per liter.

(10) The maximum dry weight of the WTU shall not exceed 6,500 pounds, including the Ward Container.

(11) The WTU shall include suitable electrical cables and hoses for connection to other MUST elements.

(12) The WPU shall be capable of processing MUST waste water after treatment by the WTU, except human wastes, from the toilet, sanitizer functions, and clarified fresh or brackish water as obtained from natural sources. Treated waste waters from the WTU to be processed shall exhibit the following characteristics: i. Temperatures up to 130 degrees F; ii. Turbidity less than ten (10) JTU; and iii. the following maximum water quality standards which are not to be exceeded:

	mg/l		mg/l
Total Organic Carbon	5.0	Iron	0.3
Chemical Oxygen Demand	10.0	Lead	0.05
Alkyl benzene sulfonate	0.5	Magnesium	150.0
Ammonia (NH_3)	0.5	Manganese	0.05
Arsenic	0.05	Nitrate-Nitrogen	10.0
Barium	1.0	Phenolic Compounds	0.001
Cadmium	0.01	Selenium	0.01
Chloride	600.0	Silver	0.05
Chromium (hexavalent)	0.05	Sulfate	400.0
Copper	1.0	Total Solids	1500.0
Cyanide	0.2	Color	50 units
Fluoride	4.0		

(13) The WPU shall be rated at not less than 3500 gallons of treated water per day at 77°F (+5°F). The amount of potable water produced shall exceed 90 percent of the total daily influent water to the WPU. For influent waters having a total dissolved solids content greater than 3,000 milligrams per liter or silica content greater than 50 milligrams per liter as SiO, the percentage produced shall not apply.

(14) The potable water produced by the WPU shall have a residual free chlorine content not less than 5 milligrams per liter.

(15) The maximum dry weight of the WPU shall not exceed 6,500 pounds, including Ward Container.

5.2 OZONE GENERATOR SELECTION

The URM testing indicated that ozone concentration has a strong bearing on residence time. An ozone generator which provides the highest ozone concentration from air with the minimum power consumption is required. Ozone concentration is dependent upon such ozone generator operating variables as oxygen content of incoming air, temperature of the available heat sink, dryness of incoming air, and power input. The maximum economic concentration at which ozone can be generatred using air is about 1.9 weight percent using water cooled generators.

For field application, an air-cooled ozone generator is preferred since the requirement of cooling water increases the process complexity. At this time the maximum capability of air-cooled ozone generators is about 1.5% O_3.

5.3 DESIGN FEATURES OF URM

The full-scale URM system will be designed to reduce 12-15 mg/l TOC hospital composite permeate to 5 or less mg/l TOC. The influent permeate flow will be 3.5 gpm and with a pH of 9 and a temperature of 30-35°C. The urea content of the permeate will be 12 mg/l.

Reactor designs are delineated for 3 levels of O_3 concentration. All three reactors are designed to operate at 2-5 psig pressure to minimize system weight. The reactor height is 30 inches in all 3 cases. This height proved to be sufficient for the efficient utilization of O_3 in the pilot URM testing. Also, it is easier to install and remove the lamps within the confines of the MUST Ward Container.

The design characteristics of the three full scale systems are shown in Table 5-1. The number of 39 watt UV lamps for each size reactor is the optimum number required for 3.5 gpm. As described in Section 4.7.6, increasing the number of lamps allows greater throughput of permeate (see Figure 5-1 as an example). If greater throughput is to be anticipated, additional banks of lamps can be provided on a stand-by basis for increased flow conditions.

TABLE 5- 1

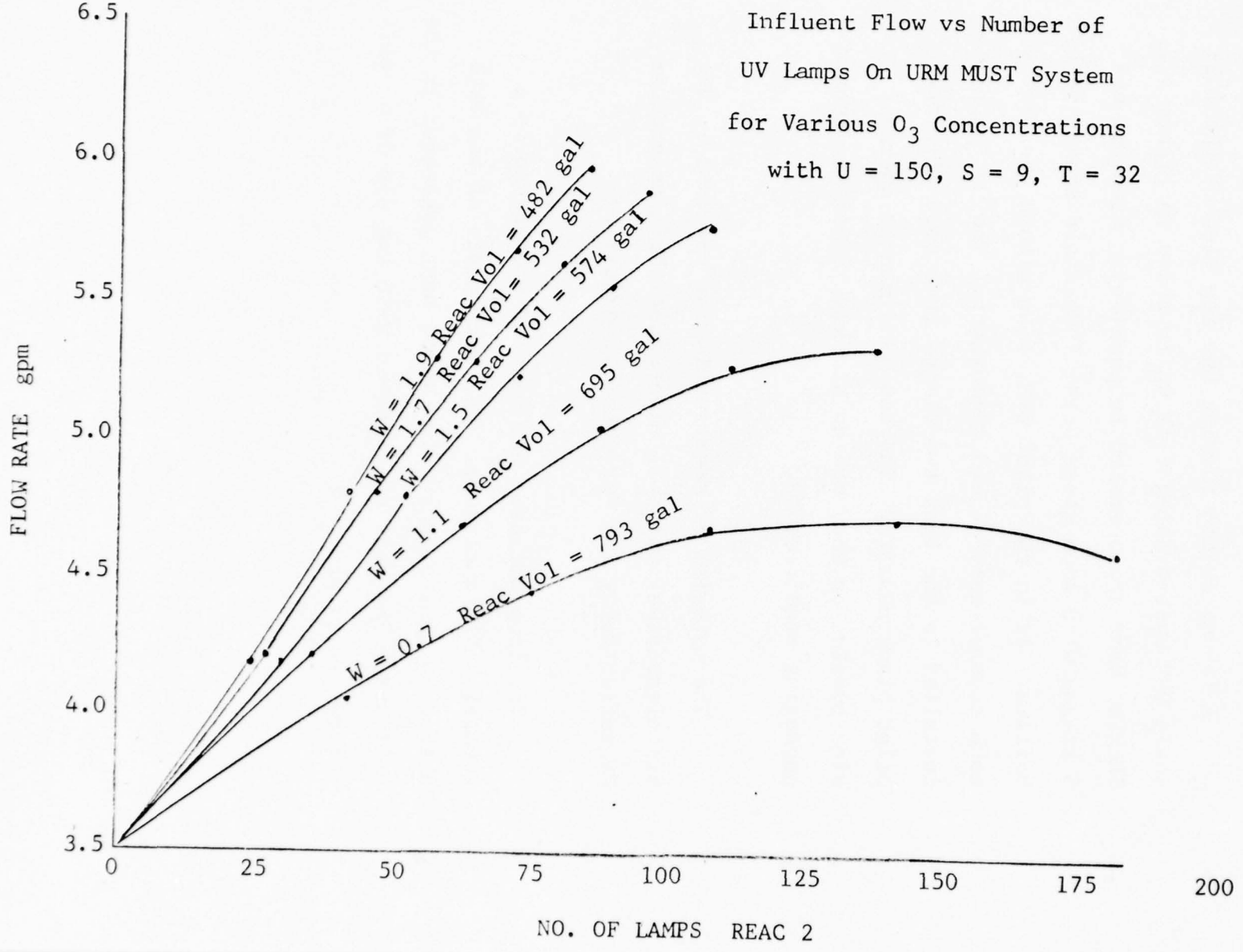
Design Characteristics of Full-Scale URMs –

3 Different O_3 Concentration Inputs

Design Number	Input O_3 Conc Wt %	Residence Time min	Reactor Volume gals	Reactor Size Ft - In	Reactor Weight lbs	O_3 Mass Flow gm/hr	No. of 39 W UV Lamps	UV Power Input KW	Total Power KW
1	0.7	189	662	6' x 5' x 2'6"	800	98.5	40	1.6	3.1
2	1.1	163	569	5'6" x 5'6" x 2'6"	750	84.6	34	1.3	5.0
3	1.5	136	476	5'1" x 5'1" x 2'6"	700	70.9	28	1.1	6.2

FIGURE 5-1

Influent Flow vs Number of UV Lamps On URM MUST System for Various O_3 Concentrations with U = 150, S = 9, T = 32



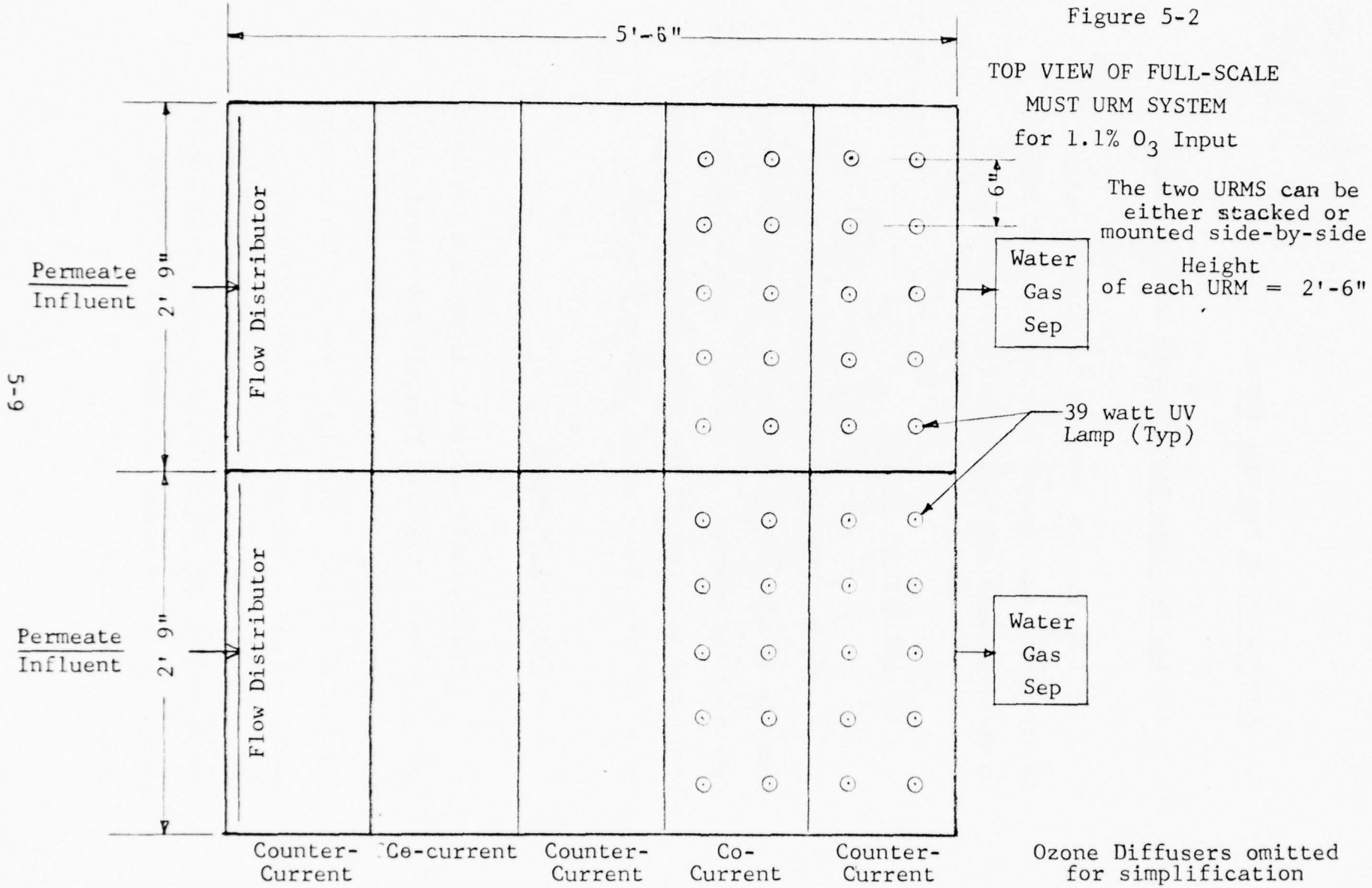
A layout sketch showing the top view of the full scale URM system using 1.1% O_3 is shown in Figure 5-2. The two URMs are operated in parallel. Each URM has 5 stages with each stage being formed and separated by baffles. As in the pilot URM, flow within the URM is both counter-current and co-current. The UV lamps are installed in the last two stages in accord with the pilot plant results. The two URMs can be operated side-by-side or they can be stacked, depending upon packaging requirements.

The material of construction of the URMs is 304 stainless steel which is electropolished for greater UV reflectivity and for chemical passivity.

The lamp ballasts are mounted and housed in a separate NEMA enclosure. The back plate of the NEMA acts as a heat sink for the waste heat generated in the ballasts. The heat is rejected with the aid of a small rotary air blower.

Figure 5-2

TOP VIEW OF FULL-SCALE
MUST URM SYSTEM
for 1.1% O_3 Input



5.4 ADVANTAGES OF THE URM DESIGN

1. Low Pressure Operation (3 to 5 psig max)

Low pressure provides for lighter weight construction, less hydraulic pumping power, less air compressor power and weight, and greater safety.

2. Low Reactor Height

In the URM pilot plant tests, 30 inches was found to be a practical height for the efficient oxidation of the hospital composite. This height has been found satisfactory for other waste waters tested under separate IR&D studies, such as pink water.

3. Vertical UV Lamps

The installation of UV lamps in a vertical configuration is the most flexible and energy-saving method of applying ultraviolet light to ozone photochemical oxidation. Horizontal lamps which traverse several or all reaction stages is wasteful of energy. The URM pilot testing and the resulting mathematical models showed that UV radiation in the early reaction stages was just a waste of power and there was no speed-up in the reaction.

4. No Precontactor

URM pilot testing indicated that only 5% of the incoming ozone remained in the off-gases. The O_3 concentration in the off-gas (0.05%) is much too low to be reused effectively in any precontactor. The elimination of the precontactor saves power, weight, space, and reduces the process complexity.

SECTION 6 DESIGN CHARACTERISTICS OF UV-OZONE SYSTEMS FOR MANNED SPACECRAFT

6.1 DESIGN CONSIDERATIONS

The UV-ozone process can be considered for either wash water purification or maintenance of stored water disinfection for manned space flight.

6.1.1 Wash Water Purification

On long-term manned space flight, wash water is generated from shower and sinks, from utensil washing, and clothing wash machines. Particulate material is filtered out of the raw wash water which is then processed through a reverse osmosis unit. As presently conceived, the final purification and disinfection of the wash water permeate is activated carbon adsorption and a silver ion generator.

The UV-ozone system can be considered as an alternate final purifier for wash water. There are no cartridges to replace or store, and the UV-ozone can remove refractory organics such as urea and sodium acetate, which are not readily adsorbed by activated carbon.

It is assumed that 8 liters of water will be used per man-day for personal hygiene and housekeeping on a long-term manned space flight. This is the approximate amount of water used per man-day in the McDonnell Douglas Astronautics Company 90-day simulated manned space flight test.*

Volume of water processed in 24 hours and other variables which may have an influence are then fixed at the following levels:

Water volume	40 liters
Temperature	25 to 28°C
Reaction time	24 hours/day
Pressure	760 mm HgA
O_3 concentration	2% in O_2
Water flow	1.67 liters per hour
Effluent	less than 5 mg/l TOC
Size of crew	5 men

If the permeate from the reverse osmosis unit to be purified contains 50 to 100 mg/l of a mixture of organics derived from body wastes, detergents, biocides and phenols, this composition can be considered similar

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*Wong, W. and Putman, D.F., "Water Recovery for Spacecraft Applications," January, 1973, MDC G4338

to the 5-component, 20 mg/l TOC water. Using the above conditions, and calculating in a similar fashion as done for the MUST system, the working volume in the reactor will be:

$$1.67 \frac{\text{liters}}{60 \text{ min}} \times 45 \text{ min} = 1.25 \text{ liters}$$

Ozone mass flow will be:

$$\frac{(20\text{-}3) \frac{\text{mgTOC}}{\text{liter}} \times 1.25 \text{ liters} \times 100}{1/8 \, (\dot{W}O_3) \quad 45 \text{ min}} = 29.2\%$$

$$\dot{W}O_3 = 12.9 \text{ mg } O_3/\text{min}$$

This mass flow of O_3 requires 17 watts of power for a 24 hour day.

The number of 43 watt UV lamps required will be:

$$\frac{43 \text{ watts} \times 45 \text{ min} \times N_L}{(20\text{-}3) \frac{\text{mgC}}{\text{liter}} \times 1.25 \text{ liters}} = 9.5$$

N_L = 0.10 lamps which require 4.3 watts input power

A smaller UV lamp is required. For this purpose, 2 Sylvania G4T4/1 lamps consuming 8 watts will have the equivalent 253.7 nm output of 1/10 of a 43 watt, low-pressure mercury lamp.

6.1.2 Water Supply Disinfection

Iodine and silver ion injection has been used or will be used in manned space flight water supplies to prevent back-contamination of the water from outlet ports. An alternate method of disinfection is the use of low-dosage, UV-ozone. In the first year study on the feasibility of using the combination of UV and ozone for organic removal and water sterilization, experimental studies in a stirred reactor showed that 0.3 mg O_3/liter for 2 minutes or more in water was an effective disinfectant when 8 watts input power, UV light was present.*

As an example, the UV-ozone process can be used to maintain sterility if water originates from a hydrogen-oxygen fuel cell. In the mission studies of the shuttle orbiter, the water supply rate from the fuel cells can range from 2 to 12.4 pounds per hour.**

If a minimum of 0.3 mg O_3/2.2 pounds (1 liter H_2O) plus 8 watts input power (0.2 watts, 253.7 nm UV output)

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*Zeff, J.D. et al, "UV-Ozone Water Oxidation/Sterilization Process," for USAMERDC, Contract DADA 17-73-C-3138, Final Report (1401) September 1974

**Houck, O.K. and Wynveen, R.A., "An Automated Water Iodinating Subsystem for Manned Space Flight," ICES Meeting, Seattle, Washington, July 1974, ASME Paper 74-ENAS-54

are applied to the maximum 12.4 pounds/hour, 1.7 mg O_3 and 1.13 watts UV (253.7 nm) will be consumed.

6.2 SYSTEMS DESIGNS

6.2.1 Wash Water Purification

On the basis of the design calculations made in Section 6.1.1, a concept sketch of a zero-gravity wash water permeate purifier is shown in Figure 6-1. The UV-ozone reactor fabricated from stainless steel is 7 inches in diameter and 8 inches long. The reactor holds about 2.5 liters of water which is held by centrifugal action against the outer wall by the rotating, flow-directing fins. The fins are rotated by means of the electric motor at the base of the reactor at a speed sufficient to maintain positive separation of the gas and water phases.

Ozone from the ozone generator is diffused uniformly into the water by means of porous diffuser tubes mounted along the reactor wall. The UV radiation is directed into water from the two, 4-watt UV lamps which are housed within the quartz sheath in the center of the reactor.

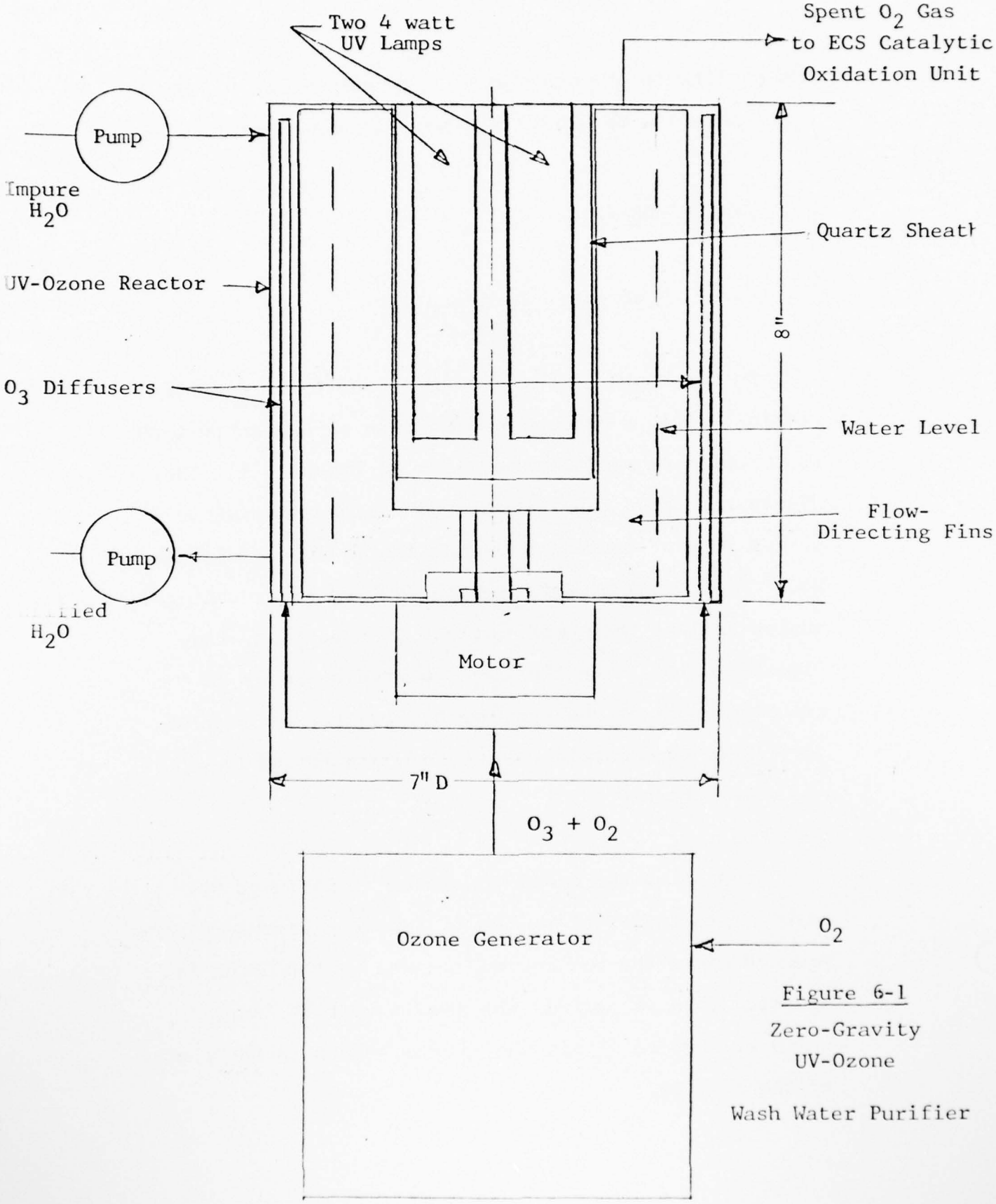


Figure 6-1

Zero-Gravity
UV-Ozone

Wash Water Purifier

The water flow in and out of the reactor is continuous at 1.25 liters/hour. Metering pumps are used to introduce and remove the water from the reactor.

Oxygen from the ECS supply is metered into the ozone generator at a flow rate of 0.5 standard liters/min to generate 15 mg O_3 per minute. The oxygen with traces of unreacted ozone are removed from the reactor to the ECS catalytic oxidizer where the residual ozone is decomposed to oxygen.

The estimated weight, size, and power of a prototype-system version of the components are:

	Size	Weight	Maximum Power
1 - UV-Ozone Reactor	7" dia x 8"	5 lbs	33 watts
2 - Water Pumps	8 3/4" x 3½" x 2 5/8"	2 lbs	42 watts
1 - Ozone Generator	12" x 8" x 8"	5 lbs	25 watts

Electrical Energy/lb of purified water = 36.3 $\frac{\text{watt-hrs}}{\text{lb}}$

6.2.2 Water Supply Disinfection

Figure 6-2 presents a concept sketch of a zero-gravity water supply disinfection system using ozone

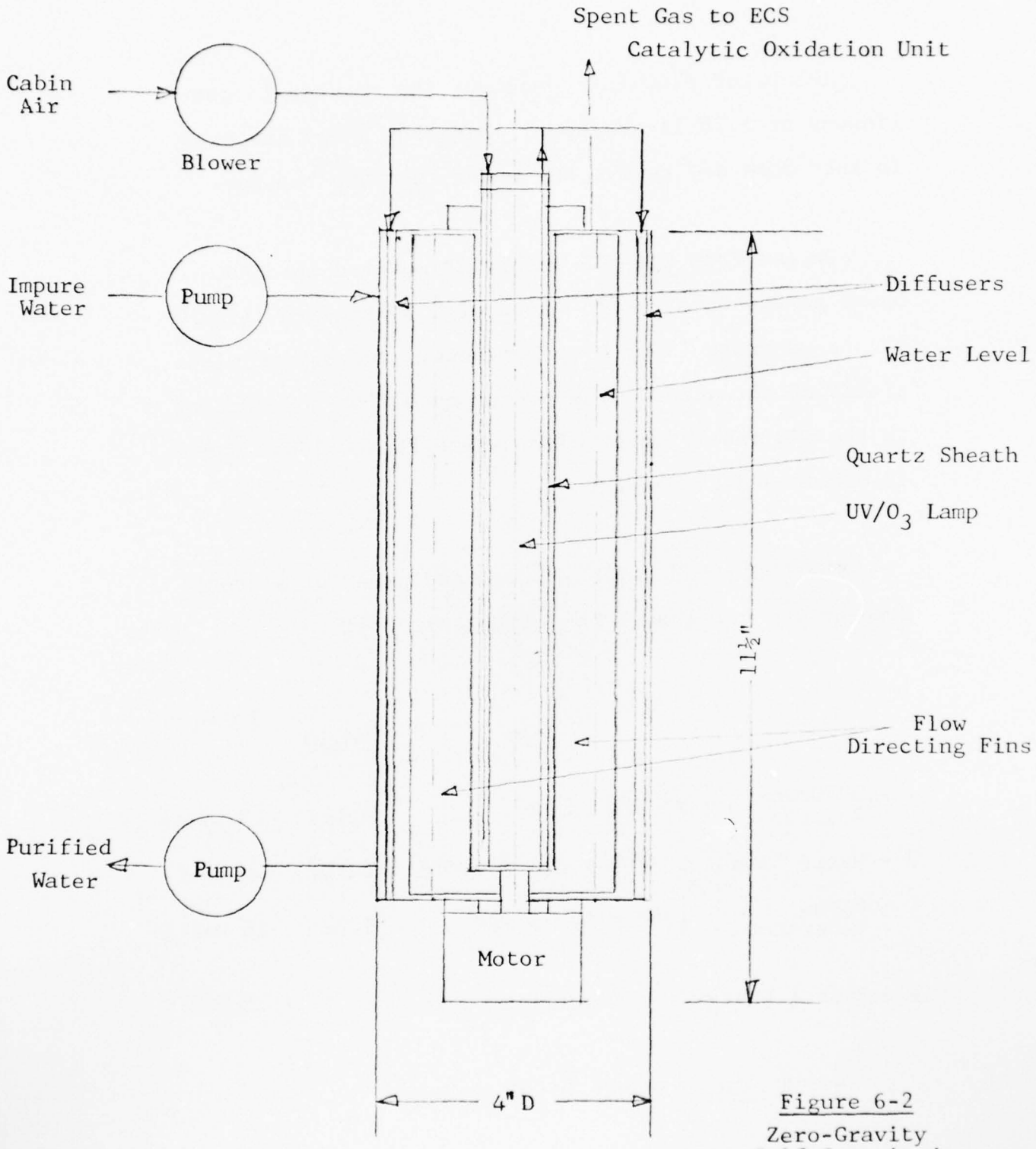


Figure 6-2

Zero-Gravity Self-Contained UV - O_3 Water Disinfection System

and UV. Basis of the design is provided in Section 6.1.2. The system is designed to disinfect a maximum of 12.4 pounds of water per hour.

The reactor design is similar to the wash-water purification system shown in Figure 6-1. Rotating fins are used to maintain water-gas separation, and operation of the system is continuous. Since only small quantities of O_3 are needed, ozone is generated by passing cabin air around the UV lamp and the ozonated air is sparged into the water via the diffusers.

The 16 watt UV lamp is housed within the quartz sheath. The lamp radiates both 185 nm and 253.7 nm UV to generate ozone and germicidal UV. The 253.7 nm UV output is 5.3 watts and the approximate O_3 output is 100 mg/hour, depending upon the condition of the incoming cabin air.

The design characteristics of a prototype system are estimated as follows:

	Size	Weight	Maximum Power
UV-Ozone Reactor	4" dia x 11 1/2"	5 lbs	41 watts
Blower	6¼" x 3 5/8" x 4 1/2"	2 lbs	15 watts
2 - Water Pumps	3 3/4" x 3½" x 2 5/8"	2 lbs	42 watts

Electrical Energy/lb of purified water = 7.9 $\frac{\text{watt hrs}}{\text{lb}}$

SECTION 7 STUDIES ON UREA REMOVAL

Bench and pilot plant tests found that urea is resistant to oxidation by ozonolysis or UV-ozonolysis. A study consisting of a literature survey and laboratory investigations was undertaken.

7.1 LITERATURE SURVEY

The literature survey consisted of searching for (1) other methods of removing urea from water solution and (2) photochemical methods.

7.1.1 Alternative Methods of Removing Urea from Aqueous Solution

As a water pollutant, urea is a refractory compound because as an important end-product of metabolic processes, it is relatively stable and is not easily degraded, whether by physical, chemical, or microbial means. Furthermore, urea is readily soluble in water[1] and it is therefore not amenable to separation by filtration. As a compound which does not complex easily with other

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[1] 79.0 g. 1100 g. water at 20°C.

chemicals, it cannot be precipitated or co-precipitated out of solution, and other than adsorption on cationic resins or on activated charcoal,[2] it is very difficult to eliminate it from waste waters.

Because of its refractory nature, urea as an actual pollutant has been mostly ignored, since it is non-toxic (no effect at 2 g/kg in mice), and whose taste threshold (10 mg/l) is so high that this level is considered to being acceptable.[3]

The best methods for urea removal from waste waters appear to be:

(1) Adsorption on activated charcoal (see Ref. 2 for KAD and AGIZ activated charcoal which, under dynamic conditions respectively adsorb 93.5 and 185 millimoles urea/l for a 5 ppm level of contamination).

(2) Adsorption on strongly acid cation exchange resins (see Ref. 2 for KU-2 x 8 ch -H from which adsorbs 79 millimoles urea/l for a 5 ppm level of contamination).

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(2) E.V. Zambrovskaya, et al, Zh, Prikl, Khim, (Leningrad), 47 (1, 178 (1974)

(3) I.N. Skachkova, Nauch. Tr. Aspir. Ordinatorov, 1-I Mosk, Med. Inst., 1967, 207

(3) Reaction with the enzyme urease. (See Ref.(4) for urease addition at 74°C to space vehicle laundry water and see Ref.(5) for urease bound to Zr $(NaPO_4)_2 \cdot H_2O$ where the enzyme converts the urea to $(NH_4)_2\ CO_3$ while the Zr $(NAPO_4)_2 \cdot H_2O$ exchanges NH_4^+ for Na^+. The bound urease retained 67% of its original activity.) Urease is very stable as a dry powder, even at room temperature, and can be dispensed or metered in at a predetermined rate or else as required.

7.1.2 Photochemical Urea Removal Methods

Degradation of an organic compound, such as urea, can be achieved by photolysis using a radiation source having an output wavelength at or near the absorbance band(s) of the compound.(6)

Upon irradiation with a photon of an appropriate wavelength, the organic molecule is promoted to an

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(4) R.W. Lawrence, et al, U.S. Nat. Tech. Inform. Serv., PB Rep., 1974

(5) L.B. Morontz, et al, (CCI Aerospace Corp., El Monte, Calif.) Ger. Offen., 1960, 504 (Cl. B Old, A 61 m).

(6) E.S. Gould, "Mechanism and Structure in Organic Chem.," Holt, Rinehart & Winston, N.Y., 1959, p. 688

excited state. The excited state is described as having an electron in an orbital of higher energy than in the molecule's normal ground state. The fate of the excited molecule, from that moment on, depends on the four possible major paths it may take in returning to a lower energy level.(7)

(A) Fluorescence, whereby the molecule deactivates to a lower energy state by allowing the promoted electron to drop to a lower energy molecular orbital. This is accompanied by photon emission.

(B) Phosphorescence, whereby intersystem crossing of states proceeds, followed by photon emission: i.e., singlet to triplet interchange or vice versa occurs because the spin of the promoted electron undergoes a flip, allowing for (a) pairing of 2 electrons in one orbital, as is the case in the singlet state, or (b) unpairing into 2 separate orbitals, as is the case in the triplet state.

(c) Energy transfer to a neighboring molecule (i.e., photosensitized reaction), which is unlikely in dilute aqueous solutions.

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(7) F. Daniels and R.A. Alberty, "Physical Chemistry," 3rd ed., J. Wiley & Sons, N.Y., 1966, p. 616.

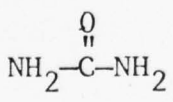
(D) Disintegration into free radicals: i.e., photolysis, which is a common occurrence in most instances.(8)

Photolysis is therefore carried out at or near a wavelength of maximum absorbance of the compound, λ_{max}.

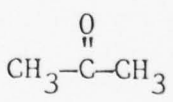
In a typical UV-VIS spectrum scan, from 700 nm to 200 nm, a urea aqueous solution shows no absorption pattern. However, from 200 down to 180 nm, urea shows the pronounced shoulder of a significant absorption band which actually peaks somewhere just below 180 nm.(9)

Acetone, which is structurally and spectrophotometrically related to urea, shows a very strong absorption band at λ_{max} = 187 nm. This is due to a promotion

Urea



Acetone



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(8) J. March, "Advanced Organic Chemistry: Reactions, Mechanisms, and Structure," McGraw-Hill, N.Y., 1968, pp. 174-175.

(9) Dr. Thomas M. Hooker, Jr., Dept. of Chemistry, Univ. of California at Santa Barbara, Private communications.

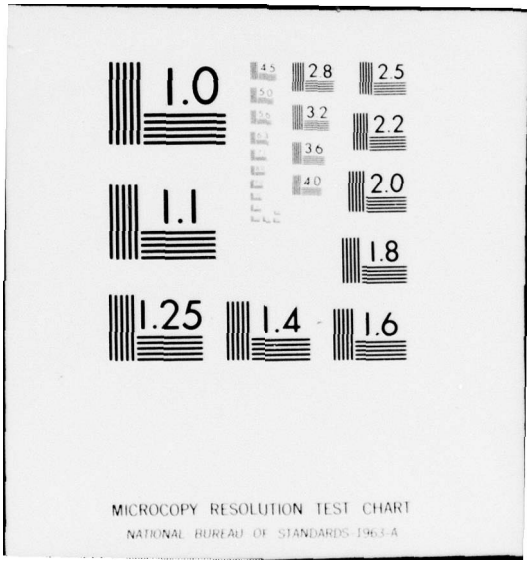
AD-A038 609 WESTGATE RESEARCH CORP MARINA DEL REY CALIF F/G 13/2
UV-OZONE WATER OXIDATION/STERILIZATION PROCESS.(U)
NOV 76 J D ZEFF, J WARK, R SHUMAN DAMD17-75-C-5013
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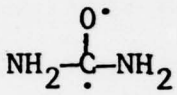
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of a π electron to the anti-bonding π^* orbital (i.e., bond dissociation) in the C=O group.(10)

This same C=O group is present in urea and it is believed that the strong absorption band for urea,(9) at λ_{max} = approx. 180 nm, is due to the same electron promotion to yield the radical:(11)



which can then further react. This includes degradation reactions.

Acetone shows even a very weak absorption band at λ_{max} = Approx. 300 nm (weaker photon energy)* due to n to π^* transition of a non-bonded oxygen electron into the C=O orbitals.

This is very effectively put to use in the degradative photolysis of this molecule at 300 nm.(11)

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(9) Dr. Thomas M. Hooker, Jr., Dept. of Chem., Univ. of Calif. at Santa Barbara, Private communications

(10) D.J. Cram & G.S. Hammond, "Organic Chemistry," 2nd ed., McGraw-Hill, N.Y., 1964, pp. 734-745.

(11) R.D.C. Norman, "Principles of Organic Synthesis," Methuen, London, 1968, pp. 292-293 and pp. 465-466.

*Approx. 105 kcal/mole.

No such weak band is actually reported in the case of urea. Rather than to rely on a possible urea weak band near 300 nm, photolysis at about 180 nm (approx. 160 kcal/mole)* is selected for cleavage of the C=O group as discussed above.[10,11]

7.2 LABORATORY INVESTIGATIONS OF PHOTOCHEMICAL UREA REMOVAL

7.2.1 Batch Oxidation of Urea Solutions in 6 inch Diameter Reactor

Batch tests were run in one of the 6 inch diameter, 12 liter stainless steel reactors to determine if a lamp with a 185 nm band can increase the rate of oxidation of urea.

A series of tests were run using 70 mg/l urea in distilled water. The quartz tube housing the UV lamp was flushed with dry nitrogen to remove oxygen which normally absorbs 185 nm UV. With nitrogen flush, 185 nm UV will be transmitted through the quartz sheath to the ozonated aqueous urea solution.

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(10) D.J. Cram & G.S. Hammond, "Organic Chemistry," 2nd ed., McGraw-Hill, N.Y., 1964, pp. 734-745.

(11) R.D.C. Norman, "Principles of Organic Synthesis," Methuen, London, 1968, pp. 292-293 and pp. 465-466.

Figure 7-1 presents a series of batch tests to determine the effect of nitrogen purge on the rate of oxidation of 70 mg/l urea in water. There appears to be no difference in the rate of oxidation between the no-purge UV (Experiment U312) and the ozonation without UV (Experiment U313). There appeared to be an increase in the rate of oxidation with the purging of the annular space between the UV lamp and the quartz sheath (Experiment U311).

Figure 7-2 presents a comparison of urea oxidation rates with the nitrogen purge at three levels of ozone mass flow. The rate of oxidation at the 57.6 mg O_3/min level (Experiment U315) was less than at the 92.6 mg O_3/min level (Experiment U314). Increasing the flow to 118 mg O_3/min did not improve the rate of oxidation.

7.2.2 Batch Oxidation of Urea Solutions in 3 inch Diameter Reactor

Further experimentation was carried out in a 3 inch x 36 inch reactor in place of the 6 inch diameter reactor to provide a shorter UV path and greater intensity throughout the reactor.

70 mg/l urea was used in the initial 3 inch diameter

Figure 7-1

UV-O_3 OXIDATION OF 70 mg/l UREA IN WATER
EFFECT OF N_2 PURGE
12 liter Batch Reaction
185 - 254 nm lamp
118 mg/min O_3

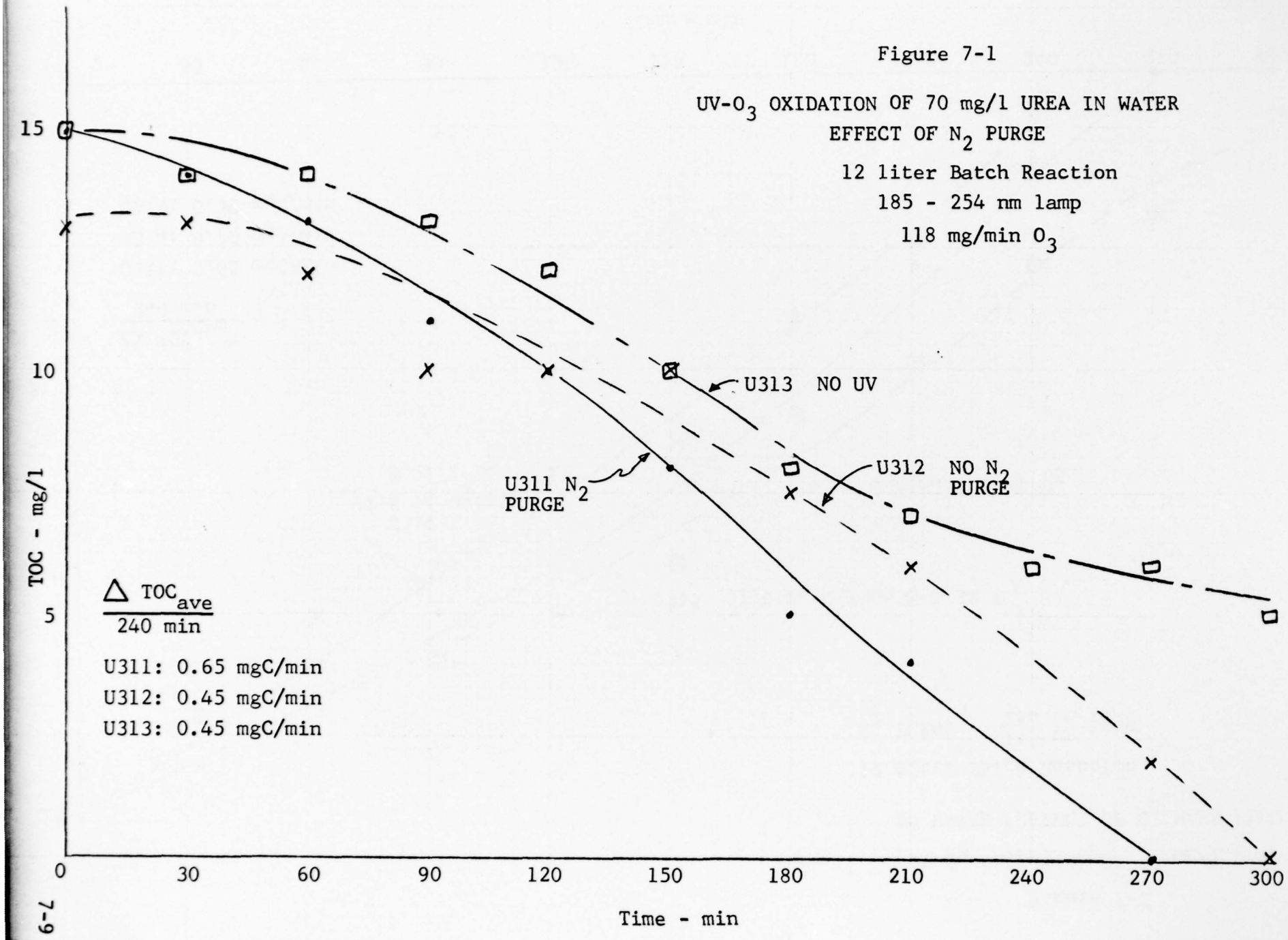
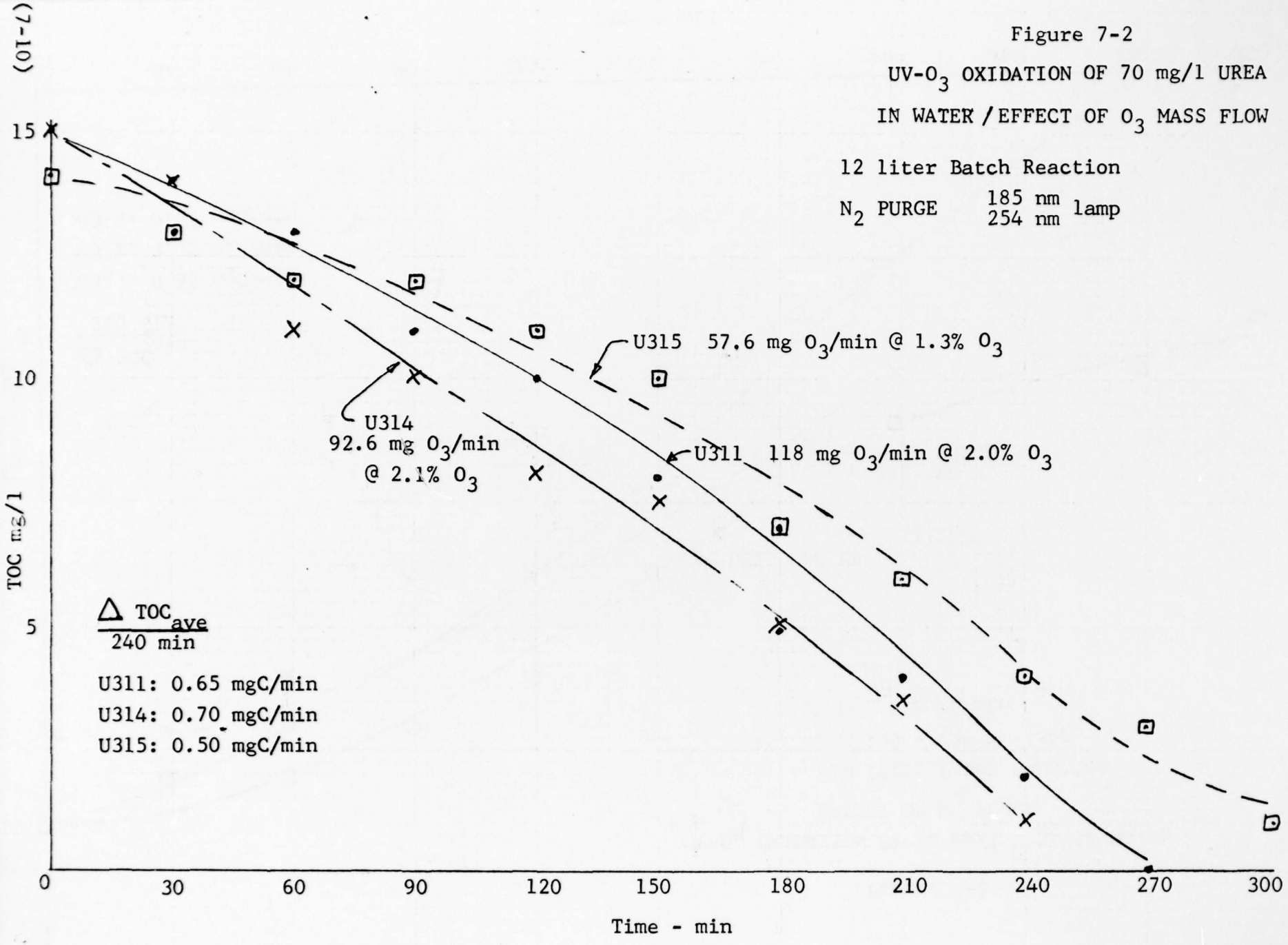


Figure 7-2

UV-O_3 OXIDATION OF 70 mg/l UREA IN WATER / EFFECT OF O_3 MASS FLOW

12 liter Batch Reaction

N_2 PURGE 185 nm / 254 nm lamp



reactor tests. As shown in Figure 7-3, N_2 purge at this urea concentration appears to improve the rate of oxidation.

The effect of nitrogen purge was then determined on 18 mg/l urea in water, using about 12 mg O_3/min. Figure 7-4 indicates that there is a slight increase in the rate of oxidation when using nitrogen purge at these conditions.

Water containing 40 mg/l urea was also oxidized as shown in Figure 7-5. Very little difference in oxidation rate is found at the 10-12 mg O_3/min rate.

Additional batches of water containing either 12 mg/l or 40 mg/l urea were oxidized using 10-12 mg O_3/min as shown in Table 7-1.

Analyses by USAMBRDL of the samples for urea and NO_3^-, NO_2^- found N_2 purge did not improve the rate of oxidation.

In summary, the laboratory testing showed some difference in the rate of oxidation of 70 mg/l urea when using TOC analysis. But no distinct difference in oxidation rate occurs at lower concentrations of urea as shown by TOC or chemical analysis.

Figure 7-3

Effect of N_2 Purge
on Oxidation of 70 mg/l Urea in Water

3 liter Batch Reaction
185 - 254 nm Lamp

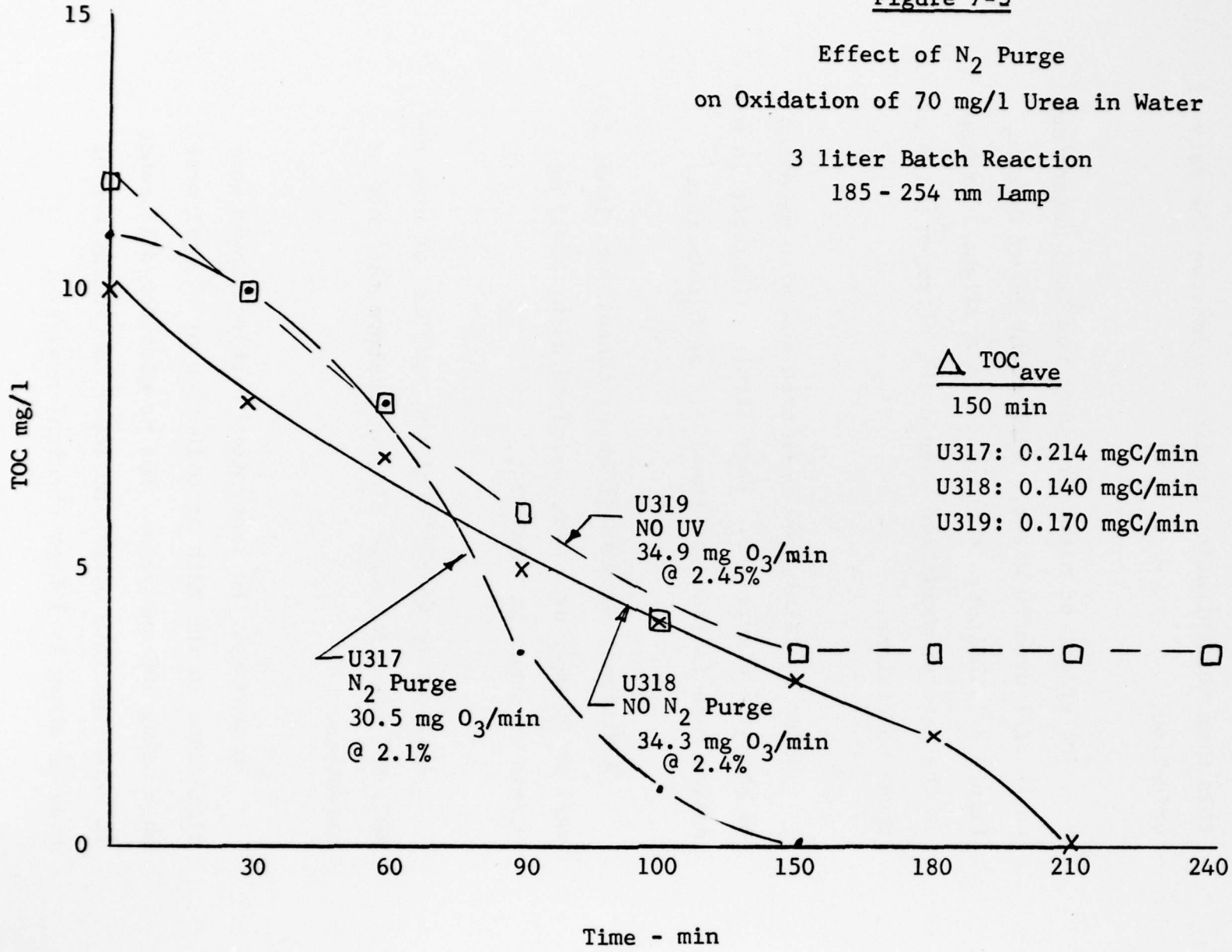


Figure 7-4

Effect of N_2 Purge
on Oxidation of 18 mg/l Urea in Water

3 liter Batch Reaction
185 - 254 nm Lamp

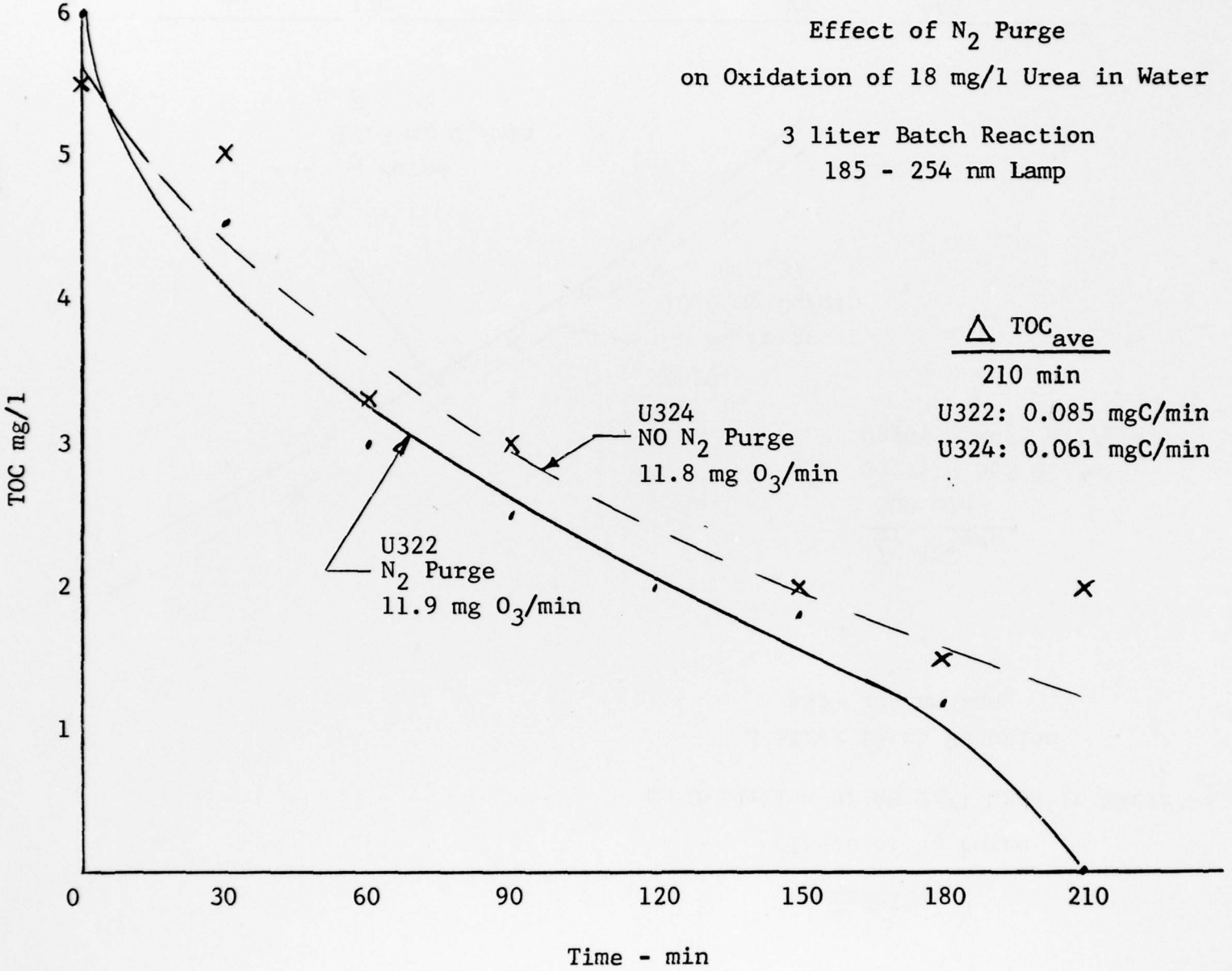
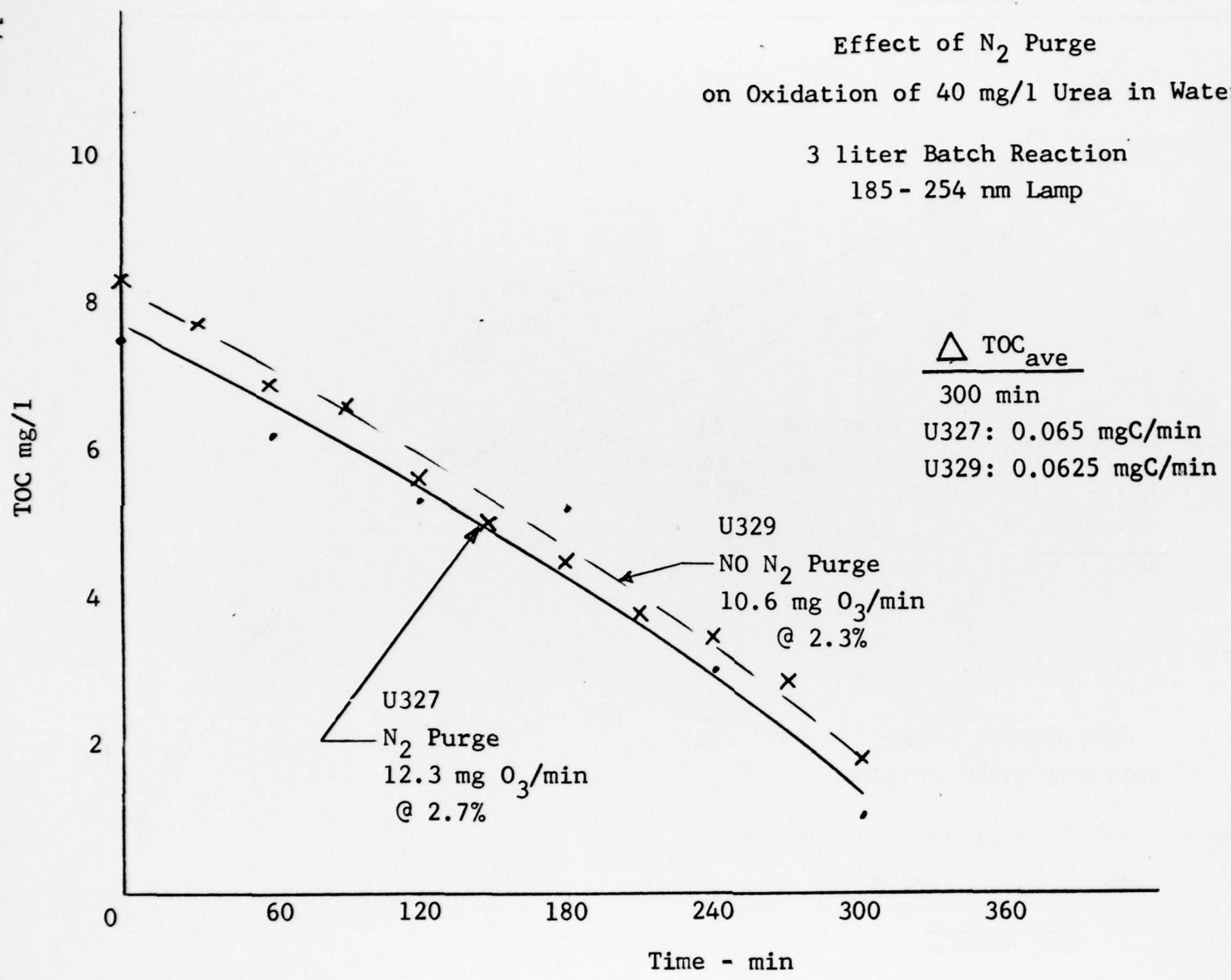


Figure 7-5

Effect of N_2 Purge
on Oxidation of 40 mg/l Urea in Water

3 liter Batch Reaction
185 - 254 nm Lamp



$$\frac{\Delta\ TOC_{ave}}{300\ min}$$

U327: 0.065 mgC/min
U329: 0.0625 mgC/min

Table 7-1

Water Containing either 12 mg/l or 40 mg/l Urea
Oxidized Using 10 - 12 mg O_3 min

12 mg/l and 40 mg/l UREA Batch Tests						Analysis Conducted by AMBRDL		
Exp. Number	Starting Urea Conc mg/l	Reaction Time-min	N_2 Purge	O_3 Mass Flow mg/min	O_3 Conc	UREA mg/l	UREA (as N) mg/l (calculated)	NO_3^-, NO_2^- (as N) mg/l
U332 - 1	12	0	+	8.73	0.8	15.3	7.1	15.3
2		30	+					
3		60	+			10.4	4.8	5.15
4		120	+			9.9	4.6	6.7
U333 - 5	12	30	-	11.0	1.1			
6		60	-			12.2	5.7	3.0
7		120	-			8.2	4.1	5.2
U334 - 8	40	0	+	11.0	1.1	39.4	18.4	0.25
9		90	+			28.8	13.4	6.2
10		180	+			21.6	10.1	11.1
U335 - 11	40	90	-	11.5	1.1	28.8	13.4	9.4
12		180	-			17.2	8.0	9.6

Before any conclusions can be made, further tests are required using a lamp with greater UV power output below 185 nm to evaluate the role of far UV in the decomposition and oxidation of urea in water.

SECTION 8 CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions and recommendations can be made from the bench and pilot plant tests and the resulting mathematical models.

8.1 CONCLUSIONS

1. In the URM pilot plant tests using hospital composite RO permeate + 12 mg/l urea, it was found that total input power is influenced by:

- ozone concentration
- the number of UV lamps
- pH

2. In these same tests, the retention time is affected by:

- ozone concentration
- number of UV lamps on in the second stage
- pH

3. The pilot plant tests and resulting models also determined that the location of the UV lamps is important in reducing reactor volume. For hospital composite (HC) RO permeate with 12 mg/l urea, the lamps should be installed either in the last or the last two stages of the reactor.

4. Increasing the ozone mass flow at various O_3 concentrations has no effect on reactor volume as per the pilot tests providing that 2 x stoichiometric O_3/C ratio is used.

5. No significant stripping effect of organic volatiles was noted in the pilot testing or in the models for a temperature of 40°C and a gas flow of up to 20 slpm.

8.2 RECOMMENDATIONS

1. Only 3 pilot plant tests were run at temperatures above 23-26°C. The mathematical model indicated that power can be reduced and permeate flow rate can be increased at 40°C. Time did not permit additional elevated temperature tests verifying the model. Section 4.7.10.1 describes the tests required.

2. All pilot plant URM tests were run with the same waste water - HC RO permeate. The mathematical model for the URM should be expanded to include other waste waters. (See Section 4.7.10.2.)

3. The mathematical model should also be broadened to include the effect of number of stages, and the mass flow of O_3 required per stage. (Section 4.7.9.3.)

4. When the above tests are completed and the mathematical models formulated, a full scale URM MUST system should be designed and developed and incorporated into the MUST WPE.

5. Additional bench testing should be conducted on the effect of $\leq$185 nm radiation on the photolysis or the photolytic oxidation of urea in water. If these tests prove successful, shorter-wave lamps can be installed in the present URM configuration to more effectively remove urea.

6. The continuous bench tests and the derived mathematical models indicate that both urea content and the total recipe concentration of HC RO permeate have an effect on total power and reactor volume. These effects should be defined quantitatively as per Recommendation No. 2.

7. About 95% of the incoming O_3 at 125 mg O_3/min was consumed in the URM pilot plant tests, and the ozone utilization efficiency is comparable to that obtained by investigators using reactors of twice the height of the URM. For hospital composite RO permeate tested, the height of 30 inches appears adequate. Also, there is no need for a pre-contactor stage since very little ozone remains.

APPENDIX

MEMORANDUM FOR RECORD

BY

CPT JEREMIAH J. MC CARTHY

DATED 15 OCTOBER 1975

SGRD-UBG-L 15 October 1975

MEMORANDUM FOR RECORD

SUBJECT: UV-Ozone Water Oxidation/Sterilization Process, Jack D. Zeff, Principal Investigator (Contract/Grant No. C-5013)

1. A meeting was held 10 October in Building 524, USAMBRDL concerning the above contract. The following persons were present:

Mr. Jack D. Zeff - Westgate Research Corp., Principal Investigator
Cpt. Jeremiah McCarthy - Technical Monitor - USAMBRDL
Mr. Mitchell Small - Technical Monitor - USAMBRDL
Dr. William Cowen - USAMBRDL
Mr. William Cooper - USAMBRDL

2. The object of the meeting was to enable all interested parties to meet in person, to discuss in general work done for the previous two years on the contract, and to discuss in detail the work and approach to be followed for the latest extension to 31 July 1976.

3. As a platform for discussion, a concise statement of objective was agreed to. The objective for the extension is "To provide a minimum cost analysis (as a function of power and volume) within given constraints for a MUST-type ozonation wastewater reuse unit process which includes ozone, ultraviolet light, and agitation considerations.

4. In terms of past contract work, the following were identified as actual or potential factors in planning the current contract work:

a. MUST wastewater constraints (volume, TOC, COD);

b. Type of Reactor. Three and twelve liter reactors are available, in which UV light path is fixed at 3 or 6 inches from light to wall respectively. A 25 gallon reactor is proposed in which other light path distances can be studied.

c. Number of reactors. One or multiple (for series operation).

d. Type processing. Batch; continuous with either co-current or counter-current gas-liquid flow could be done.

e. UV lamp configuration. Type of lamp; distance between lamps; configuration of multiple lamps in a reactor.

f. UV operation. Steady vs programmed light intensities; different intensities in series reactors.

g. Ozone operation. O_3 concentration in air or oxygen; air or oxygen flow rate; O_2/O_3 reuse; O_3-bubble size.

h. Agitation of system.

i. Wastewater to be used.

5. After a discussion which included consideration of previous experimental results, ozone characteristics, experimental (statistical) design, the desired objective, and contract constraints, the most desirable parameters and approach were outlined. The approach will insure good experimental design which includes generation of statistically adequate data and replication of experiments. The most important parameters are:

- two, 12 liter reactors in series; countercurrent flow; continuous mode
- UV lamps, 254 nm wavelengths; low pressure; variable power, distance, and configuration
- ozone manufactured from air; variable concentration (between 1 and 2%); variable gas mass flow rates
- agitation considered in 12 liter reactors
- MUST TOC and COD effluent constraints met for a "successful" run.
- two, 25 gallon reactors in series; countercurrent flow; continuous mode
- included in the measurements will be temperature and pH of the waste treated and power measurements for both UV and ozone generator; Bubble size will be noted
- wastewater composition

The liter reactors will be used to investigate ozone/UV/agitation relationships with respect to power and volume (detention time) consumption. The 25 gallon reactors will allow further exploration of variable UV lamp distance and configuration as well as gas and water flow patterns through baffle placement.

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6. Wastewater to be used will be synthetic. It will be as "realistic" as can be estimated from current data on Walden reverse osmosis permeate, i.e., containing organic substances which occur in significant quantities and considering the original Walden recipe for MUST composite waste. Any COD contribution from inorganic elements is not presently known. A tentative formation of the synthetic waste is attached as enclosure 1. It is recognized that the conception of a best hospital composite synthetic waste may change pending further study and new information. In this respect, decisions as to whether or not to change the waste used for this contract (as per enclosure 1) will be made at the appropriate time. Synthetic waste composition remains a dynamic subject and will be followed closely.

7. A schedule of the number and frequency of samples to be analyzed with GC-MS in this laboratory was provided to Dr. Cowen and Mr. Cooper. Mr Zeff will be provided with an SOP on proper sampling procedures.

8. The major changes of the Tasks as defined in the proposal are as follows:

Task I (1) De-emphasize (but not eliminate) batch and emphasize continuous mode processing.

(2) De-emphasize (but not eliminate) single stage and emphasize two-stage testing.

(3) Conduct the tests of interest to the Army on the synthetic waste (or similar waste) described in enclosure 1.

Task II (1) Eliminate Task IIa. The savings from not building the 22 liter agitation chamber will be off-set by the (now) higher cost of the 25 gallon variable lamp reactors and a longer testing program.

(2) The tasks described in IIb will be integrated with Task I work, all in the 12 liter reactor.

Task III (1) Cost analysis (as a function of power and volume) will be a function of Task I and II and possibly Task VI.

Task IV No change

Task V To be determined pending NASA funds.

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Task VI (1) De-emphasize (but not eliminate) batch and emphasize continuous mode processing.

Task VII No change

9. The NASA funds for this contract are pending. Similarly NASA's desires concerning this contract are pending. In this sense, the contract work program continues to be flexible. Urea makes up a relatively large portion of the synthetic waste and is not disregarded.

10. Currently, Westgate Research has received 50 gallons of laboratory R.O. permeate and 50 gallons of hospital composite R.O. permeate from Walden Research. The plastic liner bag holding the laboratory permeate ruptured. As a result, the permeate is contaminated with iron from the sides of the parent 50 gallon drum (pH of the permeate is about 3 for preservation purposes). The hospital composite waste arrived satisfactorily.

11. Progress for the 5th quarter (thru October) has been as follows:

a. Running tests on Walden laboratory permeate in batch mode in the 3 and 12 liter reactors to establish UV-ozone efficiencies and residence time.

b. Running preliminary tests on the 12 liter, two stage reactor, continuous mode to establish operating parameters (flow rates, detention time, ozone concentrations). Three and five component wastewater was used.

The 5th quarterly report detailing these activities will be here within the month. The annual report summarizing last year's activities is also due to arrive shortly.

Jeremiah J. McCarthy

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