ULTRAVIOLET DISINFECTION OF A WASTEWATER TREATMENT PLANT EFFLUENT

By

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ULTRAVIOLET DISINFECTION OF

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PLANT EFFLUENT

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CHAPTER I

INTRODUCTION

History

Shortwave ultraviolet light's ability to destroy microorganisms was discovered in the late 1800's. Some ultraviolet units were installed in the early 1900's. However, these early designs were complicated, expensive, difficult to operate and maintain, and of questionable reliability. Therefore, ultraviolet (UV) light was used only on very specilized applications until the early 1970's (1).

An EPA epidemiology study published in 1973 linked chlorine by products in drinking water to high occurences of kidney and bladder cancer in New Orleans (1). Safety problems with gaseous chlorine transportation, handling and storage could be principle forces behind the use of UV in order to reduce the possibility of injury to persons from accidental exposure to chlorine gas (2). Ozone used as a disinfectant has proved to be a very expensive alternative (3).

During the 1970's and early 1980's, there were significant technological advances in UV disinfection. For example, automatic mechanical wiper systems

were developed for quartz sleeve UV units to lengthen the time interval between chemical cleaning (1). Efficiency of UV systems was improved and capital and operating costs were drastically reduced. These improvements led to UV disinfection of potable and industrial water in the early 1970's, but it's use for disinfecting effluent from secondary treatment plants has been more recent. Only since the 1979 publication of a national symposium of wastewater disinfection increased the application of UV disinfection at U.S. and Canadian secondary wastewater treatment plants.

Reasons often cited to support UV disinfection include: lower life cycle cost, superior ability to kill viruses at typical dosages, low energy requirement, does not form harmful byproducts and reaction contact times are low which eliminates the need for large contact basins (1).

Mechanism of Disinfection.

Microbial cells contain the nucleic acids, DNA and RNA. To live and reproduce, the cell must be able to replicate the biochemical information in these nucleic acids. The nucleic acids, the genetic material of the cell, are so important that the alternation of a single gene or two can cause the death of the cell.

Nucleic acids absorb light of different wavelengths (240nm-280nm), but show a maximum absorption when exposed to light between 255nm and 260nm (4)(2). Low pressure

mercury vapor lamps generate light at 253.7nm, which is very close to the maximum absorption wavelength for nucleic acids (4). UV irradiation is absorbed by the nucleic acids in microorganisms, and damages or modifies the genetic information. That damage does not allow the cell to reproduce, therefore it causes the death of the cell.

Project Description

The scope of the work to be presented here deals with the effects of UV dosage, exposure time, flowrate, intensity and suspended solids on a pilot-scale UV system in order to determine the system's reliability in achieving desired coliform levels.

This system was attached to one of the 3 final clarifiers of the Water Pollution Control Plant located in Stillwater Oklahoma, which is clasified as a two stage high rate trickling filter secondary effluent wastewater treatment plant.

The unit was operated at flowrates between 10-40 gpm Samples were collected for fecal coliform and suspended solids analysis.

CHAPTER II

LITERATURE REVIEW

Introduction

Research efforts previous to this paper on Ultraviolet disinfection of secondary wastewater effluent are few in number. Whereas only two UV exhibitors attended the 1979 WPCF Convention in Las Vegas, seven companies exhibited their UV disinfection systems at the 1983 WPCF Convention in Atlanta. During these last seven years an increase in sales of over 375% is worth noting (1).

Several pilot and full-scale investigations of UV disinfection have been made in recent years. Although these studies showed that UV disinfection was generally successful in meeting disinfection goals, comparison between these studies has been limited because there was no direct method of measuring UV doses nor any substantiated method for calculating doses in the complex geometries of the reactors and absorbing solutions within practical reactors. In addition, lack of dose measurement methods has prevented the controlled evaluation of the effects produced by variables such as UV absorbance, filtration, reactor design, and the different sensitivity of various organisms.

Dose - Survival Relationship

The dose - responce relationship is basic to UV analysis and system design.

Qualls et al.(5) showed through experiments that fecal coliform reduction is a function of UV light dosage. Dose is defined as:

$$\text{Dose} = (\text{intensity})(\text{exposure time}) \qquad (2.1)$$

or, in units: $mW\text{-}s/cm^2 = (mW/cm^2)(sec)$,

where mW is microWatts, s is seconds and cm^2 is centimeter to the square. The survival (N/No) of organisms is, in general, a function of dose (5).

The log survival is defined as:

$$\log \text{survival} = \log(N/No) \qquad (2.2)$$

where No and N are the density of the organisms before and after irradiation respectively. The 1st order kinetics model described by the log survival and is often presumed to be a straight line (when plotted on a semi-log paper) related to the dose but usually the relationship deviates from linearity. Based on their research the log survival versus dose showed a non lineal relationship.

Qualls et al.(6) in a more recent study, found in their investigation work evidence which suggests that most graphs presenting coliform survival show diversion below the level of -2 log survival units.

Zukovs et al.(7) in their work confirmed that there is a non-linear relationship between dose and kill. Linear

regression of log reduction in fecal coliforms of UV dosage resulted in a 5% confidence level correlation of ($r=-0.50$), however the regression coefficient was not statistically different from zero. A reduction of 2 logs (99%) was achieved on all but a few occasions; the target reduction for fecal coliforms of -4 logs (99.99%) was achieved rarely. The Enterococcis the Pseudomonas aeruginosa and the Salmonella spp. showed a statistically significant correlation between log bacteria reduction and UV dosage but not satisfactory enough to be linear.

The above results imply that the relationsip between log fecal coliform kill and UV dosage is non-linear, or there are other variables, such as suspended solids concentration, which must be incorporated in the regression analysis.

Scheible and Bassell (8) suggested that dose response relationship is better characterized by a model that assumes 2nd order kinetics with respect to coliform density. Their results showed excellent correlations when linear regressions of log effluent coliform density and the log dosage were constructed.

Dose - Intensity Relationship

There has been no verified method for dose calculation due to the complex geometries of a practical reactor. Since the dose is directly related to the

intensity, methods have been developed to measure intensity within a UV reactor.

Qualls and Johnson (9) developed a bioassay method to measure average intensity within a UV reactor. Bacillus subtilis (ATCC 6633) spores were used for the bioassay. The survival of spores of Bacillus subtilis was determined as a function of the UV dose in a collimated beam apparatus. They suggested that it can be useful for measuring dose in flow-through reactors by injecting spores as a spike and collecting samples at a known time after injection.

Dose - Photoreactivation Relationship

A portion of the experimental programs have been devoted to investigating photoreactivation, a phenomenon associated with UV disinfection. Photoreactivation is the ability of a cell to repair UV - induced damage when it is subsequently exposed to energy wavelegths in the visible light range between 310 and 500nm. Thus, simple exposure to sunlight can provide the catalyst to this repair mechanism.

Scheible and Bassell (8) in their studies developed a regression analysis for fecal coliforms which indicated that photoreactivation significantly depends on temperature. The implication of photoreactivation is that a higher dosage of UV would be required if photoreactivation were to be accounted for.

Zukovs et al. (7) in their research confirm the work of Scheible and Bassell but also concluded from their

studies that the differences between sample pairs of photoreactivated samples and pre-reactivated samples were not statistically significant.

Qualls et al.(6) claim that under favorable conditions, phoroteactivation of inactivated coliforms result in an increase in survival of 1 log unit and even up to 1.8 log survival units under optimal conditions. They proposed that units should be designed to provide a higher dosage for a good quality effluent where photoreactivation is expected.

Absorbance and Scattering Effects of UV Light by Suspended Solids

Suspended particles in wastewater effluents can play two roles in UV disinfection: they can absorb and scatter the UV light, and they can harbor bacteria that are partially protected from the UV light.

Qualls et al.(5) noted that organic particles can protect organisms from disinfectants and can become a major limiting factor in disinfection. Clays do little to inhibit UV disinfection because they tend to scatter light rather than absorb it.

Qualls et al.(6) observations led them to the following hypothesis: the UV sensitivity of the single cell and small aggregates of coliforms are relatively uniform from plant to plant, and the wide variation in survival curves is caused by varying proportion of coliforms

that are protected by association with particles and by varying degree of protection afforded by different particle sizes. Examination of the samples for differences in survival and suspended particle concentration provided a test of this hypothesis.

Zukovs et al.(7) reported similar findings. In their experimental work they showed that large aggregates containing bacteria in raw wastewater were shielded from UV light. Regardless of the UV dose applied, it seemed impossible to kill the shielded bacteria. When fecal coliform effluent densities were tested as a function of Total Suspended Solids (TSS) concentrations, no statistically significant correlations found, however, at elevated suspened solids concentrations, the effluent fecal coliform density tended to be higher and the reductions were generally lower.

Absorbance measurement is required for calculation of average UV intensity. Wastewater effluents contain paticles that may scatter as well as absorb the UV light. Because normal spectophotometric measurements do not distinguish scattering and absorbance and tend to significantly overestimate UV absorbance due to scattering, a new method was introduced (5).

A special quartz curvette was ground so as to be translucent on the side nearest the detector was used to correct for forward scattering for UV light. This method is called the opalescent plate method. This method gave a

close estimate of the true absorbance which is equal to soluble absorbance plus particular absorbance. As a conclusion of this study spectrophotometric absorbance caused by particles was about 75% absorbance and 25% scattering.

Zukovs et al.(7) developed the following expression to account for the scattering interferences proposed by Qualls et al.(5):

corrected absorbance = centrifuged absorbance (2.3)
+ 0.75(uncentrifuged absorbance - centrifuged absorbance)

Qualls et al.(6) suggested a different correction factor for scattering. Using a regular cell they measured the scattering to be 10.3% of the UV absorbance. This scattering correction was roughly estimated from the turbidity. They claimed that because the scattering correction is fairly small, the error using the turbidity to estimate the scattering results is only minor in the estimate of the true absorbance. In addition, part of their study was based on comparison of filtered and unfiltered effluent samples from five municipal wastewater treatment plants. Evidence of their study was that in all cases but one which contained very low suspended solid concentrations the number of survivors in the corresponding filtered samples was less than 20% of those in the corresponding unfiltered samples. It should be noted that

from 0 to -2 log survival units the filtration had little effect on survival at a given dose, however beyond that range the slope of the curves for the unfiltered samples decreased substantialy and flattened out.

UV / Sedimentation Process

Effluent suspended solids concentrations follow a seasonal pattern; high solid concentrations occur in the summer months when algae growth is greatest and also during the spring and fall as a result of overturn. Many methods of suspended solids removal have been used to remove algal cells from suspension in lagoon effluents.

Borup and Adams (4) suggested that UV disinfection followed by sedimentation could be a successfull process for suspended solids removal from lagoon effluents. Their research proved that the UV/Sedimentation process was advantagous with a removal between 15 and 54% of suspended solids. They suggested that this process could be easily applied seasonally, and flow could continue through the unit all year, and the UV lamps could be operated only during times of high suspended solids. This could significantly decrease the annual operating costs. One advantage of this process is that further disinfection is unnecessary, which would significantly reduce the net cost of the system, particularly if chlorination/dechlorination would otherwise be required.

UV a Cost Effective Process

It is difficult to make generalizations regarding relative economics between UV and chemical disinfection because of widely varying local costs and conditions. There is also wide variation in UV units and chemical disinfection system selling prices. Caution is warranted in any direct comparison made in the following discussion.

Whitby et al.(10) have compiled an excellent cost comparison between the capital and operating costs of chlorination, dechlorination, chlorination/dechlorination, ozonation, and UV disinfection by using the "Innovative and Alternative Technology Assessment Manual", information from the UV disinfection project they performed, and data from the manufacturer of the UV disinfection system. Their comparison showed that UV can be a cost effective alternative to other disinfection methods. Ozonation is not cost competitive with UV irradiation because it has high installation and operation costs. UV lamps replacement and power usage make up the majority of the UV operating cost when the amortization costs are excluded. UV is a viable alternative to chlorination if the UV unit is designed specifically for disinfection purposes. This study also demostrated that UV devices can be designed to require minimal maintenence and very little on-site modifications.

Scheible and Bassell (8) have prepared a cost

comparison table which indicated that UV disinfection appears to be paricularly competitive at the lower flow levels. As the design flow increases, UV disinfection is estimated to be comparable in cost to chlorination, chlorobromination and chlorination/dechlorination, and considerably less than ozonation.

Design Characteristics of UV Systems

The design objective in any UV disinfection system is to efficiently and reliably deliver the required UV dosage to microorganisms in the fluid. Only two materials, quartz and FEP Teflon, have practical UV transmission and lack of degredation under high intensity of UV light.

There are two basic design approaches: shellside flow and tubeside flow.

Cruver (1) has compiled an excellent review of the two designs for UV disinfection. In his discription of a shellside flow design he states that water flows over one or more quartz sleeves similar to flow on the shellside of a shell-and tube heat exchanger. Inside each quartz sleeve is a germicidal UV lamp. The outer shell is usually constructed of stainless steel or polyvinyl chloride. The quartz sleeves penetrate bulkheads at both ends of the outer shell and are sealed with UV - resistant o - rings. Electrical connections to the germicidal lamps are made at both ends of the unit, and the ballasts are placed in a seperate enclosure outside the disinfection chamber.

Advantages of the shellside design are:

1) Compactness.

2) High UV intensity levels.

3) Better efficiency of UV light on small systems.

4) High-pressure capability because of strength of quartz in compression.

Disadvantages of the shellside desigh are:

1) Difficulty in maintaining an even flow and exposure time distribution.

2) Dependence on many "o"-ring seals.

3) Maintaining optimum lamp temperature (insulating air-gap between the lamp and sleeve is insufficient to maintain optimum lamp temperature for very cold or very hot water).

Cruver describes a tubeside flow design as a system where water flows inside one or more tubes usually made of FEP Teflon. The tubes can be connected in parallel to large diameter headers to achieve large flow capacities. Germicidal lamps are placed outside and in between the flow tubes to evenly exposure fluid to UV light.

Advantages of a tubeside design are:

1) Uniform flow pattern and exposure time.

2) Complete separation of the fluid and electrical circuits.

3) Thermostatic temperature control to the optimim.

Disadvantages of a tubeside design are:

1) Larger size than equivalent capacity shellside

units.

2) Lower intensity levels.

3) Lower efficiency on smaller units.

4) Limited pressure capability because of the low strength properties of Teflon and quartz in tension.

White, Jernigan and Venosa (2) have prepared a survey which identified 52 UV systems that currently operate in the U.S. and Canada. Inspection of these UV facilities provided insights in the practical application of UV disinfection theory that can be useful in future applications of this technology. Most of the difficulties encountered were unrelated to the UV process itself, and instead resulted from electrical, mechanical and hydraulic problems. In some cases the equipment design was inconsistent with good engineering application of the fundamentals of disinfection theory. They claimed that to achieve the best performance from a UV unit, it is desirable to maximize mixing in the direction perpendicular to the flow (transverse dispersion or radial mixing) and to minimize mixing in the same direction as the flow (axial dispersion). Adequate radial mixing can be achieved by designing the system for turbulent flow. Axial dispersion is another issue altogether. When dispersion is low, the unit approaches plug flow and all the organisms are exposed to the disinfectant for the same length of time. When dispersion is high, short circuiting occurs and some

organisms pass with little exposure. Their studies suggested that low axial dispersion may be accomplished by minimizing turbulence at the entrance and exit of the reactor and by maximizing the aspect ratio (length/width) of the reactor vessel itself. A perpendicular to lamp flow configuration is susceptible to short circuiting and uneven irradiation of the unit through put. A parallel-to-lamp flow pattern promotes plug flow.

Besides the reactor hydraulics, electrical problems could be caused by inadequate ventilation of the heat-generating electrical components. Ballasts relays and meters housed in metal panels require ventilation to avoid excessive temperatures that could lead to early failure.

White, Jernigan and Venosa (2) also suggested that large ventilating fans and more covered vents could be used to alleviate the build up of heat in these panels.

Cleaning is another important consideration in UV designs. The medium that seperates the lamps from the wastewater must be kept clean to maximize the dose of UV irradition that reaches the microorganisms. Three common cleaning methods are ultrasonics, mechanical wipers and chemical cleaning.

High-frequency ultrasound cleans the quartz sleeves similar to ultrasonic cleaning of laboratory glassware. Mechanical wipers periodically seperate fouling deposits from the wetted surface of the quartz sleeves. Chemical cleaning was recommended as the most efficient

method. Both ultasonic and mechanical wiper systems proved to be supplement of chemical cleaning. The cleaning agents vary from soap and water to acid solutions like citric acid, sulfuric acid, sodium hypochlorite, sodium hydrosulfite and commercial acid detergents that have been used especially for quartz sleeves. If the quartz sleeves are coated with a thin layer of FEP Teflon, fouling-resistance is increased.

Various methods of enumerating coliform bacteria have been used in research studies of UV disinfection.

Qualls et al. (11) have conducted a study in which they compared the survival of UV-irradiated coliforms in wastewater, (as enumerated by the two methods most commonly used) the standard membrane filtration (MF) method and the most-probable-number (MPN) method for enumerating both total and fecal coliforms. They showed no significant difference in their comparison which proves that all methods can yield reliable and conservative measurements for meeting disinfection standards.

CHAPTER III

MATERIALS AND METHODS

Experimental Apparatues

The pilot-scale UV system used for this study was attached to one of the 3 final clarifiers of the Water Pollution Control Plant located in Stillwater, Oklahoma, which is classified as a two stage high rate trickling filter secondary effluent wastewater treatment plant.

Water flows inside a tube made of quartz, a UV transmitting material. Six germicidal lamps are located outside the flow tube to evenly expose fluid to UV light. Flow through the unit was parallel to the longitudinal axis of the tube and the longitudinal axis of the lamps.

The lamps are shield with a stainless steel cover in a zig-zag shape in order to reflect the UV light on the quartz tube.

Figure 1 shows the experimental apparatus used. The characteristics of the UV system are listed in Table I.

Originally the pump used was a submersible pump with maximum capacity of 46 gpm. Due to mechanical problems it was replaced by a pedestal type pump with a maximum capacity of 70 gpm.

The UV system was housed in a metalic encasement with

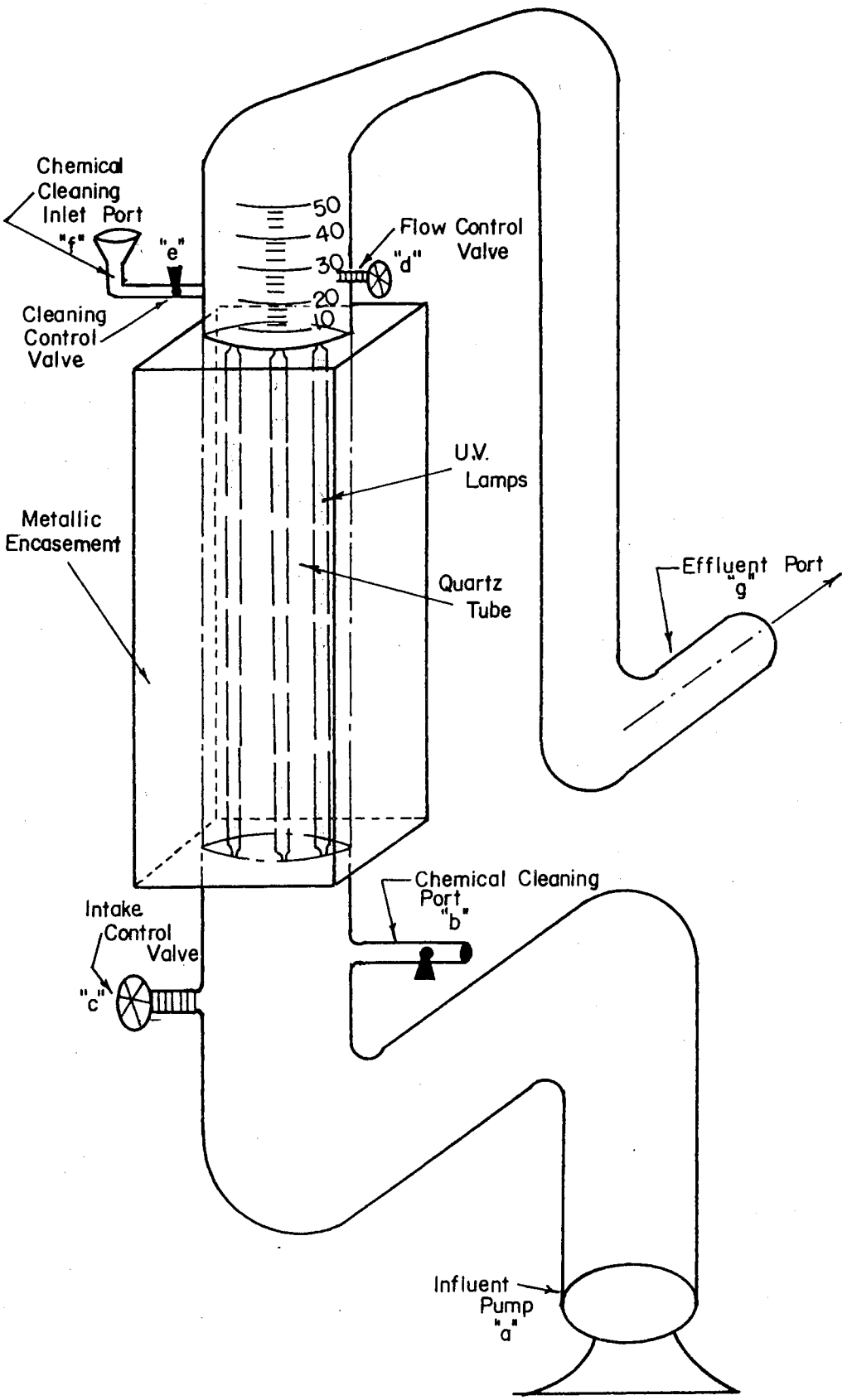

Figure 1. Experimental Apparatus

TABLE I

CHARACTERISTICS OF THE UV SYSTEM

Manufacturer	WEDECO GMBH D-4900 Herford, West Germany
Fabrication Number	43058
Type	E/10-6
Fabrication Completion Date	July 1983
Max Pressure	6 Bars
Max Temperature	25C
Frequency	50Hz
Power	230 Watts
Voltage	465 Volts
Quartz Tube Diameter	69 mm
Quartz Tube Length	1 m
Number of UV Lamps	6
Nominal Length of UV Lamps (including lamp holders)	0.80 m
Center to Center Distance Between Lamps	50 mm

dimensions of 23X20X97 cm.

Since the system was manufactured by a European firm and the frequency was 50Hz, a transformer was used toconvert the frequency to 60Hz and the voltage from 115 Volts to 230 Volts.

Samples of the water before irradiation were collected from port b and samples after irradiation from the place of discharge point g. (see Figure 1.)

The quartz tube would became coated with a scale formation after a period of use. Whenever the scale increased to the point that the target fecal coliform level was no longer achieved, (target level is equal to 200 fecal coliforms/100 ml) the unit was cleaned with a sulfuric acid solution. Run times between chemical cleaning ranged from one to two weeks. After each chemical cleaning a new flowrate was set, therefore chemical cleaning was performed each time prior to each tested flowrate run. Since a backup quartz tube was not available for the experiment, the system had to be shut down during chemical cleaning. The coating was easily removed by injecting the acid in port f, with valves b and c closed, and valve e open. After the acid remained in the tube for a interval of 6 hours, (arbitrary time chosen) it was drained at the outlet port b. (see Figure 1.)

Besides the mechanical problems with respect to the submersible pump, no other problems occured of significant importance.

Experimental and Analytical Procedures

The UV system was operated at flowrates of 10, 20, 30, and 40 gpm. Samples before and after irradiation were collected almost daily during the run time for each flowrate application.

The membrane filtration method was used for enumerating fecal coliforms. Analysis of the samples before and after irradiation was done according to the Fecal Coliform Membrane Filter procedure of "Standard Methods"(12) section 909C. A sample volume of 25 ml was estimated to yield countable membranes. Eight samples of the wastewater were filtered, 4 with the wastewater before irradiation and 4 samples with the wastewater after irradiation. Densities were recorded as fecal coliforms per 100 ml.

Samples of wastewater before irradiation were also analysed for Total Suspended Solids(TSS) according to "Standard Methods"(12) section 209A. Testing of TSS was done by filtering duplicate portions of 100 ml of sample with glass fiber filters. Concentrations of TSS were recorded in milligrams per liter.

CHAPTER IV

RESULTS

Based on the physical dimentions of the quartz tube, the total power supplied by the six UV lamps and the tested flowrates, the intensity and the exposure time were calculated. Since dose is defined as intensity times exposure time based on equation (2.1), the dose was able to be calculated for each flowrate. Exposure times and dosages with respect to each flowrate are shown in Table II.

Total exposure surface is equal to DH, where D is the diameter of the quartz tube and H is the nominal length of UV lamps surrounding the quartz tube, which defines the part of the tube that was exposed to UV light. Using the data from Table I, D is equal to 69mm or 6.9cm and H is equal to 0.8m or 80cm. Intensity is equal to the total power supplied by the six lamps distributed over the total exposure surface. Power is equal to 230 Watts or 230X10^6uW based on the information given in Table I. Therefore,

$$\text{Total Exposure Surface} = \pi DH \qquad (4.1)$$

$$\text{Total Exposure Surface} = \pi(6.9\text{cm})(80\text{cm}) = 1734.16\text{cm}^2$$

$$\text{Intensity} = \text{Power}/\text{Total Exposure Surface} \qquad (4.2)$$

$$\text{Intensity} = (230\text{X}10^6\text{uW})/(1734.16\text{cm}^2) = 132629\text{uW/cm}^2$$

The exposure time of the volume irradiated in seconds

TABLE II

EXPERIMENTAL DATA AND CALCULATED VALUES

DATE	TIME	FLOW	DOSE	EXPOSURE TIME	SUSP. SOLIDS	FECAL COLIFORMS No	N	LOG(N/No)
	day	gpm	uWs/cm^2	SEC	mg/l	# per 100ml		
4/27/86	2	10	628662	4.7420	15.50	2900	26	-2.05
4/28/86	3	10	628662	4.7420	15.00	7500	36	-2.32
4/29/86	4	10	628662	4.7420	13.00	2500	105	-1.38
4/30/86	5	10	628662	4.7420	16.50	10900	22	-2.70
5/1/86	6	10	628662	4.7420	16.50	4300	35	-2.09
5/2/86	7	10	628662	4.7420	43.50	17400	92	-2.28
5/3/86	8	10	628662	4.7420	21.50	12800	92	-2.14
5/4/86	9	10	628662	4.7420	36.50	13067	45	-2.46
5/6/86	11	10	628662	4.7420	23.00	19733	77	-2.41
5/7/86	12	10	628662	4.7420	22.00	2200	50	-1.64
5/8/86	13	10	628662	4.7420	22.00	16100	107	-2.18
5/13/86	1	20	314331	2.3710	31.00	8100	107	-1.88
5/14/86	2	20	314331	2.3710	23.00	6600	89	-1.87
5/15/86	3	20	314331	2.3710	21.50	8900	144	-1.79
5/16/86	4	20	314331	2.3710	20.00	7200	93	-1.89
5/17/86	5	20	314331	2.3710	29.50	10200	219	-1.67
4/10/86	1	30	209554	1.5807	12.50	2267	25	-1.96
4/11/86	2	30	209554	1.5807	12.00	4800	120	-1.60
4/15/86	6	30	209554	1.5807	10.50	8000	128	-1.80
4/16/86	7	30	209554	1.5807	10.50	2200	192	-1.06
4/18/86	9	30	209554	1.5807	11.00	5300	196	-1.43
4/21/86	12	30	209554	1.5807	12.00	2267	206	-1.04
4/22/86	13	30	209554	1.5807	16.50	4900	312	-1.20
5/18/86	1	40	157165	1.1855	13.00	3869	176	-1.34
5/19/86	2	40	157165	1.1855	18.50	4100	121	-1.53
5/20/86	3	40	157165	1.1855	18.00	3200	155	-1.31
5/21/86	4	40	157165	1.1855	24.00	10000	189	-1.72
5/22/86	5	40	157165	1.1855	23.00	5700	251	-1.36

is equal to the total exposure volume divided by the flowrate applied. For example: At a flowrate equal to 10gpm, the exposure time is equal to :

$$\text{Exposure Time} = \text{Volume}/Q \qquad (4.3)$$

where Volume is equal to:

$$\text{Volume} = \pi(D^2)(H)/4 \qquad (4.4)$$

Volume = π(6.9cm^2)(80cm)(2.642X10^-4gal/cm^3)/4=0.79gal

At a flowrate of 10gpm or 0.1667gal per second, the exposure time is equal to:

Exposure Time = (0.79gal)/(0.1667gal/sec) = 4.7420sec.

The exposure times for each flowrate are shown in Table II.

Since the dose is defined as the intensity times the exposure time as shown in equation (2.1), the dose was calculated for each flowrate. Dosages for each flowrate are shown in Table II.

In previous studies the log survival [Log(N/No)], equation (2.2), showed a 1st order kinetics relationship with respect to exposure time or dosage (intensity is assumed to be constant). For evaluating the fecal coliform kill, this ratio was calculated as shown in Table II. In the same table, the experimental data are shown as well. The date and the interval between sampling (usually daily) as well as the fecal coliform densities before and after irradiation are shown.

From previous studies it was shown that a good reduction in fecal coliforms, depends on the efficiency of

the UV system. In other words, it depends on the UV dosage, on the exposure time, and the suspended solids allowed in the system. These parameters were compared to the log fecal coliform kill ratio (survival ratio = log[N/No]), equation (2.2). In addition to this comparison, a direct comparison of the effluent fecal coliform density was made with the same parameters. This additional work was done with the objective to verify or disaprove the assumptions previously made by others in their studies.

Figure 2, shows the fecal coliform kill ratio [log(N/No)] versus the UV dosage applied. Fecal coliform kill ratios show a large variation with respect to fixed UV dosages. The straight line drawn based on linear regression has a correlation coefficient r equal to -0.72 and shows a maximum average reduction ratio of -2.16 at a UV dosage of 628662 uWs/cm^2 and a minimum reduction ratio of -1.44 at a UV dosage of 157165 uWs/cm^2. Therefore, at higher UV dosages better fecal coliform kill ratios can be achieved.

Figure 3, compares the exposure time (which is directly proportional to the UV dosage by a constant factor equal to intensity) with respect to the effluent fecal coliform densities. This figure shows the fecal coliform reduction of the bacteria remaining within the quartz tube during irradiation. The straight line drawn based on linear regression has a correlation coefficient equal to -0.68. The best average fecal coliform reduction achieved,

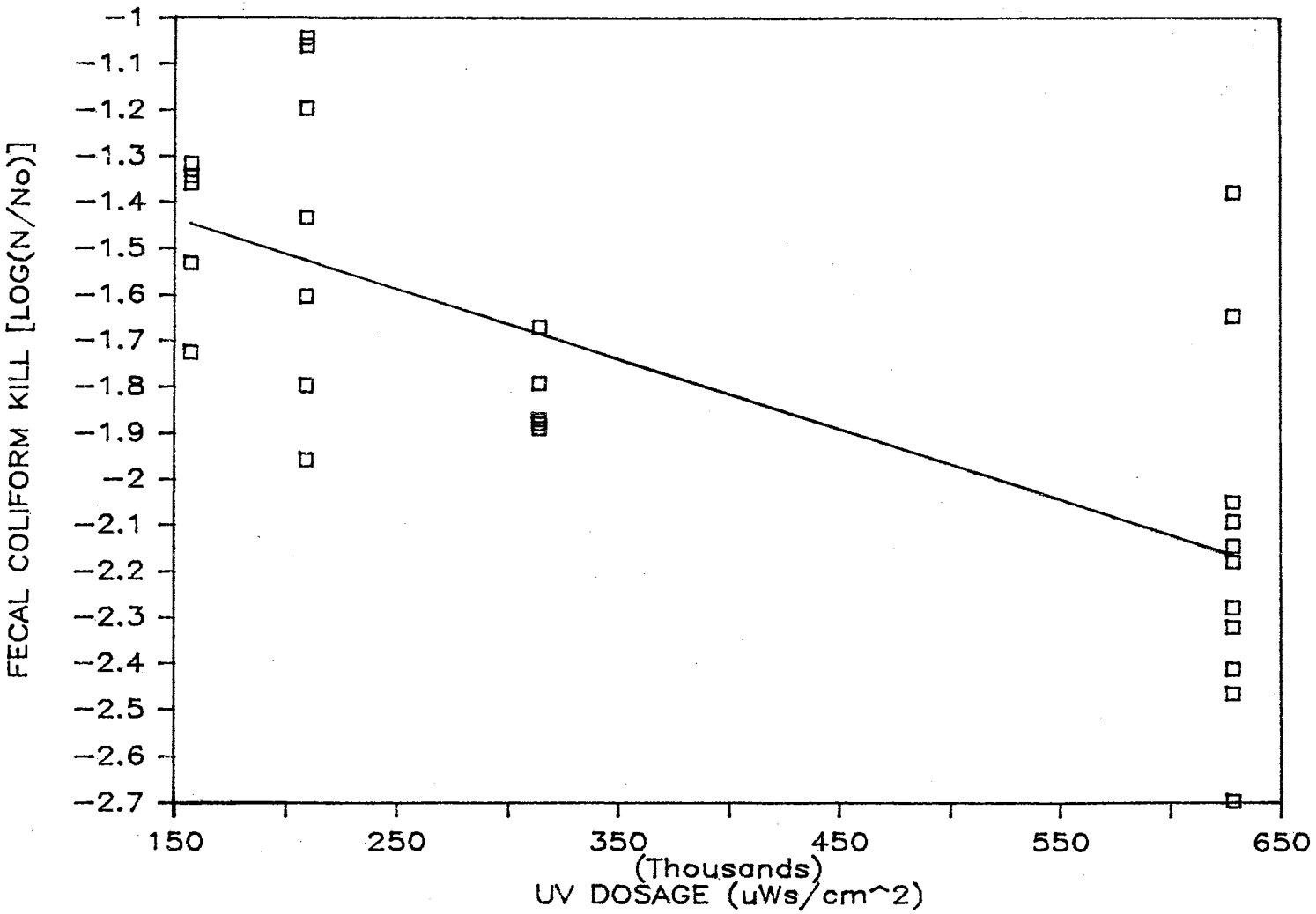

Figure 2. Fecal Coliform Kill Ratio Versus UV Dosage.

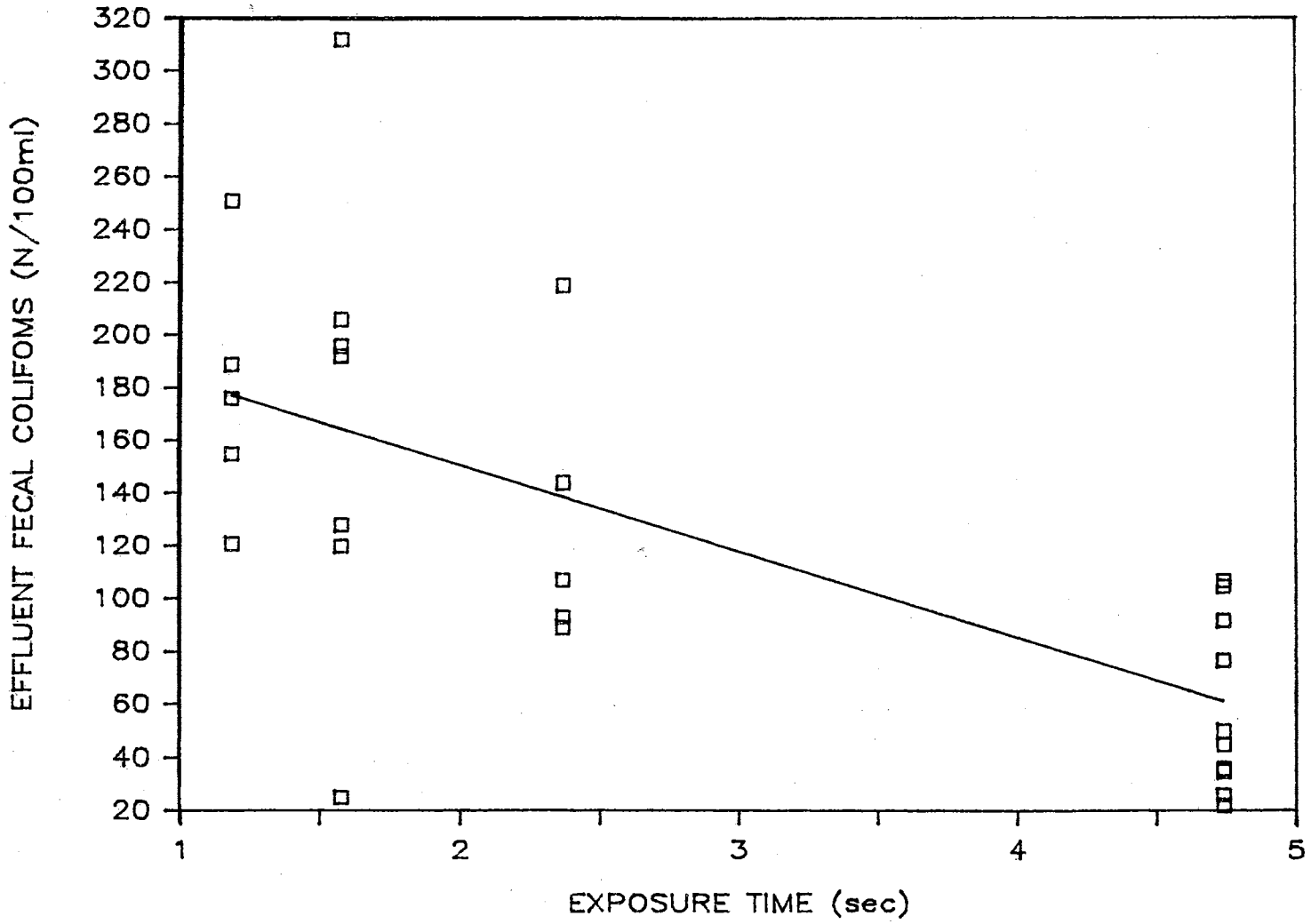

Figure 3. Effluent Fecal Coliforms Versus Exposure Time.

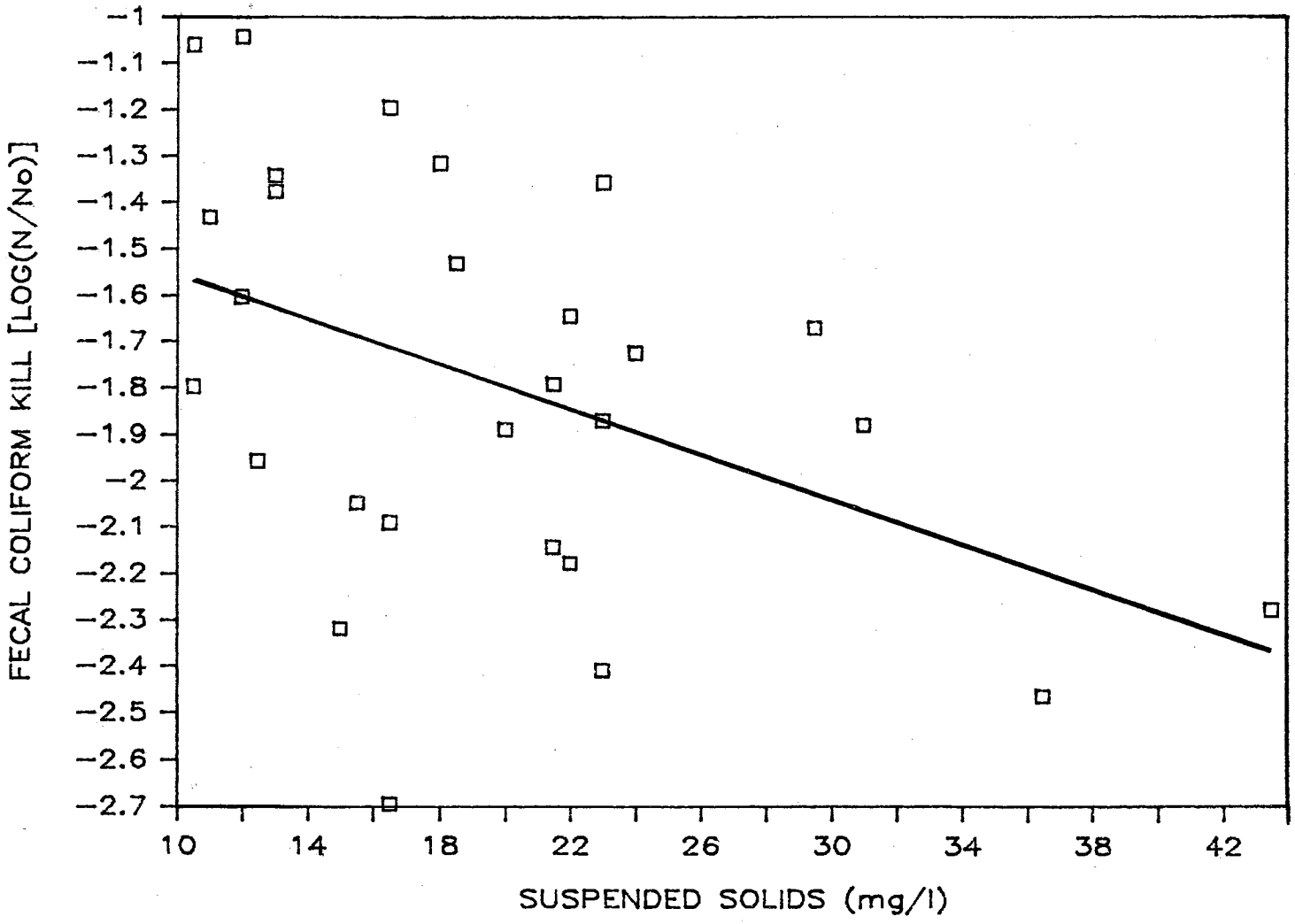

Figure 4. Fecal Coliform Kill Ratio Versus Suspended Solids.

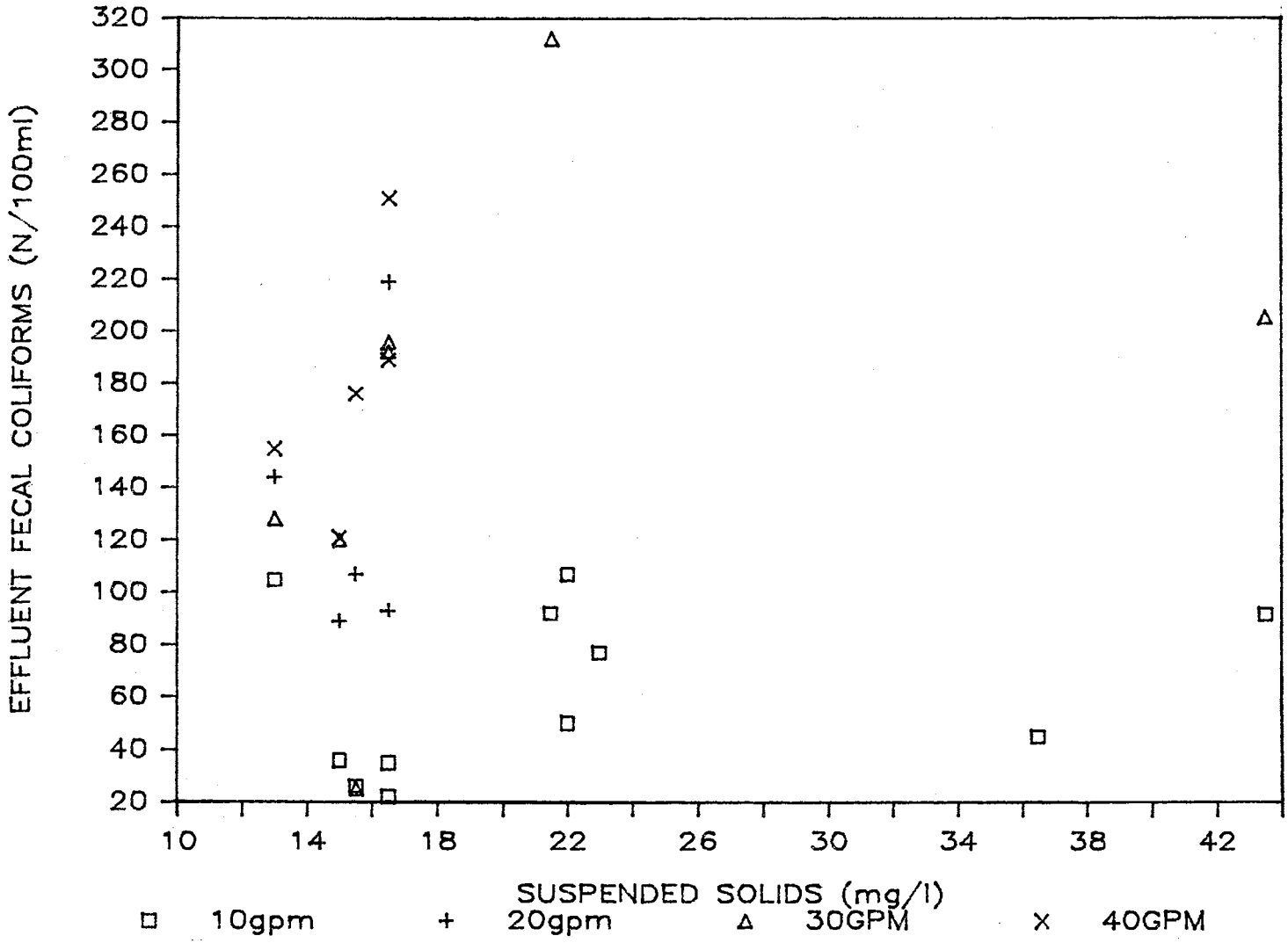

Figure 5. Effluent Fecal Coliforms Versus Suspended Solids at 10, 20, 30, 40 gpm.

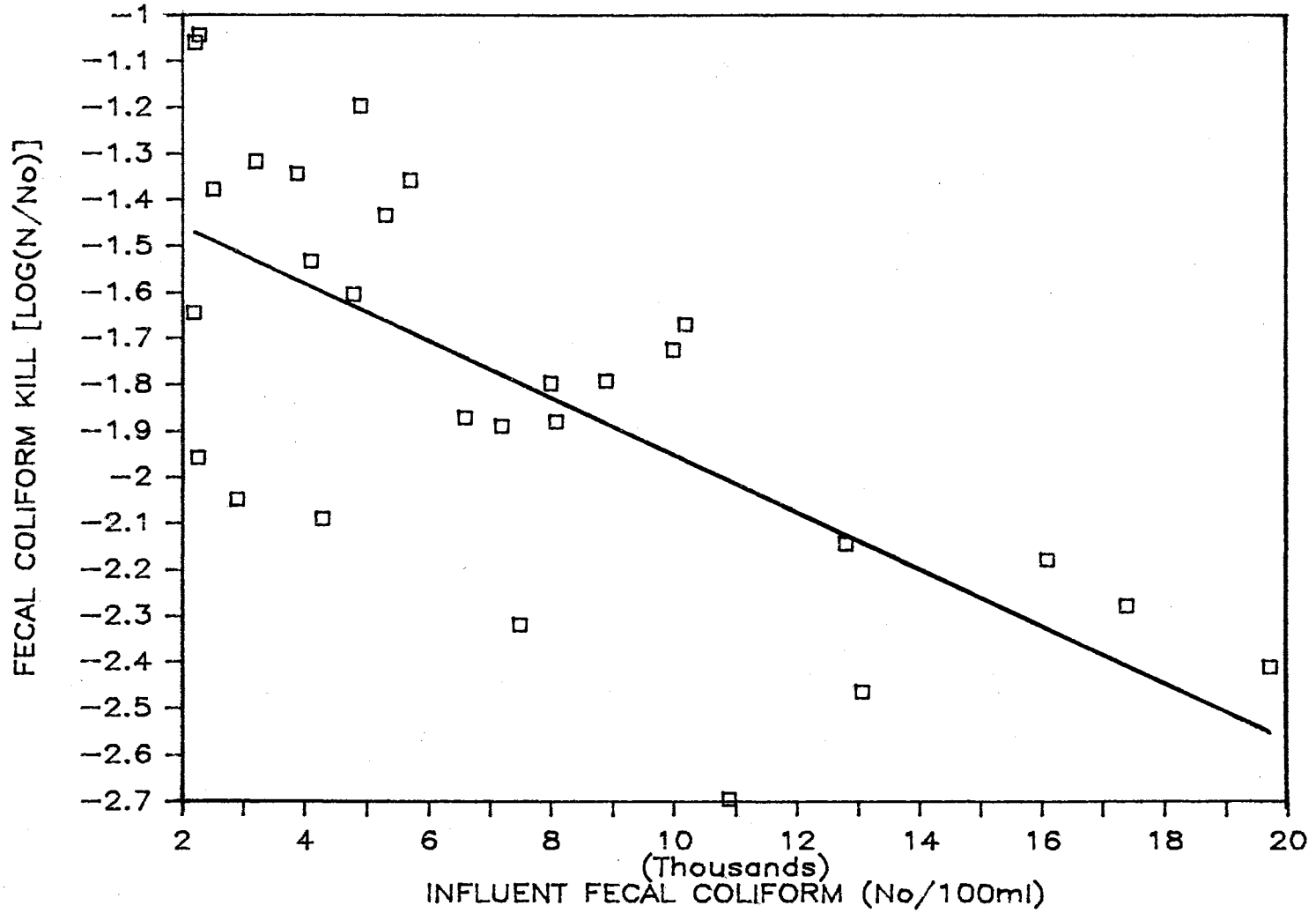

Figure 6. Fecal Coliform Kill Ratio Versus Influent Fecal Coliforms.

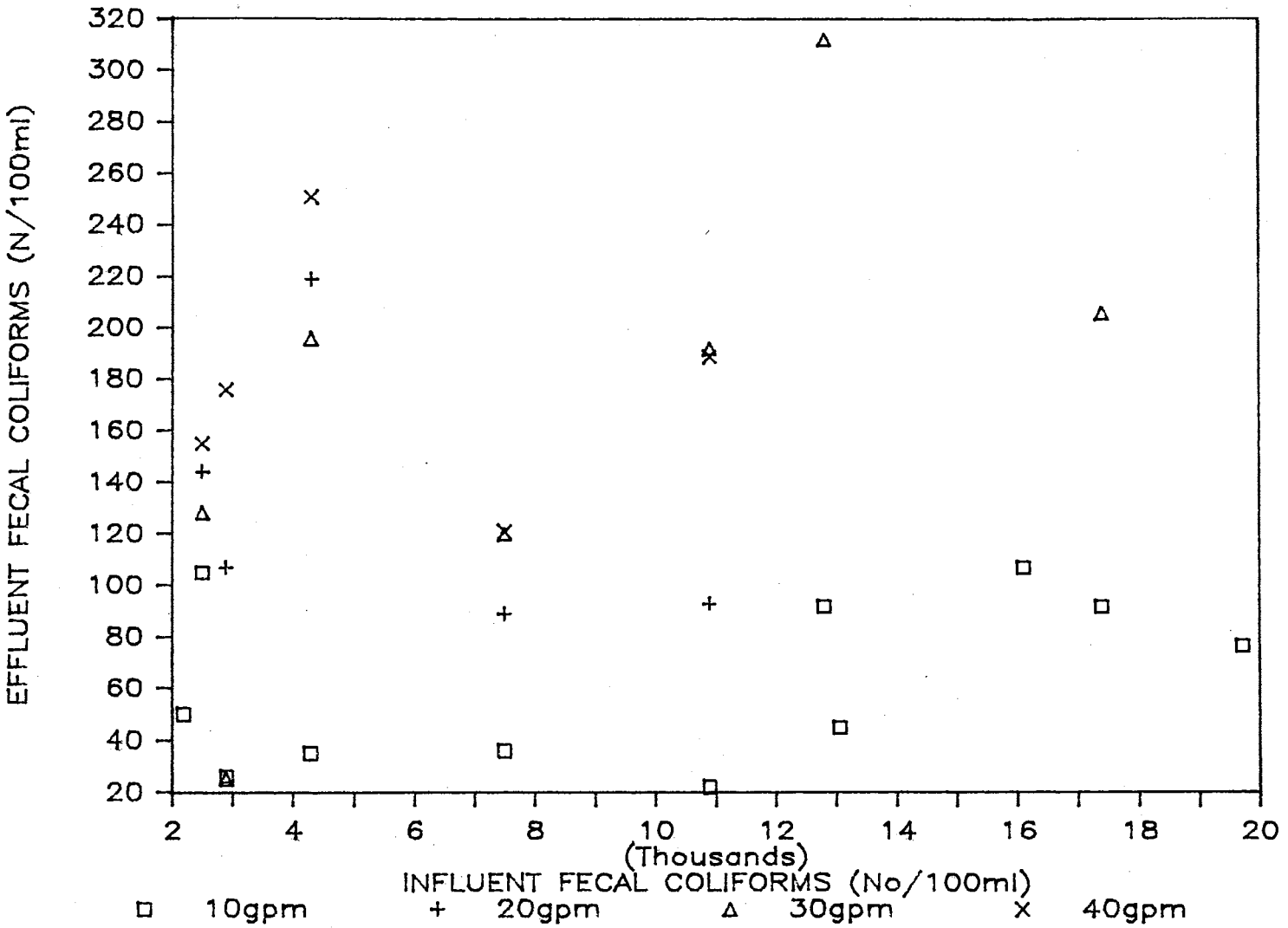

Figure 7. Effluent Fecal Coliforms Versus Influent Fecal Coliforms at 10, 20, 30, 40 gpm.

based on linear regression, was 61.45 at 4.74 sec and the worst average fecal coliform reduction achieved was 177.52 at 1.19 sec. The higher the exposure time the lower the effluent fecal coliform kill.

Figure 4, shows the overall effect of the total suspended solids during the entire experiment with respect to the survival ratio. The large scattering of data (based on linear regression the correlation coefficient r is equal to -0.44 indicates that suspended solids do not have a significant effect on the fecal coliform kill ratios. Based on the linear regression line it is shown that at higher suspended solids concentration, lower fecal coliform ratios are achieved which does not seem logical. A maximum average ratio of -2.37 was achieved at a suspeded solids concentration of 43.5 mg/l and a minimum average ratio of -1.57 was achieved at a suspeded solids concentration of 10.5 mg/l.

Figure 5, shows the effect of the total suspended solids at different flowrates with respect to the effluent fecal coliform densities achieved. It is shown that at each flowrate the effluent fecal coliform densities vary within a small range parallel to the suspended solids concentration axis, which once again shows independence of the fecal coliform reduction with the suspended solids concentrations.

Figure 6, shows the overall effect of the influent fecal coliform densities with respect to the survival

ratio. Based on linear regression with a correlation coefficient equal to r=-0.69, the worst average fecal coliform kill ratio achieved was -1.46 at an influent fecal coliform density of 2200 per 100 ml and the best average fecal coliform kill ratio achieved was -2.55 at an influent fecal coliform density of 19733 per 100 ml. The fact that better fecal coliform kill ratios are achieved at higher influent fecal coliform densities is what one would expect.

Figure 7, shows the direct effect of the influent fecal coliform densities with respect to the effluent fecal coliform achieved when different flowrates are applied. It is shown that at each flowrate the effluent fecal coliform densities vary within a small range parallel to the influent fecal coliform density axis, which shows that effluent fecal coliform densities are independent of influent fecal coliform densities.

CHAPTER V

DISCUSSION

It has already been mentioned through out this report, that good reduction in fecal coliforms has usually been evaluated with respect to the fecal coliform kill ratio, which is the log ratio of the fecal coliform densities after irradiation divided by the fecal coliform densities before irradiation. Good kill of fecal coliforms was justified based on the negative log units. The higher the negative log , the better the kill (-4 is higher than -3). This ratio shows that if a density of 200 fecal coliforms per 100ml was to be the target fecal coliform reduction, then if the density of the fecal coliforms before irradiation was very high, for example 2,000,000 fecal coliforms per 100 ml, then the log would be equal to -4, which represents a very good kill. If, on the other hand, the density of the fecal coliforms before irradiaton was 20,000 fecal coliforms per 100ml, then the log would be equal to -2, which represents a moderate kill. A few questions arose due to the fact that in both cases the target fecal coliform densities would be met despite the density level of the fecal coliforms before irradiation. In order to answer these questions data from Table II were

plotted in different combinations.

In Figure 2, different UV dosages applied were plotted versus their corresponding calculated fecal coliform kill ratios. The line drawn represents the linear regression relationship of the data. Although, it was proven in previous studies that the higher the UV dosage, the better the kill, it is hard to verify this statement based on the data in Figure 2, due to the wide range of data scattering. At a UV dosage of 628662uW/cm^2 or at a flowrate of 10 gpm, the kill varies from -1.38 to -2.70, and at a UV dosage of 314331uW/cm^2 or at a flowrate of 20 gpm, the kill varies from -1.67 to -1.89. This comparison shows that at the higher UV dosage, a better average kill ratio was achieved, but at the same time, lower kills were observed than achieved at lower dosages. This conclusion does not seem very reasonable, so a direct comparisom of the exposure time was made with respect to the effluent fecal coliforms. Looking at Figure 3, which represents almost the same X coordinate (exposure time is directly proportional to UV dosage by a constant factor equal to intensity), shows a clear influence of the exposure time or UV dosage with respect to effluent fecal coliforms reduction. The data show significant reduction of effluent fecal coliform densities at higher exposure times. Therefore, higher UV dosage, and lower flowrate (since exposure time is inversely proportional to flowrate) would enhance better

effluent qualities.

Previous studies showed that high suspended solids concentrations interfere with the effectiveness of a UV system. In Figure 4, a comparison of the suspended solids concentration during the entire operation was plotted versus the fecal coliform kill ratio. The line shown is based on linear regression to provide any possible statistically significant relationship between the two parameters. Surprisingly enough, the data showed that at higher suspended solids concentrations, better kill was achieved compared to the lower concentrations. Based on the linear regression line the fecal coliform kill ratio is shown in this study to be inversely proportional to suspended solids concentrations present during irradiation. Once again the question arose how valid is the use of the fecal coliform kill ratio in evaluating fecal coliform reduction. Since this conclusion appears to be illogical, a new comparison was made to clarify the problem.

In Figure 5, the suspended solids concentrations present at different flowrates have been plotted versus the corresponding effluent fecal coliform densities acheived at the time. The data appear to be scattered, but it can be very clearly seen that at suspended solids concentrations between 15mg/l and 17mg/l, where flowrates of 10, 20, 30, and 40 gpm were applied, better effluent fecal coliform densities were achieved at lower flowrates than at the higher flowrates. Since the effluent fecal

coliform densities show a small variation within the same flowrate parallel to the X axis. Itis apparent that suspended solids do not effect the effluent fecal coliform densities based on the range of suspended solid concentrations present in this study.

Figure 6, shows that the higher the influent fecal coliform density, the better the kill. Since the point of interest is the effluent fecal coliform density levels, two actual cases shown in this set of data with respect to effluent fecal coliform reductions are compared. For an influent of 16100 fecal coliforms per 100 ml, the effluent was reduced to 107 fecal coliforms per 100 ml with a log of -2.18. For an influent of 8100 fecal coliforms per per 100 ml, the effluent was reduced to 107 fecal coliforms per 100 ml with a log of -1.88. Both cases showed a reduction to 107 fecal coliforms per 100 ml. In order to explain the significance of this phenomenon a direct comparison of the effluent fecal coliform densities was made with respect to the influent fecal coliform densities. This comparison is shown in Figure 7. It is very obvious in this plot that at lower flowrates better effluent is achieved no matter what the influent fecal coliform density level was. For example, at a flowrate of 10gpm, influent fecal coliforms vary from 2200 to 19733 fecal coliforms per 100ml, and the reduction level shows to be very similar in both cases.

The overall results from the data evaluation leads to

the following conclusions and suggestions. The UV dosage and the exposure time do effect the fecal coliform reduction. The higher the UV dosage and the higher the exposure time, the better the fecal coliform reduction is. Suspended solids concentrations in the ranges observed in this study had no effect on the UV disinfection process. The last conclusion is that effluent fecal coliform density reduction does not depend on the influent fecal coliform density.

The above results were concluded based on the comparison of the UV dosage, exposure time, and flowrate with respect to effluent fecal coliforms reduction and not with respect to the fecal coliform kill ratio. It is recognized that in this study, the influent fecal coliform densities were not very high, but the results shown from this experimental study encourage the belief that if higher influent fecal coliforms were present the effluent reductions would still be satisfactory.

This study provided results that questioned the fundamental equation used in most of the previous studies performed with respect to UV disinfection of wastewater treatment effluents. It is suggested that UV dosage, exposure time and suspended solids could be better related to the effluent fecal coliform densities rather than to the effluent to influent fecal coliform ratio (log kill).

CHAPTER VI

CONCLUSIONS

The results of this study in which the flowrate, UV dosage, exposure time and suspended solids were varied led to the following observations:

1. Flowrate or exposure time affects the effluent fecal coliform density.
2. UV dosage affects the effluent fecal coliform density.
4. Suspended solids did not affect the effluent fecal coliform density at the levels present in this study.
5. Effluent fecal coliform density is independent of the influent fecal coliform density.

CHAPTER VII

SUGGESTIONS FOR FUTURE WORK

1. Additional experimental work should be performed to further investigate methods of measuring intensity.
2. Experimental work should be performed to determine the required time between chemical cleaning periods of the quartz tube.
3. Additional experimental work should be performed to further clarify the concept of photoreactivation.

LITERATURE CITED

1. Cruver, J. E., "Ultraviolet Disinfection of Water and Wastewater." (Unpublished paper presented at the AWWA/WPCA Joint Conference, Keystone, Colorado, September, 1984).

2. White, S. C., Jernigan, E. B., and Venosa, A. D., " A Study of Operational Ultraviolet Disinfection Equipment at Secondary Treatment Plants." J. Water Pollution Control Federation, 58, 181-192 (1986).

3. Venosa, A. C., Petrasek, A. C., Brown, D., Sparks, H. L., and Allen, D. M., "Disinfection of Secondary Effluent with Ozone/UV." J. Water Pollution Control Federation, 56, 137-142 (1984).

4. Borup, M. B., and Adams, V. D., "Upgrading Wastewater Lagoon Effluents with the UV/Sedimentation Process." J. Water Pollution Control Federation, 57, 196-200 (1985).

5. Qualls, R. G., Flynn, M. P., and Johnson, J. D., "The Role of Suspended Particles in Ultraviolet Disinfection." J. Water Pollution Control Federation, 55, 1280-1285 (1983).

6. Qualls, R. G., Ossoff, S. F., Chang, J. C. H., Dorfman, M. H., Dumais, C. M., Lobe, D. C., and Johnson, J. D., "Factors Controlling Sensitivity in Ultraviolet Disinfection of Secondary Effluent." J. Water Pollution Control Federation, 57, 1006-1011 (1985).

7. Zukovs, G., Kollar, J., Monteith, H. D., Ho, K. W. A., and Ross, S. A., " Disinfection of Low Quality Wastewater by Ultaviolet Light Irradiation." J. Water Pollution Control Federation, 58, 199-206 (1986).

8. Scheible, O. K., and Bassell, C. D., " Ultraviolet Disinfection of a Secondary Wastewater Treatment Plant Effluent." U. S. Enviromental Protection Agency, U. S. Goverment Printing Office, Cincinnati, OH. (1981).

9. Qualls, R. G., and Johnson, J. D., "Bioassay and Dose Measurement in UV Disinfection." J. Applied and Enviromental Microbiology, 45, 872-877 (1983).

10. Whitby, G. E., Palmateer, G., Cook, W. G., Maarschalkerweerd, J., Huber, D., and Flood, K., "Ultraviolet Disinfection of Secondary Effluent." J. Water Pollution Control Federation, 56, 844-850 (1984).

11. Qualls, R. G., Chang, J. C. H., Ossoff, S. F., and Johnson, J. D., " Comparison of Methods of Enumerating Coliforms After UV Disinfection." J. Applied and Enviromental Microbiology, 48, 699-701 (1984).

12. Standard Methods for the Examination of Water and Wastewater. American Public health Association, 15th Edition: Washington, D. C. (1980).

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