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Research and Development

Progress in Wastewater Disinfection Technology

Proceedings of the National Symposium Cincinnati, Ohio September 18-20, 1978

SECTION 1. OPENING REMARKS

1.
OPENING SESSION WELCOME

Albert D. Venosa
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It is a pleasure to welcome all of you to the U.S. Environmental Protection Agency's National Symposium on Wastewater Disinfection. This symposium is being sponsored by USEPA's Municipal Environmental Research Laboratory (MERL) of the Office of Research and Development, and the Environmental Research Information Center, Cincinnati, Ohio. The objectives and goals of the symposium will be presented in a few moments by Mr. John J. Convery, Director of MERL's Wastewater Research Division.

I would like to highlight the symposium's program, of which all of you should have a copy. We have organized the program into seven major sessions, each of which deals with a specific topic or aspect of wastewater disinfection research. In the first session you will be introduced to the Acting Deputy Assistant Administrator of the Office of Air, Land, and Water Use, Dr. Courtney Riordan, and MERL's Wastewater Research Division Director, Mr. John J. Convery. The subsequent sessions will be technical in scope and will involve investigators who have been granted EPA funds to conduct wastewater disinfection research. Each of the first four sessions will deal exclusively with a specific disinfectant. Thus, Session 2 concerns chlorination-dechlorination, Session 3 chlorine dioxide, Session 4 ultraviolet light, and Session 5 ozone. Session 6 involves two studies which support all the disinfection projects, i.e., indigenous virus inactivation and nonvolatile organic compound formation by chlorine, ozone, and UV light. The final session was included to provide insight into how planning decisions on implementation of new disinfection technology are made at both the EPA Regional level and the municipal consultant's level. In order to permit the maximum amount of audience participation, each session will be concluded by a separate panel or round table discussion. You are encouraged to air your views to the fullest during these discussions.

Following the last panel discussion, Dr. E. J. Middlebrooks, Dean of the College of Engineering, Utah State University, an able environmental researcher himself, will summarize the findings of the symposium and provide perspective into what lies ahead for EPA's Wastewater Disinfection Program.

On Tuesday evening, there will be a social hour and banquet, beginning at 6:00 P.M. I am certain you will enjoy listening to the guest speaker, Mr. Joseph V. Karaganis, the Special Assistant Attorney General of the State of Illinois, who will discuss the microbial aspects of the case in which he won a landmark decision for the State of Illinois against The City of Milwaukee. The title of his paper is "The Law's Response to Public Health Hazards."

All presentations and panel discussions will be recorded and published in a proceedings. I hope you enjoy the symposium and encourage you all to participate actively.

2.
INTRODUCTION AND OBJECTIVES OF SYMPOSIUM

John J. Convery
Director, Wastewater Research Division
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On behalf of the Municipal Environmental Research Laboratory of the U.S. Environmental Protection Agency, I welcome you to this National Symposium on Wastewater Disinfection. The basic purpose of this symposium is to share with you the most up-to-date research findings of our disinfection research program and thereby accelerate the practical application of these findings to the construction grants program. A corollary objective is to obtain feedback from you on your ideas or problems which can be incorporated into our future research program. The Office of Research and Development of EPA wants to be responsive to the needs of you, the practitioners of pollution control technology.

During the next three days there will be opportunities for audience participation. I would like to second Al Venosa's invitation to participate in these discussions. If additional thoughts on disinfection research needs occur to you after the symposium is finished, please share them by writing to me.

This is the second effort of the disinfection research staff to share timely research findings through the medium of a public meeting. In October 1974, we held a workshop in Wyoming, Michigan, where the results of continuous fish bioassays on chlorinated, chlorinated/dechlorinated, ozonated, and bromine chloride treated wastewaters were presented. The primary interests at that time were the relative degrees of disinfectant-induced fish toxicity and the methods of reducing or eliminating the toxicity. The prevention of fish toxicity is still an important design objective and a fundamental reason for our interest in improved chlorination and dechlorination. The current EPA criteria for total residual chlorine to prevent fish toxicity is 2.0 µg/l for salmonid fish and 10.0 µg/l for other freshwater and marine organisms (3).

Several events have occurred since 1974 which make the task of developing acceptable disinfection technology more difficult for all of us. Widespread occurrence of the formation of trihalomethanes in chlorinated waters and recognition of their potential health effects together with passage of the Toxic Substances Act (PL94-469) and the signing by EPA of the consent degree (2) to control 129 priority pollutants within 3 years, have added analytical chemistry and toxicological screening requirements to our evaluation of disinfection alternatives. This is particularly true for potential reuse situations. A significantly expanded analytical methods development program is underway to permit surveying the occurrence of priority pollutants in municipal raw wastewaters, process influents and effluents, and sludges. Recommended analytical methods should be available by the first of November, 1978. The Health Effects Research Laboratory, EPA, Cincinnati, is currently evaluating a variety of toxicological screening tests which may be useful in evaluating the efficacy of alternative disinfectants. A recent paper by Bull, Kopfler and McCabe (1) describes these tests, which I have listed for your information.

ACUTE TOXICITY	- MEDIAN LETHAL DOSE (LD_{50})
MUTAGENICITY	- AMES TEST: *Salmonella typhimurium* strains (bacteria)
	SRI TEST; *Saccharomyces cerevisiae* (yeast)
CARCINOGENICITY	- *IN VITRO*

	MAMMALIAN CELL CULTURE WITH TRANSFORMED CELLS INJECTED INTO MICE TO NOTE TUMOR PRODUCTION
	-SKIN TUMOR RESPONSE IN SENSITIZED MICE (SEN-CAR MOUSE)
	-*IN VIVO* ASSAY USING NEONATAL RATS
TERATOGENICITY	-FEEDING OF PREGNANT RATS AND NOTING MORPHOLOGIC CHANGES IN THE NEW-BORN

Since 1974, the disinfection program has spent approximately $3 million on projects to develop and test alternative disinfection approaches. Many of the facilities involved are "among the first of their kind" treatment plants. In this category I would include: the Estes Park, Colorado, ozonation with air facility; the Meander, Ohio, ozone with oxygen facility; and, the Northwest Bergen County ultraviolet light treatment facility. Obviously, most of our limited resources are used to monitor and evaluate performance rather than pay for capital facilities.

The amendments to the Clean Water Act (PL95-217) which passed last Fall, include a provision for innovative and alternative process or system designs which permits, after October 1, 1978, 85% construction grant financing of the capital requirements and provides for a 100% replacement or modification guarantee. To qualify as innovative technology, a process must save 15% of the total life costs or 20% of the energy requirements compared to conventional technology. This provision illustrates two other significant elements of concern in comparing disinfection alternatives-energy utilization and total treatment costs. Comparisons cannot be made accurately unless the same endpoint or treatment objective is stated. This brings me to my final point. In reading through disinfection literature I am always impressed with the number of variables that need to be recognized, and the necessity of their measurement or identification to permit meaningful comparison of results. The following list may not be all inclusive but it serves to illustrate my point.

DISINFECTANT — type (chlorine), form (monochloramine)

DOSAGE — APPLIED - DISINFECTANT DEMAND = EFFECTIVE DOSAGE

QUALITY OF THE FEED WATER (AND COST IF A NECESSARY PRETREATMENT REQUIREMENT FOR A PARTICULAR DISINFECTANT)—Suspended solids, color, COD, pH, NO_2, NH_3, H_2S.

BACTERIOLOGICAL QUALITY MEASUREMENT — indicator (coliform, MPN, MF), pathogen (bacteria or virus [wild or cell cultured]), density objective, point of measuring effluent quality, opportunity for regrowth or photoreactivation, influent density effect on % removal vs. number remaining.

CONTACTOR — mixing conditions (GT), type (pressure or open), geometry (length to width ratio), real vs. theoretical detention time.

My purpose in raising the issue of variables and comparable treatment objectives is to encourage more complete descriptions of your evaluations and thereby permit more meaningful comparisons and the rational assignment of pre- and post-disinfection process costs when comparing disinfectants. Examples might be the cost of chemical clarification and filtration to meet a 2.2 MPN/100 ml coliform disinfectant objective or the reaeration costs to meet a dissolved oxygen requirement for a dechlorination facility.

I hope you experience an enjoyable and worthwhile symposium.

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1. Bull, R. J., et al. 1978. Toxicity and Mutagenic Effects of Organics. Presented 1978 Annual AWWA Conference, Atlantic City, N.J.

2. *Natural Resources Defense Council* vs. *Train*. 8 ERC 2120 (D.D.C. 1976).

3. Quality Criteria for Water. 1976. U.S. Environmental Protection Agency, Washington, D.C. 20460.

DISCUSSION

DR. HARVEY ROSEN, *Union Carbide Corporation:* I would just like to reiterate your last point. I think it is very important.

Recently, in a National Academy of Sciences study,

investigators had been trying to collect information to do meaningful comparisons among different disinfectants as well as comparisons using a single disinfectant in different quality waters. They are discovering that, although there are thousands and thousands of reports dealing with these studies, lack of quality in the reporting is evident. Certain specific information, needed to determine the validity of the results, is missing. This is becoming very important in terms of all the money that is being spent in this area since results that can be used and understood by everybody on a common basis are not available.

SECTION 4. ULTRAVIOLET LIGHT

13.
UTILITY OF UV "DISINFECTION" OF SECONDARY EFFLUENT

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INTRODUCTION

The criterion utilized in these studies to determine the adequacy of the "disinfection" level achieved was a fecal coliform content of 200/100 ml. Fecal coliforms comprise only a part of the total coliform group, and since some members of the coliform group are acknowledged pathogens, we believe that some caution and understanding should accompany the use of the terms "disinfection" or "disinfected". There is also the matter of the Glossary (2) definition of disinfection which excludes viruses, thus reinforcing the need to exercise caution and understanding.

At the onset of this project, the factors that we thought would be among the most important of the many confounding variables (other than the absolute number of fecal coliforms and the ultraviolet dose) were total suspended solids, turbidity, and probably the transmissability at 254 nm. Our subsequent experience taught us that over the range of suspended solids (5-50 mg/l) and turbidity (0.5-12 Ntu) that we encountered, these two quality parameters had relatively little influence on the results. Transmissability, however, emerged as quite important, and furthermore was observed to be a factor of the operation of the biological treatment facility — a complete-mix activated sludge system.

This project was conducted over a 16-month period at the Dallas Water Reclamation Research Center by personnel from Dallas' Water Utilities Department, the Civil Engineering Department of Texas A&M University, and the U.S. Environmental Protection Agency. Detailed descriptions of the Demonstration Plant at this Facility have been published (1). Two ultraviolet (UV) generating units were used (3). First, a Kelly-Purdy unit originally designed for use in shellfish depuration studies (3), and later, a proprietary unit loaned by Ultraviolet Purification Systems, Inc., located in Scarsdale, N.Y. The UV units were applied directly to final effluent, to mixed-media filtered effluent, to dual-media filtered effluent, to tertiary clarified effluent, to chemically clarified effluent, and to tertiary clarified plus dual-media filtered effluent. Additionally, following the protocol used in previous work (5), and in full recognition of its limitations, three virus seeding experiments were conducted using poliovirus type 1 and F2 coliphage.

An attempt was made by the plant operational staff to utilize as a baseline of biological operation the production of a highly nitrified effluent, i.e., ammonia-nitrogen (NH_3-N) effluent concentrations of <1 mg/l as N. We failed all too often to achieve this level because of fragile oxygen transfer systems and a gross operator failure. Actually, three different oxygen-transfer systems were used during the study, two proprietary types and one inadequate home-made type. The operator failure occurred when he left a waste sludge valve wide open all-night long — in the cold month of December.

A stringent sampling program was followed in these studies. The unit processes prior to the UV unit were sampled on a flow-composited basis and analyzed by *Standard Methods* (7) procedures. The UV units were grab sampled at 11 AM and 4 PM — the times when the diurnal curve for organic content was maximum at the Dallas facility. Separate samples were taken for chemical and microbiological analyses. The membrane filter procedure was used with the Kelly-Purdy unit and the MPN procedure with the Ultraviolet Purification Systems unit. Eight paired irradiated samples were run for comparison using both methods. The

mean log results were 2.07 by MF and 2.01 by MPN showing essentially no difference between the two.

Kelly-Purdy Unit Results

The Kelly-Purdy (K-P) ultraviolet light disinfection unit (Figure 1) consists of a shallow-tray exposure chamber 185 cm (6 ft.) long, 92 cm (3 ft.) wide, and 9.2 cm (3-5/8 in.) deep. Flow passes through the tray underneath 13 30-watt UV lamps (G30T8). The influent flow was measured with an undulating disc meter, and water depth was controlled by changing the elevation of the effluent weir.

Figure 1. Kelly-Purdy UV Unit (lid open) and Ultraviolet Purification Systems Model EP-50 (on blocks on the floor)

Five runs were made with the K-P unit ranging from 2-1/2 hrs. long to 24 days. The first three runs were applied directly to activated sludge effluent, the last two to a mixed-media filtered effluent. In the first three runs, flow rate was varied from 0.32 to 1.58 l/sec (5-25 gpm) and depth from 2.54 to 5.08 cm (1 to 2 in.). The microbiological results of the samplings showed no association with flow and little with depth, but more importantly, the effluent quality did not achieve the fecal coliform level sought, 200 fecal coliforms per 100 ml. However, the results were definitely promising, giving over-all reductions in fecal coliform concentrations of 2-3 logs. Figure 2, for example, illustrates the results obtained during Run K3. The theoretical detention time for this run was 43 seconds and the theoretical dose 32,000 μwatt-sec/cm^2. Table 1 shows for each run the types of effluent treated, the time and duration of each run, and the average COD and NH_3-N content of the composited samples. For run K3, the effluent composited samples averaged a COD of 43 mg/l and NH_3-N of 1.1 mg/l which indicates good biological treatment — although not quite as good as was sought (NH_3-N $<$ 1.0 mg/l). COD: BOD_5 ratios for this effluent generally average 2.7:1, hence, a BOD_5 of about 16 mg/l is suggested.

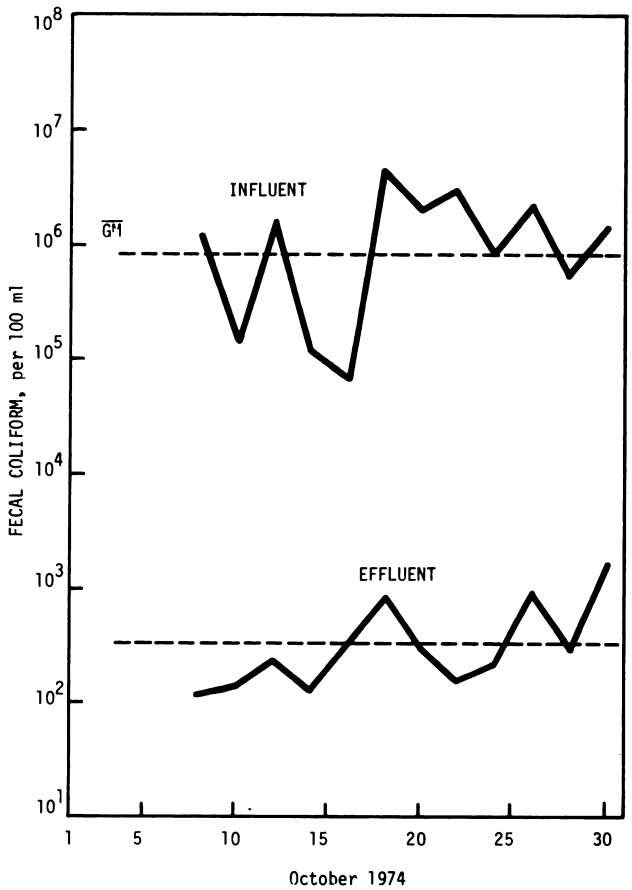

Figure 2. Fecal coliform data for Run No. K3

One of the difficulties encountered with the K-P unit was the accumulation of solids in the tray. Hence, for the last two runs made with that unit, the final effluent was filtered through a mixed-media filter (anthracite-sand-garnet, Neptune-Microfloc Co.) prior to UV irradiation. The microbiological results of Run K4 (Figure 3) show that all samples met the 200/100 ml fecal coliform limit. For Run K5 the flow rate was increased from 0.96 l/sec to 1.4 l/sec (15.25 to 22.2 gpm) thus decreasing the theoretical detention time to 29 seconds. More importantly, however, it was during this run that the operation failure occurred. The result was that only a couple of effluent samples met the fecal coliform limit.

Ultraviolet Purification Systems Unit Results

It was at this point that the Ultraviolet Purification Systems (UPS) firm loaned their Model EP-50 unit (Figure 1). This unit consists of a 53.6 liter (14.2 gal.) stainless steel cylindrical chamber that houses nine longitudinally-mounted 40-watt UV lamps. Each lamp is enclosed by a quartz sleeve and has an individual ammeter mounted on a control panel. The unit is

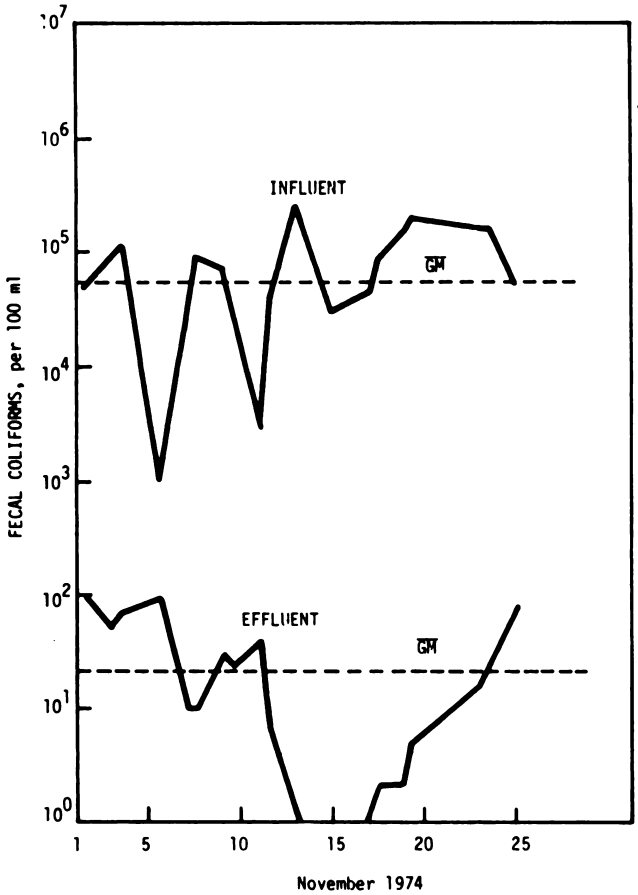

Figure 3. Fecal coliform data for Run No. K4.

equipped with a water quality meter which measures UV light intensity on a unitless scale. Hence, all UV intensity measures in this study were made with an IL 500 radiometer manufactured by International Light, Inc., Newburyport, Massachusetts, through a quartz window on the side of the tank.

The location of the nine UV lamps with respect to the system geometry is shown in Figure 4 which also shows lines of equal intensity calculated for the unit. Flow enters from above at a right angle to the lamps at one end, moves parallel to the lamps toward the other end, and exits at the top at the far end.

The quartz sleeves were cleaned with a solution supplied by the manufacturer. Each run was commenced with a freshly cleaned unit. The cleaning frequency required to keep the system operating at peak efficiency can be expected to vary with the quality of the effluent, but intervals of two to three weeks seem reasonably consistent with the data and temperatures observed.

A total of eight runs were made with the UPS unit varying from 2 days duration to 127 days. All effluent samples of Run Ul of 13 days duration applied to straight secondary effluent at a flow of 1.8 l/sec (29 gpm), resulting in a detention time of 29.8 seconds, met the 200/100 ml fecal coliform criterion (Figure 5). Runs U2 and U3 applied to tertiary settled effluent and to tertiary settled dual-media filtered effluent were even more effective — the latter is shown in Figure 6.

Run U4 was the 2-day run and was short because we only had a 2-day supply of chemicals. Ferric chloride was applied in the Densator (Infilco Co.) prior to UV

Run No.	Type of Effluent Treated	Date Run	Length of Run, days	Composite COD mg/l	Sample NH_3-N mg/l
K1	Secondary effluent	7/26	2½ hrs.	42	1.1
K2	Secondary effluent	9/14-10/7	23	42	3.2
K3	Secondary effluent	10/8-10/30	23	43	1.1
K4	Mixed-media filtered effluent	11/1-11/25	24	14	0.2
K5	Mixed-media filtered effluent	12/7-12/27	20	92	10.1
U1	Secondary effluent	1/23-2/5	13	33	2.2
U2	Tertiary clarified	2/7-2/17	10	35	1.8
U3	Clarified and dual-media filtered	2/19-3/3	12	42	1.5
U4	Chemically clarified	3/6-3/7	2	—	0.2
U5	Secondary effluent	3/8-7/14	127	54	7.1
U6	Dual-media filtered effluent	7/15-8/3	19	107	12.8
U7	Dual-media filtered effluent	8/8-10/5	58	62	4.6
U8	Secondary effluent	10/7-11/30	54	63	5.4
V1	Secondary effluent	4/22	—	46	1.8
V2	Secondary effluent	5/13	—	37	4.4
V3	Secondary effluent	6/26	—	75	10.3

TABLE 1. TYPES OF EFFLUENTS TREATED, TIME AND LENGTH OF RUNS, AND COMPOSITE SAMPLE COD AND NH_3-N MEAN CONCENTRATIONS.

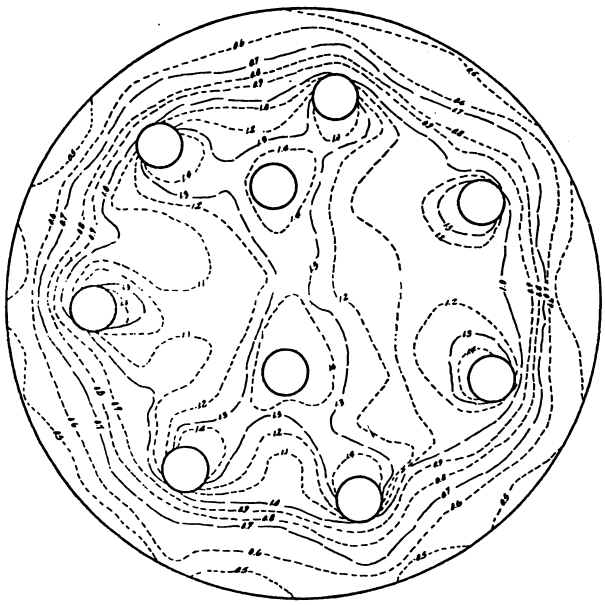

Figure 4. Isointensity patterns for UPS exposure chamber.

irradiation. Geometric mean fecal coliform values of the effluent were less than 4.3/100 ml with a maximum of 33/100 ml.

The shortest UPS run was followed by the longest.

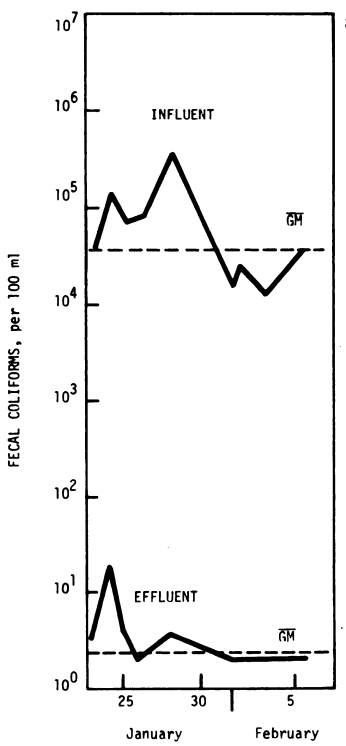

Figure 5. Fecal coliform data for Run No. UI.

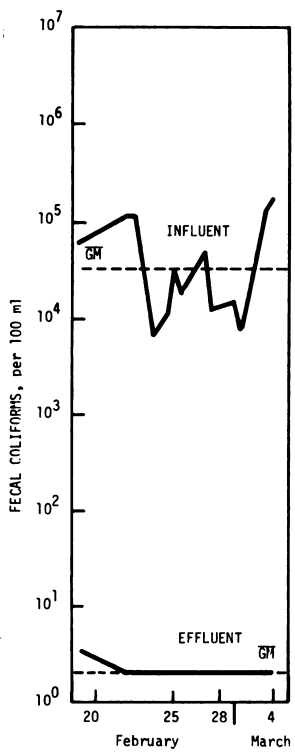

Figure 6. Fecal coliform data for Run No. U3.

Run U5 lasted for 127 days. It was during this run that the oxygen transfer system commenced to fail and many heartaches were encountered in trying to limp along. The fecal coliform limit during this period was not often achieved.

The proprietary oxygen transfer equipment was removed and a home-made diffused air system substituted. It was inadequate to achieve the nitrification desired, but Run U6 using dual-media filtered effluent was nevertheless conducted. The fecal coliform limit was achieved about half the time (Figure 7).

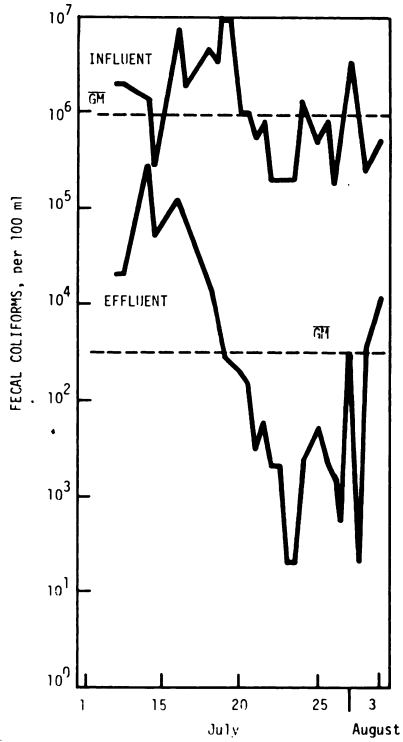

Figure 7. Fecal coliform data for Run No. U6.

In Run U7, new Penberthy oxygen transfer equipment had been installed and the UV system was applied once again to a dual-media filtered effluent. Most of the effluent samples met the fecal coliform limit but, as compared to the earlier runs, the UPS unit during Run U7 was operating near its design hydraulic capacity of 3.1 l/sec (49 gpm) giving a theoretical contact time of 17.3 seconds.

The last run, U8, was made at the maximum flow rate attainable, 3.2 l/sec (51 gpm) which gave a theoretical contact time of 16.8 seconds, and using straight final effluent. Most of the fecal coliform samples exceeded the limit desired during this run (Figure 8). Nitrification was still incomplete — NH_3-N averaging 5.4 mg/l. The resulting effluent COD of 63 mg/l, although higher than when better nitrification is occur-

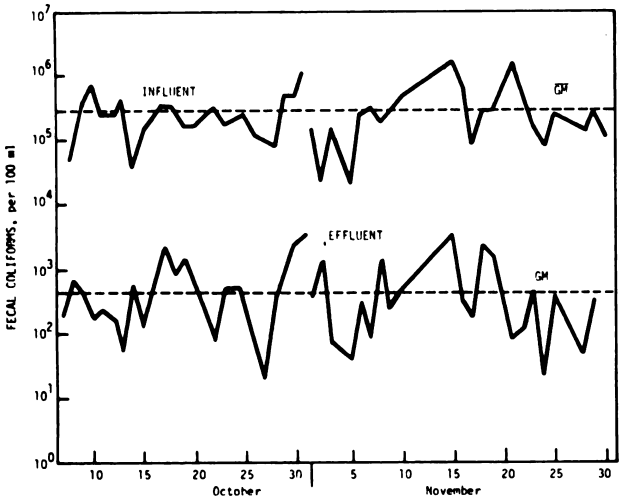

Figure 8. Fecal coliform data for Run No. U8.

ring, is still at a reasonable level for the usual activated sludge effluent. For example, applying the COD: BOD_5 ratio of 2.7:1 results in an effluent BOD_5 of about 23 mg/l.

Virus-Seeding Experiments

The three virus runs were each made at four flow rates which provided exposure periods of 11.4 to 85 seconds (theoretical). The runs were made during the period of equipment difficulties when effluent COD values ranged from 37 to 75 mg/l. The highest COD waters gave the poorest microbiological results, but little difference was observed between phages and poliovirus. The phages ($y = 1.59x - 4.68$, x = log calculated UV dose in μ watt-sec/cm^2, y = log reduction) were possibly a little more resistant than the poliovirus ($y = 1.62x - 4.48$), and both viruses, in turn, were more resistant than the fecal coliforms ($y = 1.48x - 3.21$). Figure 9 shows fecal coliform log reductions as a function of the log of the calculated UV dose. Figure 10 shows the same curve for coliphages. The correlation coefficients for these curves were fairly low (0.70-0.72); hence, additional research is warranted. The no effect dose (determined by setting $y = 0$ and solving for x) ranges from 148 (fecal coliforms) to 871 (coliphages) μ watt-sec/cm^2.

CONCLUSIONS

During the course of these experiments, we once again observed that high quality effluents (low COD's) were associated with nitrified operation, a relationship that is even more marked after an adsorption process application (6). Our plots of turbidity vs. transmittance, and suspended solids vs. transmittance yielded shotgun patterns (4). On the other hand, transmittance and COD correlated at 0.76 and transmittance and TOC at 0.95.

Both TOC and COD correlated well with effluent NH_3-N, COD at 0.97 and TOC at 0.88 (Figure 11). The result is the seemingly unlikely correlation of effluent NH_3-N content with transmittance at $r = 0.81$.

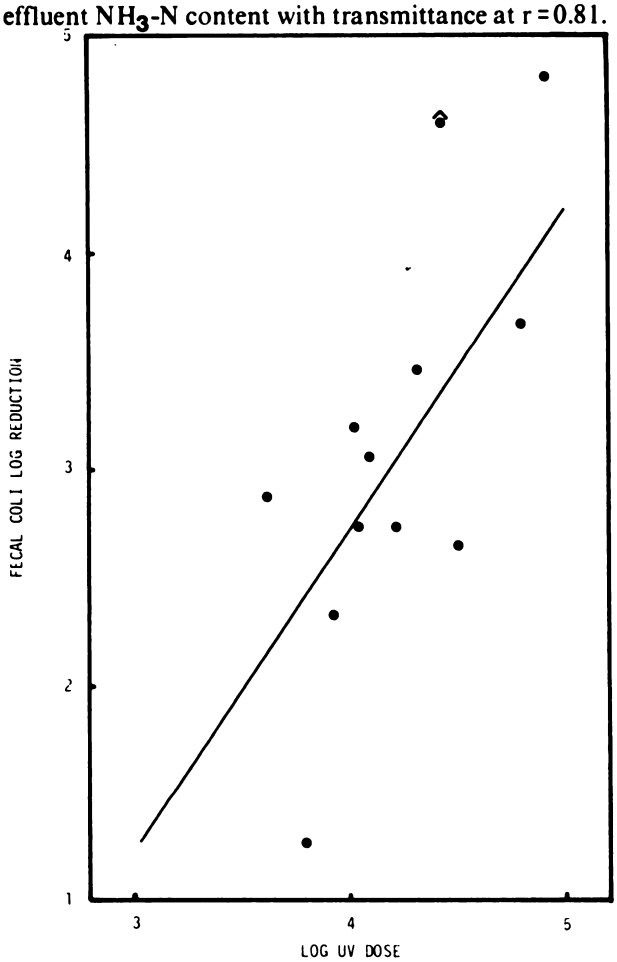

Figure 9. Fecal coliform reduction vs. UV dose

Additionally, highly nitrified operation results in lower coliform concentrations. Figure 12 reflects this observation. The data in Figure 12 compare the average activated sludge effluent NH_3-N concentrations for each K and U run of Table I with the mean log fecal coliform content entering the UV unit. The latter value is impacted by the additional unit processes employed such as filtration or tertiary settling. For example, the lowest fecal coliform value on Figure 12 (6.3×10^3) was obtained during Run U4 when chemical clarification was utilized. In spite of these additional treatments, a relationship is apparent. A correlation coefficient was not calculated because two points (⊖) are less-than values and one point (⊕) is a greater-than value, and also because of the ameliorating effect

of the additional treatments on the coliform values.

Light-dark experiments were performed during the course of these studies (6). UV irradiated effluent was directed into two parallel and baffled chlorine-contact basins (without chlorine addition) providing a detention period of about an hour. One basin was covered with black plastic sheet, the other was open. Statistical evaluations of the data showed significant (at a 95% level) regrowth of total coliforms but not of fecal coliforms — although the latter also showed higher effluent concentrations.

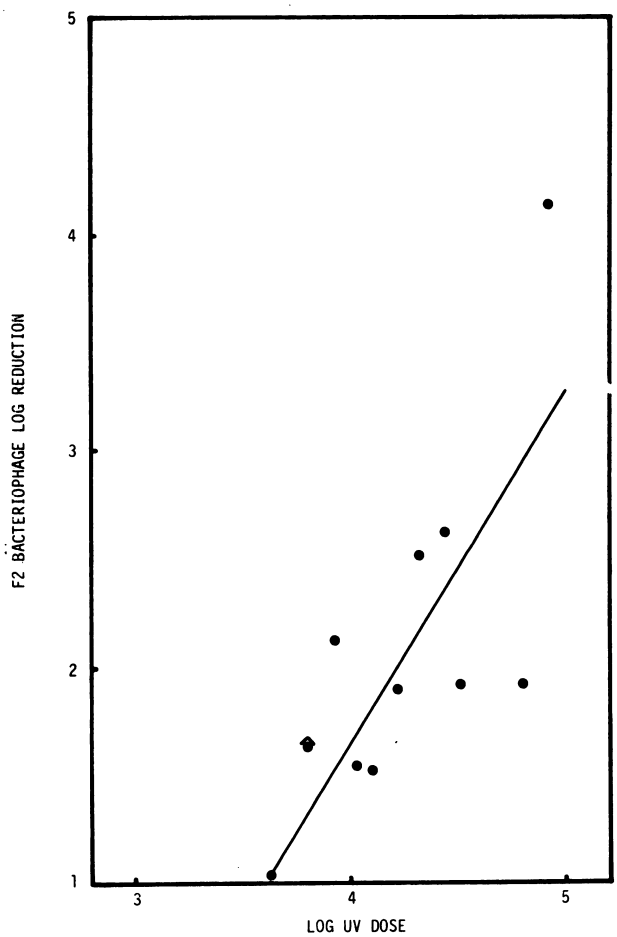

Figure 10. Coliphage reduction vs. UV dose

Clearly, ultraviolet irradiation of secondary effluents is a viable alternative "disinfection" procedure for achieving a 200 fecal coliforms/100 ml effluent criterion. Like ozone, however, UV is quite sensitive to effluent quality variations and will have to be designed to accommodate the expected variations.

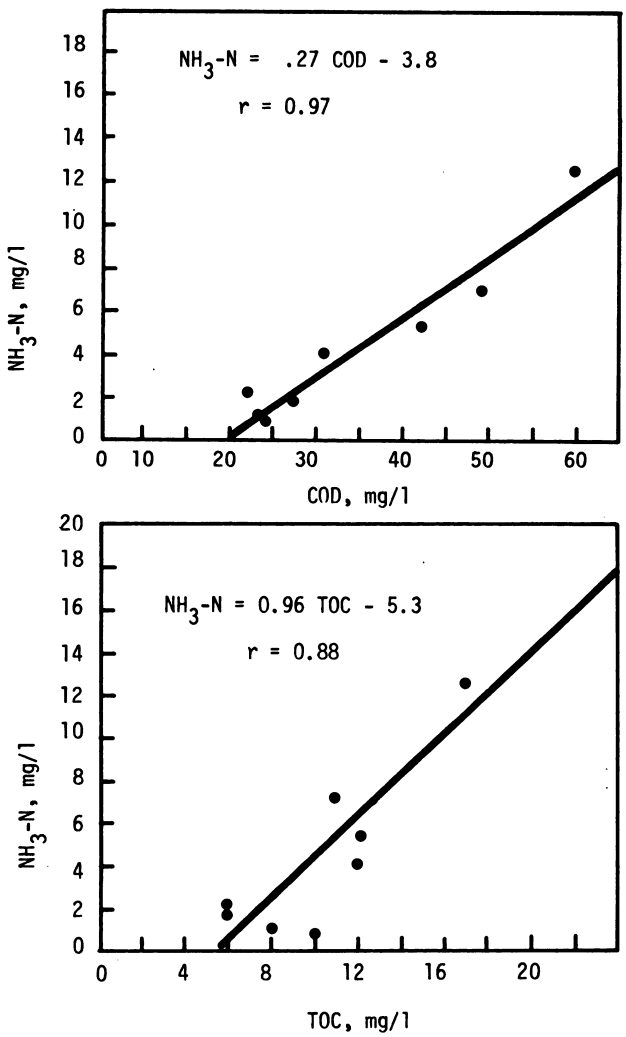

Figure 11. Correlations between ammonia-N and COD and TOC.

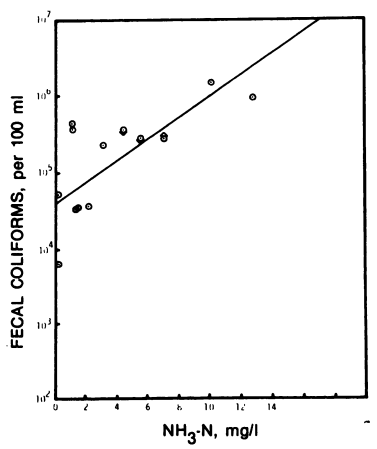

Figure 12. Relationship of Fecal Coliform Concentration to NH_3-N Content of Activated Sludge Effluent

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DISCUSSION

MR. DeSTEFANO, *Riddick and Associates:* Did you do any correlations between UV transmittance and coliform counts?

DR. WOLF: I will have to check that.

MR. DeSTEFANO: It seems to me the correlation between the ammonia and the coliform counts are more correlation between the transmittance and the counts rather than the ammonia itself.

DR. WOLF: I will check that. I have the report with me.

MR. SEVERIN, *FMC Corporation, Chicago:* Did you change your flow rate on this unit during any fecal coliform runs?

DR. WOLF: Yes.

MR. SEVERIN: Did you find a straight line relation with time or did your curves taper off?

DR. WOLF: I had one transparency I was going to show in which we maintained a constant flow rate with the Kelly-Purdy unit and doubled the depth. There was an increased effectiveness of UV due to the increased exposure time which resulted, on the order of about one log. We did vary flow, and flow enters into the UV dose very much by affecting the exposure period. Does that answer your question?

MR. SEVERIN: The reason I am asking is that I have done tests with the EP 50 unit, and found that in primary and filtered secondary effluents there was a linear relationship between survival and $t^{1/3}$ and I am trying to explain this to myself.

DR. WOLF: What kind of factor?

MR. SEVERIN: Time to the one-third.

DR. WOLF: Time to the one-third. I will have to check that out.

MR. SEVERIN: Also, I would like to agree with your suspended solids information. I was able to put all these on a single line, and the indication that you can use a single line for a log reduction with primary effluent as well as with dual media filtered effluent would indicate that suspended solids are not really interfering in the range up to say 100 mg/l.

DR. WOLF: Good. That one has been worrying me right along.

MR. FLUEGGE, *Carborundum Company:* I have tried to go through some calculations in determining what dosages of ultraviolet light are to the wastewater. Looking at your numbers it looks like you have assumed for one thing only one pass of the photon, that the photon is not reflected off the walls or not absorbed by the bulb and then readmitted. Is that what you have done, or did you try to take that into account through measurements?

DR. WOLF: When you get into photons, you are getting out of my field, but we went through two basic types of calculations. This gave us problems all the way through. With the Kelly-Purdy unit we could put the sensing meter on the bottom of the tray, move it along different locations, integrate it and so forth. With the UPS unit we could not get inside to do these things. So we had to do it on a calculated basis, and if you do it by a calculated basis you have some problems because you have a slime buildup on the lamps. It is very slow initially, but once it starts it develops very rapidly, and you also have the problem on the inside of the quartz window.

MR. FLUEGGE: You mean between the bulb and the outer casing.

DR. WOLF: Yes, and so we are relatively insecure with respect to our measurements. When we did the Kelly-Purdy test, for example, we did not even have the UV measuring device at the time, but we went ahead and did it anyway thinking we could come back and measure it, that perhaps there would not be that much deterioration in the bulbs, but when we got into this study it is not as simple as we thought originally. The extinction coefficient becomes terribly important,

and so we could not run the extinction coefficient on the early examples any more, so we assumed an extinction coefficient for those particular studies.

MR. FLUEGGE: All of your data then would indicate a constant light source intensity. Is that correct?

DR. WOLF: That is correct.

DR. JOHNSON: Your iso-intensity lines on your diagram there show very low values along the wall. You did consider reflections off the wall.

DR. WOLF: That is a good question. I believe that is correct. I will have to check that out.

QUESTION: Question on maintenance. These units look like they would be maintenance nightmares on a large scale, cleaning them off, especially if you could not easily replace the bulbs or get inside these units. Is that true?

DR. WOLF: There is a lot of proprietary people here and I will let them answer that question, but one of the things that we wanted to do in this study was some cost work with respect to an application in Dallas, and we came up with a pretty large unit for application to Dallas. Furthermore, we just did not have enough information to make a reasonable estimate of cost. So we did not even bother to do it. I also thought we could store the water and get some off-peak power rates and then disinfect during the off-peak power periods, but as I found out the Dallas Light and Power gives power so cheaply to the Dallas Water Utility that they would not even entertain off-peak rates.

QUESTION: Was the smaller unit rated at the same capacity as the large one?

DR. WOLF: It was higher capacity. Almost double.

MR. ELLNER, *Ultraviolet Purification Systems:* Just one point here: the gentleman mentioned the fact earlier that the two units were rated similarly. I think Harold will point out that there is a considerable difference in the UV generators even though you had almost a similar number of lamps in the Kelly-Purdy. There are differences in UV sources, and the ratings of the 30 watt or 40 watt did not refer to UV output but to electrical input, so you cannot make any correlation.

The two quick points that I wanted to make were: there is a tendency to try and describe the acceptability of an effluent based upon visible light determinations, terms such as color and turbidity which are measurements of visible light. I think Harold mentioned earlier in his statement that those factors just do not apply to ultraviolet. You can have situations with very high visible light transmittance but very low UV transmittance, and you can have the opposite under certain circumstances. The point that I would like to make is the combination of all of the factors can be measured with just one measurement, and that is the UV transmittance at 254 nm on a spectrophotometer. That would take into consideration all of these variables, and I was curious, Harold, whether you had some of those ratings such as UV transmission to correlate.

DR. WOLF: Yes, we do, Sid. They are in this report.

MR. ELLNER: And the only other comment at this time is that you will agree that the dosages are theoretical. Would you hang your hat on any of those dosage numbers that appear in the paper?

DR. WOLF: No, I am rather reluctant.

14.
UV DISINFECTION OF SECONDARY EFFLUENT

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ABSTRACT

Ultraviolet disinfection studies are being conducted on a pilot scale using two commercial 230–285l/min (60-75 gpm) units. Potassium ferrioxalate actinometry is used to measure UV dosages. Log reductions of Escherichia coli *in buffered tap water were compared to dosages measured both by the actinometry method and by multiplying the ultraviolet intensity times the retention time. Actinometry dosages were found to have the advantage of being directly related to the average depth of fluid through which the light penetrates and the average intensity within these multiple lamp units. Photoreactivation in UV treated samples exposed to 45 minutes of sunlight caused an average 1.4 log recovery in total coliforms at 25° C. Lower photoreactivation was found at a lower temperature and at a higher UV dose in one of the units. A study of the effects of water quality parameters and unit design on UV disinfection of filtered and unfiltered 2° effluent is still under investigation. Log reductions of total and fecal coliforms are being influenced primarily by the different flow patterns within the units rather than by variations in the parameters or the UV dosages applied. Short-circuiting of fluid through one of the chambers appears to be responsible for this observation.*

INTRODUCTION

Chlorination has to date been the most widely utilized disinfection process because of its low cost, simplicity of operation, and ability to provide residual protection. However, in light of the suspected carcinogenic properties of chlorinated hydrocarbons and the undue stress of chlorine residuals on stream ecology, the use of ultraviolet disinfection is being seriously considered as an alternative. Further justification arises from the fact that chlorination does not reduce wastewater virus concentrations effectively.

Ultraviolet radiation, being a physical agent, is not believed to cause the formation of toxic chemical substances. Also, its germicidal effect is not limited primarily to bacteria. UV absorption by nucleic acids causes disruption of the DNA or RNA molecules which are vital to all organisms including viruses. This suggests that UV radiation should be as effective a disinfectant of the viral component of wastewater as it is of the bacterial component.

In the present study, some aspects of the UV disinfection process which are still poorly understood are under investigation. These are the use of chemical actinometry to measure UV dosages, the occurence of photoreactivation in UV treated samples exposed to sunlight and the effects of water quality parameters on

the UV disinfection of filtered and unfiltered secondary effluent.

EXPERIMENTAL SYSTEM

UV disinfection of filtered and unfiltered secondary effluent is being conducted on a pilot scale in Durham, North Carolina at the city's 3.8 x $10^3 m^3/d$ (1.0 mgd) Sandy Creek contact stabilization plant. The plant produces an effluent of a quality comparable to a typical activated sludge plant. For the unfiltered experiments, water is drawn directly from the plant effluent. For the filtered runs, effluent is diverted into one of three downflow multimedia filters before entering the UV units. Water leaving the units is pumped into a large storage tank where it is subsequently used as backwash water for the filters.

The project employs two commercially available UV sterilization units. Unit No. 1 included an 8 liter cylindrical tank containing 14 25-watt, 38 cm (15 in.) mercury low pressure lamps arranged around the upper two-thirds of the chamber. The lamps are packed closely together to reduce the width of the fluid through which the UV radiation must penetrate. This is referred to as a thin-film design. Water enters the bottom of the unit through a distribution tube and flows up and over a central shaft in somewhat spiral pattern before exiting at the bottom again. Dye studies, shown in Figure 1, indicate that a significant amount of fluid short-circuits the chamber, while other portions are retained for excessively long periods. The former can be seen by noting that the actual retention times are shorter than V/Q, the theoretical retention time.

Unit No. 2 features an 11 liter cylindrical tank housing six 40-watt, 91 cm (36 in.) low pressure mercury lamps. The lamps are not as closely spaced as those in unit No. 1, and thus the reactor operates in a "thick-film" mode. Flow through the chamber is essentially linear with water entering and exiting each end of the unit from the top. Four disk shaped baffles are included to insure adequate mixing. The results of dye studies, shown in Figure 2, indicate a moderate amount of dispersion in the chamber but no short-circuiting or tailing.

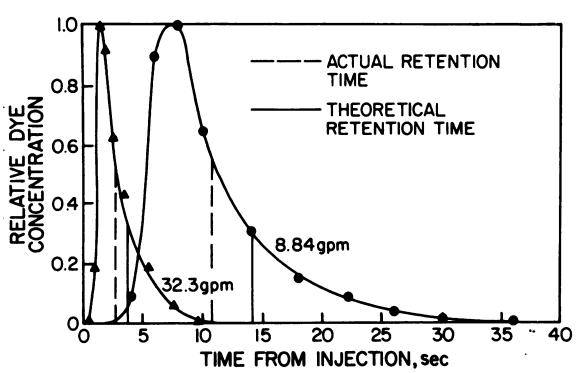

Figure 1. Unit No. 1 dye studies

For both units, the voltage input to the lamps is adjusted via a Variac. Intensity readings are taken at 254 nm with an International Light IL-500 research radiometer calibrated to standards traceable to the National Bureau of Standards. Measurements are made approximately 5 cm (2 in.) above quartz windows situated at the wall of both reactors.

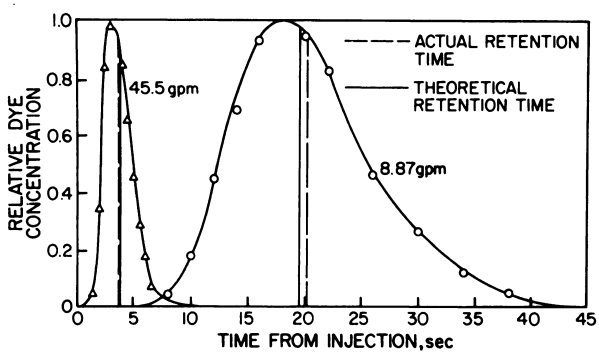

Figure 2. Unit No. 2 dye studies

ACTINOMETRY STUDIES

INTRODUCTION

UV light exhibits a maximum germicidal effect on microorganisms at approximately 265 nm. In most theoretical investigations, the log of the ratio of influent to effluent microbial counts is essentially linear with UV dosage. In wastewater studies, these dose-response curves are usually linear at first, but as dosages increase to more or less saturation levels, the curves begin to tail off before eventually assuming a slope of zero.

A lack of consistency in dose-response data, however, is a problem which is caused by the method used currently to determine UV dosages. Before UV light can be considered a viable alternative to chlorine, a means of determining a dose which more accurately reflects the actual amount of radiation to which the microorganisms are exposed must be found.

Presently, dosages are usually determined by multiplying an intensity measured at the wall of a reactor

times the retention time inside the unit. Unfortunately, intensity readings are more dependent upon the particular location of the detector in relation to the lamps than on the actual amount of radiation supplied to the unit. Secondly, the retention time does not describe the actual flow patterns within the unit such as the degree of mixing and the amount of short-circuiting. The geometry of the reactor is a very important variable in UV disinfection, which is almost completely ignored by this method of determining dosages. There is no way in which the relative effectiveness of two different units can be accurately predicted.

There are a number of factors that need to be considered in attempting to obtain a true measure of the average amount of UV radiation that reaches the microorganisms. Ideally, one would prefer a dose which takes into account variables such as the transmission of the fluid, the amount of reflections off the wall, the degree of scattering, the average distance between the lamps, and so forth. Various methods for calculating average intensities have been presented in the literature which deal with some of these factors. These procedures have eliminated the bias due to the position of the UV detector in relation to the lamps and have also taken into consideration the average depth of fluid.

Another way in which a more meaningful UV dose may be obtained is through the use of potassium ferrioxalate actinometry. Solutions containing 0.006N ferrioxalate ion in 0.1 N H_2SO_4 undergo a photochemical decomposition of known quantum yield, Φ, upon exposure to UV light. In the process, ferric iron is reduced to the ferrous form. Because the solution absorbs essentially 100% of the UV emitted by the lamps, and because

$$\Phi = \frac{\#\text{ molecules of product formed}}{\#\text{ photons absorbed}}$$

a measurement of the quantity of ferrous iron produced can be converted to an average number of photons emitted per volume of solution. Thus, dosages are measured in units of energy per unit volume rather than in the customary units of energy per unit area. In the present study, dosages measured in this way and in the conventional fashion were compared to log reduction of *Escherichia coli* in the two units to determine what advantages actinometry might hold over the latter method.

METHODS

The potassium ferrioxalate solutions were prepared in a 1.3 m^3 (350 gal.) polyethylene tank. From there they were pumped through either of the two units at flow rates ranging from 76-285l min. (20-75 gpm). Samples were collected in brown bottles at three lamp voltage settings for each flow rate tested. In addition, two blanks were collected ahead of the units. To insure that control over the lamps' output was maintained from one experiment to the next, intensity readings were obtained in tap water prior to each run. Intensity measurements could not be made in the actinometry solution itself, as it absorbs all UV light.

Samples were analyzed for ferrous iron spectrophotometrically using 1:10 phenanthroline monohydrate as the colorometric indicator. The exact procedure employed was described by Hatchard and Parker (2). Throughout the analysis, all samples were protected from exposure to light to eliminate any additional photodecomposition of the ferrioxalate ions. The following equation was then used to calculate dosages in μw-sec cm^3.

$$\text{dose} = \frac{[Fe^{++}]_{sample} - [Fe^{++}]_{blank}}{\Phi \times 1000\ ml/l} \times \frac{1.196 \times 10^{11}\ \mu W\ sec}{254\ nm}$$

where $\Phi = 1.25$ @ 254 nm

This calculation is based on the assumptions that 1) the actinometry solution absorbs 100% of the emitted UV radiation and 2) all of the radiation emitted is at 254 nm.

Disinfection studies were carried out by irradiating pure cultures of *E. coli* in buffered tap water over the same range of voltage and flow rates used in the actinometry studies. Organisms were enumerated before and after treatment using the 5 tube multiple-tube fermentation technique as described in *Standard Methods* (1).

RESULTS AND DISCUSSION

Typical results from the actinometry studies are shown in Figures 3 and 4. All curves exhibited some degree of non-linearity, particularly those obtained from unit No. 1. All plots extrapolate to the origin as would be expected except for the dose vs. retention time plots from the first unit. The reason for the exception is probably that actual retention times are significantly shorter than theoretical retention times in that unit.

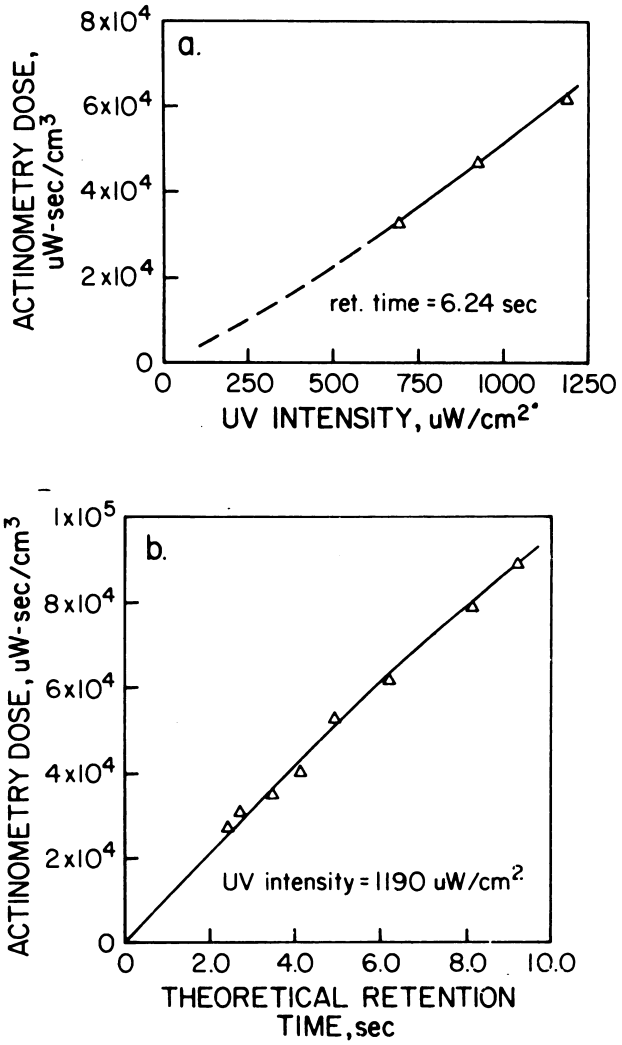

Figure 3. Unit No. 2 actinometry dosages vs. a) UV intensity at reactor wall, and b) retention time

The results of the tap water disinfection studies with pure cultures of *E. coli* are plotted in Figures 5 and 6 vs. the conventional, or intensity times retention time, dose, and the actinometry dose, respectively. Unfortunately, only the tail of the dose-response curve could be obtained because of operational constraints on the system which prevented lower dosage levels from being achieved.

If the actinometry had provided a true measure of the UV dose supplied to the microorganisms, i.e., one that takes into account all of the geometrically related variables such as reflection, short-circuiting and the average depth of fluid, then the two curves in Figure 6 would have been identical. Although they are quite different, there is an even greater lack of similarity between the two curves in Figure 5. Dosages obtained using actinometry appear to control at least some of the factors that are neglected by the conventional dose.

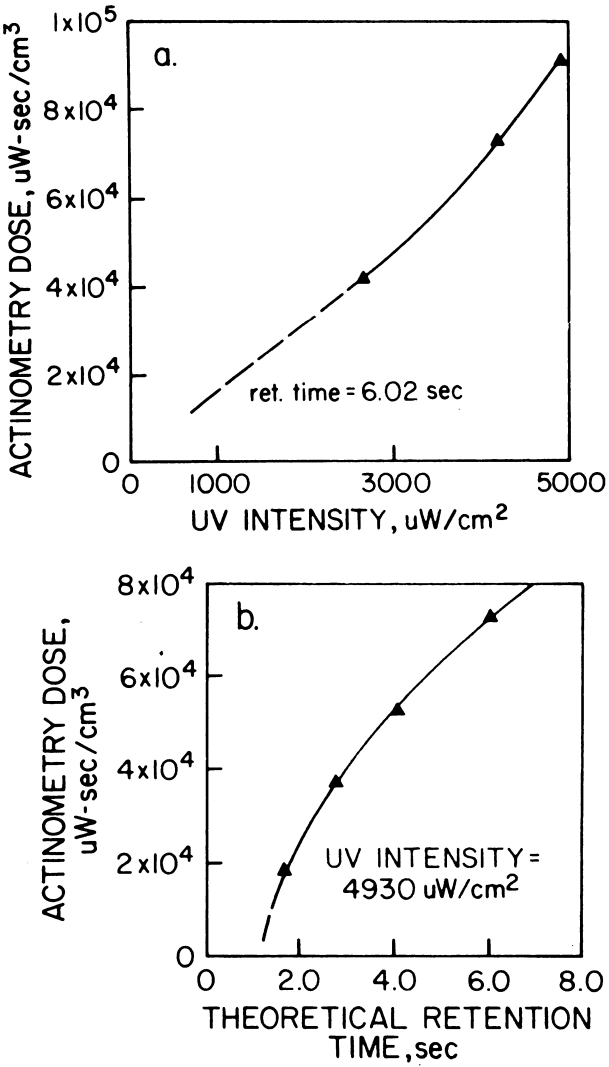

Figure 4. Unit No. 1 actinometry dosages vs. a) UV intensity at reactor wall, and b) retention time

The major difference in the relative position of the curves in Figures 5 and 6 is probably due to the actinometry's elimination of the bias caused by the position of the UV detector. The quartz window through which intensity readings were made was situated much closer to a lamp in unit No. 1 than in unit No. 2. This caused UV intensities and hence conventional dosage measurements on the former unit to be grossly inflated relative to the latter. At a given voltage setting and retention time, the first unit was found to supply a UV dose five times that of the second unit if calculated

using I x t. Actinometry dosages, on the other hand, showed only an increase of approximately 1.6 times.

Actinometry dosages provide a measure of the total number of photons emitted by the lamps per unit volume and time. This dose is directly related to the average depth of fluid through which the light passes if the latter is defined as the·

$$\frac{\text{total volume of unit}}{\text{surface area of lamps}}$$

This is because the total number of photons a lamp emits is proportional to its surface area. The average depth of fluid is an important treatment parameter which actinometry dosage measurements inherently take into account.

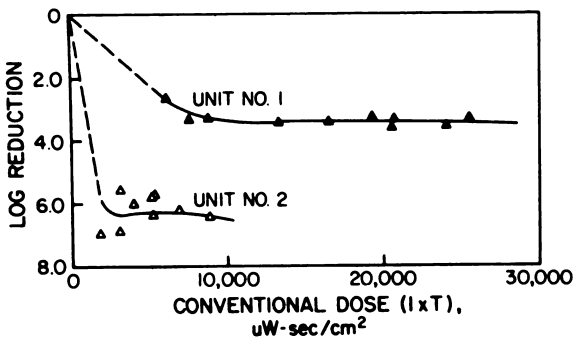

Figure 5. Log reductions of E. Coli vs. conventional dose

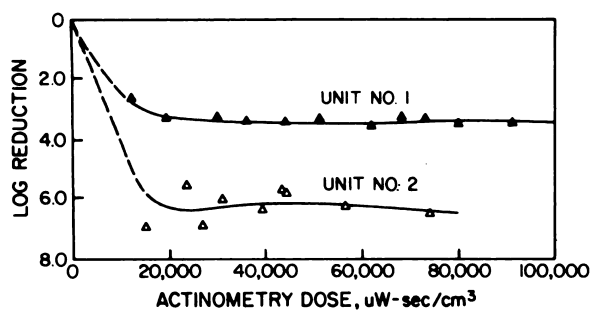

Figure 6. Log reductions of E. Coli vs. actinometry dose

The differences between the two curves in Figure 6 emphasize the failure of the actinometry method to control all of the important variables mentioned earlier; in particular, the degree of short-circuiting in the two units. For example, the first unit was unable to achieve log reductions greater than 3.6 probably because a small percentage of the fluid short-circuited the chamber. This short-circuiting, however, would not be expected to have as significant an effect on actinometry dosages as it would on disinfection efficiencies, which are based on a logarithmic scale.

Actinometry would also not be expected to control variables such as the degree of reflection of UV light off the reactor walls and the configuration of the lamps in relation to the overall unit. This is because the solution absorbs almost 100% of the radiation within a depth of only 3-4 millimeters. Finally, the effects of UV absorbing substances present in the waters to be treated are not considered. For this reason, attempts to correlate actinometry dosages with log reductions of microorganisms in wastewaters of widely varying characteristics are meaningless.

UV dosages measured using chemical actinometry are more useful than those obtained by the conventional method because they are related directly to the average depth of fluid through which the light passes. Although not all of the treatment variables involved are controlled by this method, it is still a potentially useful technique for comparing and calibrating UV disinfection units.

PHOTOREACTIVATION STUDIES

INTRODUCTION

An additional problem may be associated with the use of UV light to disinfect wastewater effluents. A situation may arise where organisms supposedly inactivated by UV radiation may restore their reproductive abilities upon exposure to visible light. Such an event is termed photoreactivation (PR). It has been defined by Jagger (3) as "the restoration of ultraviolet lesions in a biological system with light of wavelength longer than that of the damaging radiation". The repair mechanism of PR is activated upon exposure to light of wavelength between 300 and 500 nm; a major portion is stimulated in the region of 355-385 nm for most microorganisms. A phenomenon such as photoreactivation must be taken into consideration when evaluating the overall efficiency of an ultraviolet disinfection process.

METHODS

Samples of secondary effluent treated and untreated by both units were collected in sterile bottles wrapped in aluminum foil. Flow rates and voltage levels used were comparable to those employed in the actinometry studies. After being placed immediately on ice, the samples were transported back to the laboratory while being kept completely unexposed to light. Sample aliquots were pipetted into petri dishes labelled as follows: 1) influent dark control, 2) effluent dark con-

trol (wrapped in aluminum foil), 3) influent sunlight exposed and 4) effluent sunlight exposed. All dishes, control and exposed, were kept in a constant temperature bath for forty-five minutes in direct sunlight. The intensity of PR light was measured at 15 minute invervals with a General Electric light meter equipped with a glass 320-390 nm filter. After completing the exposure, the samples were immediately placed in a dark, 4°C refrigerator until further use within the hour. Total coliforms were enumerated using the membrane filter technique as recommended in *Standard Methods* (1).

RESULTS AND DISCUSSION

The initial point of interest concerning the photoreactivation of organisms in a wastewater environment dealt with the effects of temperature. Influent and effluent samples collected from unit No. 2 were exposed to sunlight as described earlier. Temperature baths at 4°C and 25°C were used to compare PR simultaneously. As shown in Table 1, the disinfection in the dark controls at each temperature was consistantly higher than in their counterparts exposed to sunlight. The decrease in coliform kills may be attributed to the organisms ability to photoreactivate and resume replication. Also of interest is the fact that sunlight exposed log reductions at 25°C are approximately 40% less than those at 4°C. This decrease, although small, is consistant and suggests that PR is more probable in a 25°C environment than at 4°C.

TABLE 1. EFFECTS OF TEMPERATURE ON PHOTOREACTIVATION

		Dark Control	Sunlight Exposure
4°C	Mean Log Reduction	2.07	1.59
	Std. Deviation	0.14	0.58
	95% Confidence Interval	1.73-2.41	0.61-3.02
25°C	Mean Log Reduction	2.07	0.93
	Std. Deviation	0.14	0.21
	95% C.I.	1.94-2.20	0.40-1.46

An interesting result which arose during the temperature study was the decrease in influent total coliform counts from the dark control to the sunlight exposed sample. At both 4° and 25°C, a small but consistant decrease was observed between all dark and light samples, especially with the first run, where greater than one log kills were found. UV light disinfects coliforms most effectively in the region of 265 nm, yet very little energy of wavelengths shorter than 290 nm are found at the earth's surface. The results thus suggest that disinfection due to the action of longer wavelengths is occuring simultaneously with photoreactivation. During sunlight exposure, these two phenomena compete with one another, with photoreactivation usually predominating.

Samples from unit No. 2 exposed to high UV dosages behaved differently upon exposure to sunlight from those exposed to a lower dose. A finding consistant with previous data was the second unit's superior performance relative to unit No. 1 in the dark controls. The result was further manifested at high dosages in the relative degree of photoreactivation observed in samples treated by the two units. The relatively ineffective unit No. 1 inflicted only minor damage to most of the inactivated organisms, thus allowing them to make use of the PR light. See Table 2. The second unit, on the other hand, operated with such a high efficiency that no organisms were capable of repairing themselves. In fact, additional disinfection was observed when these samples were exposed to sunlight.

TABLE 2. PHOTOREACTIVATION USING HIGH UV DOSE

		Dark Control	Sunlight Exposure
Unit No. 1	Mean Log Reduction	3.24	2.08
	Std. Deviation	0.14	0.45
	95% C.I.	3.14-3.38	1.60-2.55
Unit No. 2	Mean Log Reduction	4.01	5.13
	Std. Deviation	0.08	0.54
	95% C.I.	3.93-4.09	4.56-5.70

This study's approach to photoreactivation was unusual in that PR has always been studied with pure cultures of microorganisms rather than the heterogeneous populations characteristic of municipal effluents. As such, control over variables such as the chemical and biological characteristics of the wastewater and the intensity of sunlight could not be exercised in these experiments. Nevertheless, the results show quite clearly that the occurence of photoreactivation may significantly reduce the efficiency of wastewater UV disinfection.

WASTEWATER STUDIES

INTRODUCTION

A pilot plant study is being conducted to define the water quality parameters useful for predicting and

monitoring the effectiveness of a UV treatment operation in wastewater. Many parameters are therefore being measured in this study in an attempt to isolate those most directly related to disinfection efficiencies. Two independent variables are also being investigated: 1) filtered vs. unfiltered effluent and 2) lamp spacing in the UV units. The thin-film design characteristic of the first unit has potential advantages over the thick-film arrangement particularly in water with a high UV absorbance.

METHODS

The experimental design includes four variables, each of which can assume two conditions: 1) UV unit (No. 1 or No. 2), 2) flow rate (approximately 130 or 285l min), 3) voltage input to lamps (60 V or 127 V), and 4) quality of the influent to the units (filtered or unfiltered). Batch experiments are performed on each unit using randomly determined combinations of the six possible conditions. A total of nine repeats of each set of conditions will eventually be performed.

Samples used for chemical analysis are collected in 3.8 liter plastic containers, while those for bacteriological examination are obtained using sterile brown glass bottles. Lamps are allowed to warm up to 35-40°C before the samples are taken.

In an effort to correlate parameters of water quality with the efficiencies of the UV units, a battery of chemical tests are performed on all samples using procedures outlined in *Standard Methods* (1). Influent wastewater to the units is analyzed for the following:

1. Temperature
2. UV absorbance (Beckman DB spectrophotometer)
3. Alkalinity
4. Conductivity (Radiometer model CDM 2e)
5. Suspended solids
6. Nitrogen forms (NH_3, NO_2^-, NO_3^-, Auto Analyzer)
7. Total Iron (Atomic Absorption Spectrophotometer)
8. Total Organic Carbon (Beckman combustion IR carbon analyzer)
9. Turbidity (Hach 2424 nephelometer)
10. pH
11. Chemical Oxygen Demand

Effluent samples from the units are examined for temperature, dissolved oxygen (YSI Model 51B), nitrogen forms, conductivity, TOC, COD, and pH.

The 5 tube multiple-tube fermentation technique as outlined in *Standard Methods* (1) is employed for the enumeration of total and fecal coliforms in all samples. Results are reported as log reductions in coliform counts. The procedure is performed to the confirmed level with lauryl tryptose utilized as the presumptive medium.

RESULTS AND DISCUSSION

Approximately 30% of the experiments have been completed thus far. The data have been correlated and preliminary efforts to analyze the results for significant trends have been made.

Two findings are particularly noteworthy at this time: 1) unit No. 2 performs much more efficiently than unit No. 1 under all conditions, and 2) flow rate and lamp voltage have almost no effect on log reductions of coliforms at the levels tested. Both of these observations are consistant with the pure culture tap water results discussed earlier. Apparently, at even the lowest possible UV dosage level available, the units are operating where there is little increase in inactivation with increased dose. In this region, the major source of variation in the coliform log reductions is the differences between the units themselves. The second unit gave a mean log reduction of 3.56 in total coliform while the first unit gave only 1.92 logs inactivation.

In this investigation, conclusions regarding the advantages of the thin-film vs. thick-film concept in reactor design will not be possible. As shown in Figures 1 and 2, differences in the flow patterns within the units are obscuring any possible effect of film thickness. Although unit No. 1, with its 14 closely spaced lamps, yields a UV actinometry dose 1.6 times unit No. 2, short-circuiting in the reactor appears to be preventing it from achieving high log reductions of coliforms.

In attempting to correlate the various water quality parameters and process control variables with UV disinfection, problems have been encountered so far due to the overpowering effect of the unit on log reductions. For example, a strong *negative* correlation between log reductions and UV intensity was obtained simply because the less effective unit No. 1 actually yields a higher UV intensity reading than does the second unit. Plots of UV intensity vs. log reductions for each unit separately show no correlation. Most of the water quality parameters exhibit little or no correlation with log reductions at this time. However, once the statistical analysis is performed with respect to each unit, the importance of these variables will become clearer.

SUMMARY AND CONCLUSIONS

Ultraviolet disinfection studies are being conducted at a pilot plant using two commercially available 230 to 285 l/min (60-75 gpm) UV units. The use of potassium ferrioxalate actinometry to measure UV dosages has been found to have advantages over the conventional method. Actinometry dosages are directly related to the average intensity of all lamps and the average depth of fluid in the units, while conventional dosages are biased by the position of the UV detector in relation to the lamps.

Results from photoreactivation studies of UV inactivated coliform organisms exposed to sunlight show a 1 to 2 log recovery in total coliforms at 25° C. Lower recoveries were found at a lower temperature. Under high dosage conditions, photoreactivation was found to be a function of the unit, with samples from unit No. 2 actually showing additional disinfection upon exposure to sunlight.

Ultraviolet disinfection studies on filtered and unfiltered secondary effluent are still in progress. Only small effects of water quality parameters and UV dosages on log reductions of total and fecal coliforms have been found so far. The primary variable affecting inactivation is the non-ideal flow patterns of the two units. This result is due probably to the effect that short-circuiting is having on the effectiveness of unit No. 1. The importance of the other variables will become clearer following a more complete analysis of the data.

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DISCUSSION

MR. HEINSOHN, *Portstar Ind., Inc.:* Clarify for me unit 1 and 2. Which was the thin film?

MR. ALDRICH: The thin film was unit number 1, and the thick film is unit number 2.

MR. HEINSOHN: Unit number 2 was internally baffled. Is that correct?

MR. ALDRICH: Yes. It has four internal baffles.

MR. TONELLI, *Ontario Ministry of the Environment:* Apart from being a descriptive term, what does the term "thin film" versus "thick film" actually mean as regards to fundamentals of design?

MR. ALDRICH: It refers to the lamp spacing within the units. I am sure there is an arbitrary cutoff where you define something as thick film and where you define it as thin film so it is more of a qualitive kind of comparison. It relates to how closely spaced the lamps are together, and particularly what the average depth of fluid is through which the light must penetrate.

MR. TONELLI: From your actinometry results, you do not feel there is anything fundamentally different. Is it just a matter of definition or semantics?

MR. ALDRICH: Are you talking about differences between measuring the average depth and the actinometry doses?

MR. TONELLI: No, I am still talking about the thin film and thick film concept, because on the face of it there seems to be an infinity of intermediate thin films and micro-thin films. Was there any theoretical basis for selection of depth or separation of lamps for the study, or were there two units that were available?

MR. ALDRICH: No. We originally were interested in comparing the two units on the basis of the thin film versus the thick film. That was one of the original objectives of the study. As far as the actinometry is concerned, the spacing of the lamps did not really have that much to do with the actinometry. The spacing is related to the average depth of fluid and so is the actinometry, but other than that there really was no particular basis for comparison.

MR. DeSTEFANO: I have a question about the photoreactivation study. Did you do any counts immediately after collecting from the effluent, because there is also a phenomenon of dark repair and I would think that your control says that photoreactivation is a more powerful repair mechanism than dark repair is.

MISS ELLIOTT: I did not do any immediately afterwards. There was a matter of transport time in getting everything set up, and before we exposed these samples they were kept in a dark refrigerator at about 4°C. So I did not do any immediate ones afterwards.

MR. DeSTEFANO: But dark repair could have occurred in forty-five minutes?

MISS ELLIOTT: There was a possibility, but I would think that the cool environment of the refrigerator would possibly prevent that.

MR. VENOSA: I would like to make one particular comment. Our original idea in this project was that we wanted to compare thin film versus thick film, and there is no clear distinction between thin film and thick film. There is one company that makes a thin film type design, and this refers to approximately 0.25 inch of water wall. That is the distance the light traverses through the water. The distance between any two quartz sleeves is approximately 0.5 inch. Therefore, the water wall is 0.25 inch. The other unit is approximately 1 to 1.5 inches. The concept is what we were interested in, i.e., thin film, high intensity, short detention time, versus thicker water wall, long detention time, lower intensity.

MR. TRAVER, *EPA*: Any type indication we have had as far as UV disinfection deals with cleansing of the ultraviolet lamp sources in a submerged condition, be it either some type of a cleansing solution or mechanical light system. I do not remember or recall in the presentation any indication of this situation. Did you have to go on a down time basis, or how was this attempted in units 1 and 2?

MR. ALDRICH: We are not running any continuous experiments at this time. All our experiments are short term, and the two units are different with respect to the cleaning mechanism. Unit number 1 has a mechanical cleaning system powered by compressed air, and unit number 2 is cleaned with the use of a cleaning solution which is circulated through the chamber. We have not run into any problems with down time since we are not running continuously, and both of the systems seem to work quite well at this time.

MR. TRAVER: Can unit number 1, using a mechanical wiper system, be cleaned while in operation, or does it have to go down?

MR. ALDRICH: No, it is cleaned while operating.

15.
FULL SCALE EVALUATION OF ULTRAVIOLET DISINFECTION OF A SECONDARY EFFLUENT

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INTRODUCTION

This presentation is a progress report on a full scale evaluation of U.V. Disinfection of an effluent from a secondary wastewater treatment plant. The study is funded by the U.S.E.P.A. (MERL) and the Northwest Bergen County Sewer Authority. The principal investigator for the study is Hydroscience, Inc., Westwood, New Jersey. The ultraviolet equipment was developed and is manufactured by Pure Water Systems, who operate and maintain the on-site equipment.

The tasks involved in the overall program included the installation and shakedown of the U.V. equipment. Experimental work was then directed to an evaluation of the system under various operational conditions to determine dosage requirements relative to disinfection efficiency. Earlier in the program the system was continuously monitored during a viral sampling program conducted by the Carborundum Company, the results of which are to be reported in a separate presentation. The phenomenon of photoreactivation was evaluated concurrently with the primary sampling program, and the system was continually monitored for operation and maintenance efficiency. The final report to the EPA is expected in the spring of 1979.

SITE LOCATION

The site of the installation is the Northwest Bergen County Water Pollution Control Plant, located in Waldwick, New Jersey. Figure 1 presents a site schematic of the plant. It is a conventional air activated sludge plant with a design capacity of 30,000 m^3/day (8 mgd), and an average yearly flow, at present, of approximately 18,900 m^3/day (5 mgd). Completed in 1968, the plant is a modern, efficient facility discharging a well treated secondary effluent to Ho-Ho-Kus Brook, a water quality stream.

The plant has dual chlorine contact chambers. Under present flow conditions, one has remained inactive. This provided an ideal location for the installation of the gravity feed U.V. disinfection system.

EQUIPMENT INSTALLATION AND SPECIFICATIONS

A plan view of the chlorine contact chambers presented in Figure 2 shows the overall U.V. installation. To the left is the active chlorination system, and on the right the inactive chlorine contact chamber which provided the site location. The unit itself was installed at the head end of the chamber, the influent flow rate being controlled by weir gates on the influent channel. The U.V. unit was set into the channel and a platform set above it to support the ballast and provide a work area. Flow was measured by 4 V-notch weirs located at the effluent end of the contact chamber with a level sensor and recorder. A Cl_2 diffuser was located approximately 6 to 9 meters downstream of the U.V. unit in compliance with New Jersey law.

A cutout view of the Cl_2 contact chamber on Figure 3 shows the actual installation of the U.V. lamp battery. Two concrete webs provide the support. A pump is placed between the webs to keep the space dry. The lamp battery itself is supported by two steel bulkheads set into the concrete webs, with an air seal similar to a rubber inner tube along the perimeter between the bulkhead and concrete webs. Figure 3 also shows the mechanical wiper and the pneumatic cylinder which drives the wiper mechanism.

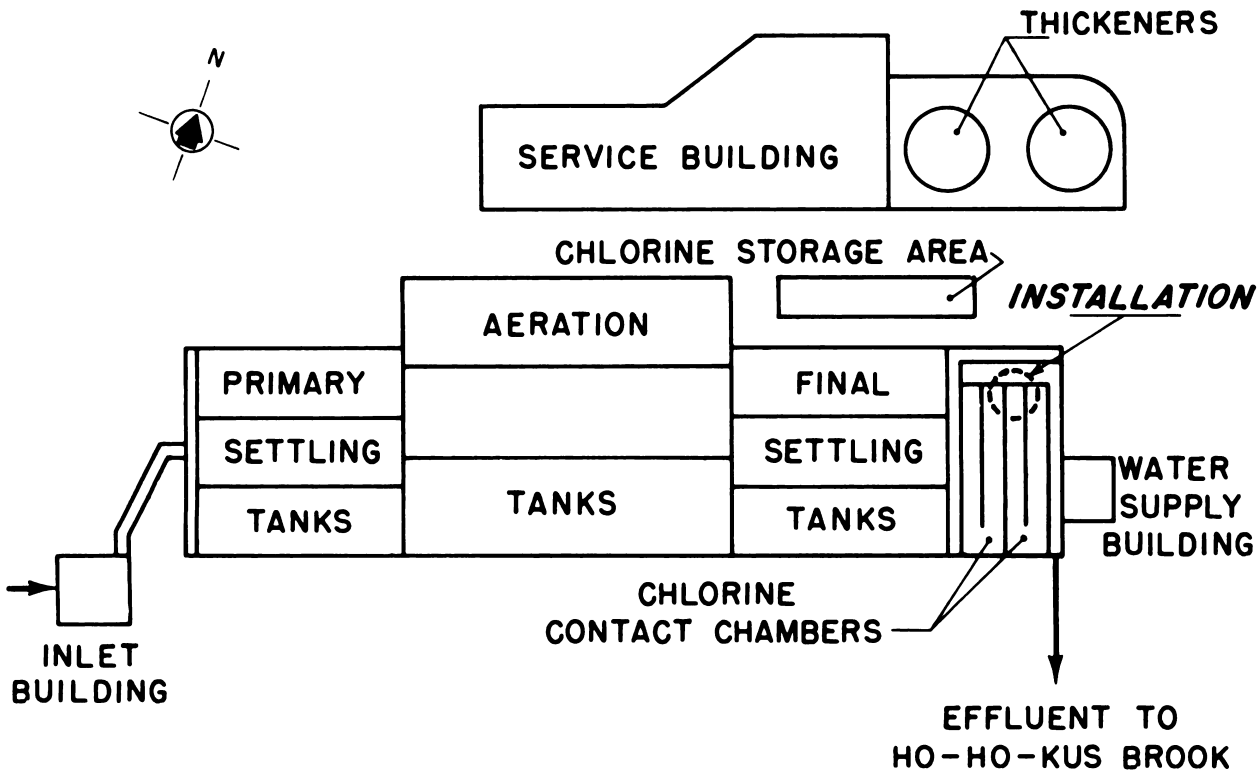

FIGURE 1. SITE SCHEMATIC

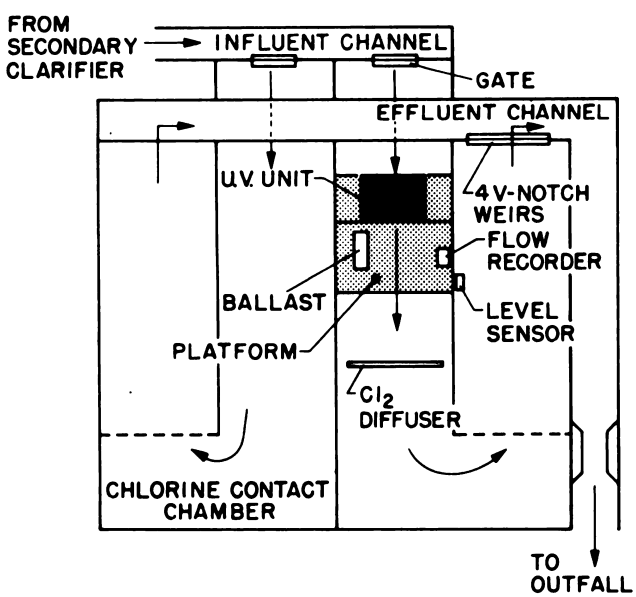

FIGURE 2. PLAN VIEW OF ULTRAVIOLET UNIT INSTALLATION

The specifications of the unit used at Northwest Bergen County are presented in Figure 4. It has a total of 400 germicidal lamps. They are 142 cm (6 ft long) 85 W lamps with an output of 30 W in the germicidal U.V. range. Each lamp is jacketed in quartz. The total effective arc length of the unit is 610 meters (2,000 ft).

Total power consumption by the unit is 45 KVA at an operating voltage of 480 V. The unit is capable of lamp battery shutoff in 1/6 increments and power variability from 40 to 100% full power.

The overall dimensions of the unit are 76 x 76 x 142 cm (3 x 3 x 6 ft) with a void volume of 0.63 m^3 (22.2 ft^3). Head loss is estimated at 15 cm (6 in) at a flow rate of 21,000 m^3/day (5.5 mgd). The mechanical wiper mechanism is comprised of replaceable elastomeric glands fitted over each of the quartz tubes. The wipers are cable driven at a variable stroke rate by a pneumatic cylinder. A unique feature of the U.V. unit it the utilization of the "thin film" concept, which is induced by the spacing of the lamps. The nominal liquid film thickness is 0.6 cm (0.25 in).

EXPERIMENTAL PROGRAM

The data reported herein represent the analysis period of June through August, 1978. During this time, two randomized sampling series were conducted. The first, conducted in June and July, evaluated the system at two specific flow rates and four applied voltage settings. The second series evaluated the

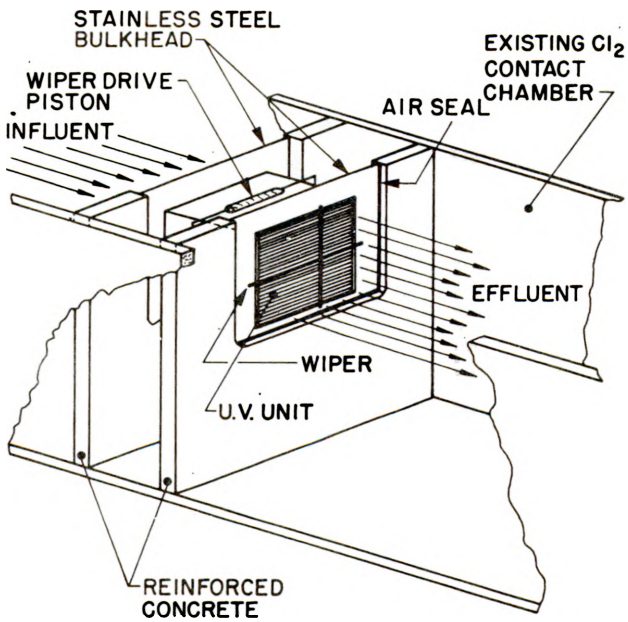

FIGURE 3. ULTRAVIOLET DISINFECTION UNIT INSTALLATION

system at a single flow rate with variable lamp operation and variable applied voltage settings.

Sampling was conducted two days per week at eight operational modes per day. Thus, sixteen samplings were conducted per week. The sequence of operational conditions was randomly selected to minimize bias due to variations in water quality. The randomized sampling series conducted during the June through August period were part of an intensive sampling program, statistically designed to provide an evaluation of the system relative to bactericidal efficiency under a wide range of ultraviolet energy dosage applications.

RESULTS

Wastewater Characterization

Figure 5 is a summary of the analyses performed on the influent to the U.V. unit. Sampling was by grab only, in sterile opaque glass bottles. Total and fecal coliform densities were measured by the 5-tube multiple tube MPN procedure. All influent grabs were analyzed for the specific wastewater quality parameters shown on Figure 5. The mean densities of total and fecal coliform were 3.6×10^5 and 9.5×10^4, respectivelv. The influent wastewater was relatively stable, and highly indicative of quality treatment; the COD averaged 26 mg/l, while the turbidity and SS were relatively low at 4 FTU and 6 mg/l, respectively. The water temperature averaged 22° C. As shown by

SPECIFICATIONS

MODEL : PWS SE - 7.5

LAMPS : NUMBER 400

TYPE : 85 W PWS-L60; 152 CM. LENGTH
30 W AT 2537 Å
2.3 CM. Ø QUARTZ JACKETING

TOTAL EFFECTIVE ARC LENGTH : 610 METERS

TOTAL POWER : 45 KVA

OPERATING VOLTAGE : 480 VAC/60 HZ/3 PH

LAMP BATTERY SHUTOFF IN 1/6 INCREMENTS

POWER VARIABILITY ; 40 TO 100 %

DIMENSIONS : 76 x 76 x 152 CM.

VOID VOLUME : 0.63 M^3

HEAD LOSS ~ 15 CM. AT 21,000 M^3/DAY

WIPER: REPLACEABLE ELASTOMERIC GLANDS, CABLE DRIVE OFF PNEUMATIC CYLINDER

FIGURE 4. U.V. DISINFECTION UNIT

JUNE, JULY, AUGUST, 1978 (119 SAMPLES)

	MEAN	MIN.	MAX.
TOTAL COLIFORM	3.63×10^5	3.2×10^4	1.6×10^7
FECAL COLIFORM	9.5×10^4	1×10^4	3.2×10^6
COD (F)	26.0	14.0	- 47.0
SS	6.0	1.0	- 18.0
TURBIDITY	4.0	1.0	- 25.0
pH		6.5	- 7.6
TKN (F)	11.0	3.0	- 24.0
NO_2 - N	1.1	0.3	- 3.7
NO_3 - N	8.9	1.8	- 20.0
NH_3 - N	9.0	1.9	- 20.0
COLOR	34.0	18.0	- 75.0
U.V. ABSORBANCE (T)(1)	0.171	0.277	- 0.137
% TRANSMITTANCE(1)	67.4	52.8	- 72.9

(1) 1 CM. CELL AT 253.7 nm

FIGURE 5. SUMMARY - INFLUENT ANALYSIS

the distribution of the nitrogen species, the plant was operating in a nitrification mode during the three month period. U.V. transmittance was measured in 1 cm quartz cells. The average transmittance was 67%, with a range of 52 to 73%. This transmittance level falls in the range indicative of a high quality secondary effluent.

Approximately one half of the effluent samples collected were analyzed for these same parameters, the results of which were tested against the influent analyses to determine if there was any change upon irradiation. A Student's t analysis at the 95% confidence level indicated no significant alteration in the wastewater parameters measured. The results of this analysis are summarized on Figure 6.

Ho: MEAN Δ = 0.0

INF. TO EFF.

(56 SAMPLES)

	MEAN Δ	CALC. t (1)
COD (T)	-0.48	0.87
COD (F)	-1.0	1.71
COLOR	-0.8	0.9
U.V. ABSORBANCE (T)	-0.0028	1.39
U.V. ABSORBANCE (F)	0.0007	0.53
TSS	0.19	1.37
TURBIDITY	0.18	0.84
TKN (F)	-2.45	1.37
NO_2 -N	0.011	0.73
NO_3 -N	0.041	0.55
NH_3 -N	-0.085	0.79

(1) SIGNIFICANT AT $t > 2.005$

FIGURE 6. TEST OF DIFFERENCES

Disinfection Efficiency

Before presenting the disinfection results, the manner in which dosage is reported should be explained. It is computed simply as the applied germicidal power (KW) divided by the flow rate (m^3/sec):

$$D = AGP/Q$$

where D = dosage (KW-sec/m^3)
AGP = applied germicidal power (KW)
Q = flow (m^3/sec)

This dosage unit, presented for use in conjunction with, or as an alternate to the standard μw-sec/cm^2 term, is reportable in both total and germicidal power applications, and may present a practical procedure for sizing and comparing alternative U.V. equipment. The reader is cautioned, however, that this type of dosage unit used alone represents a "black box" approach. Consideration must be given to intensity levels and water quality. It is anticipated that this study will provide a greater input to a more effective U.V. sizing parameter.

Figure 7 presents a composite of all coliform data collected during the three month period, representing a total of 119 samplings. The data are presented as a log-log relationship of surviving fraction to dosage. Least squares analysis was performed to compute the regression lines as shown for both TC and FC. As the figures indicate, the range of dosage levels investigated was approximately 4 to 90 KW-sec/m^3, representing exposure times in the order of 0.3 to 5 seconds. In the situation of the Northwest Bergen plant, a 99.9% removal would require a dosage of 35 KW-sec/m^3 under average flow conditions and an exposure time of approximately 2-2.5 seconds.

Design Nomograph

Assuming a linear relationship between log surviving fraction and a log dosage (Figure 7), a design nomograph was developed relating influent flow and expected influent coliform densities to germicidal power requirements. The nomograph presented in Figure 8 is based on a desired effluent average fecal coliform density of <200 MPN/100 ml.

Equipment sizing would be based on peak flow, which is assumed to be twice the average design flow of the plant. As an example, if a plant is to be designed at an average flow capacity of 30,000 m^3/day (8 mgd), the peak flow condition would be 60,000 m^3/day (16 mgd). If the expected influent fecal coliform density is 10^5 MPN/100 ml, Figure 8 indicates an estimated germicidal power requirement of 18 KW. Utilizing lamps with a germicidal output of 30 W/lamp, the implied lamp requirement would be 600. Similarly,

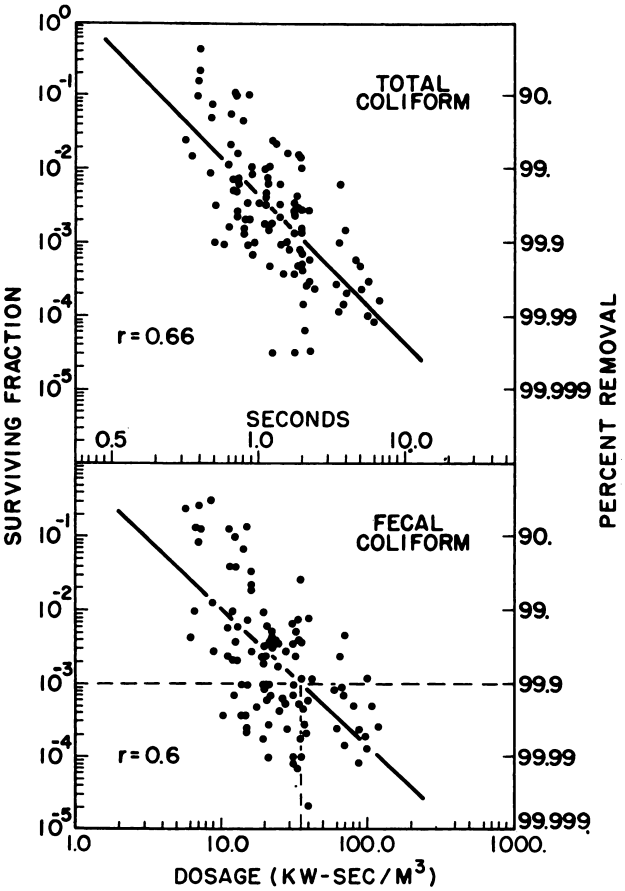

FIGURE 7. SURVIVING FRACTION

assuming a total power consumption of 110 W per lamp, the total power application becomes 66 KW.

As indicated by Figure 8, the assumption of a linear relationship in log surviving fraction with log dosage induces a sensitivity of the system design to influent coliform densities. Single log increments in influent density levels will affect system design requirements by a factor between 3 and 3.5.

Preliminary Cost Estimates

Costs were developed on a preliminary basis using equipment purchase figures provided by the manufacturer and the design nomograph shown on Figure 8. The costs included in the capital cost estimates are the equipment purchase (frame, unit and control panel, and installation), and excludes the support structure and any ancillary equipment requirements. Design and cost estimates for these have not been developed as yet. Design of the U.V. equipment is based on peak flow conditions and amortization is over a twenty year period at an interest rate of 6⅝%.

Operation and maintenance costs are reported on an average flow basis. Service is estimated at 15% of annualized capital costs. It is presently assumed that the lamps would need to be replaced at an annual rate. Power costs were assumed to be 3.5¢/KWH.

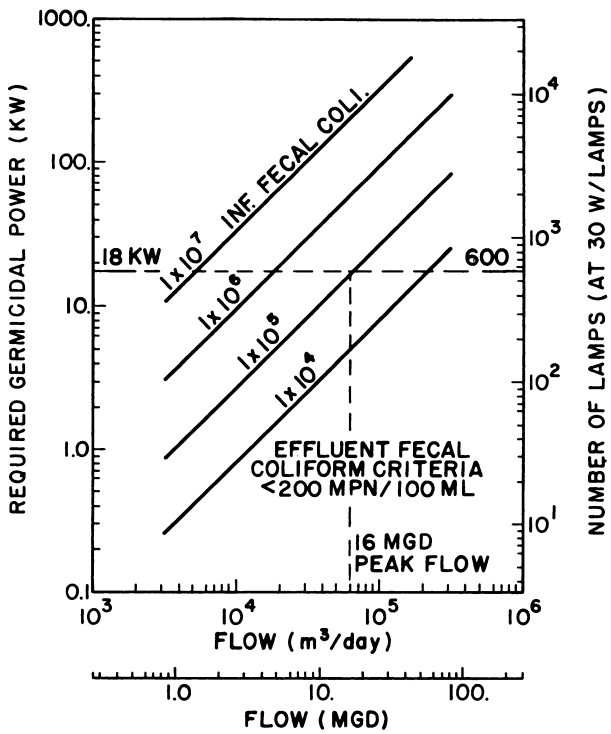

FIGURE 8. DESIGN NOMOGRAPH

In Figure 9, costs were related to the design peak germicidal power. For reference, the total power application is shown, which is in this case approximately 3.7 times the germicidal power. If the previous example is continued for the 30,000 m^3/day (8 mgd) plant requiring 18 KW peak germicidal power, the equipment purchase cost would be $240,000. O & M costs are estimated at $30,000/year, while total yearly costs (again, excluding support equipment), is estimated at $50,000/year. These cost curves were then used to develop unitary U.V. cost estimates based on flow.

The costs presented on Figure 10 are based on the assumptions of an influent fecal coliform density of 10^5 and a desired effluent fecal coliform of <200 MPN/100 ml. The costs associated with

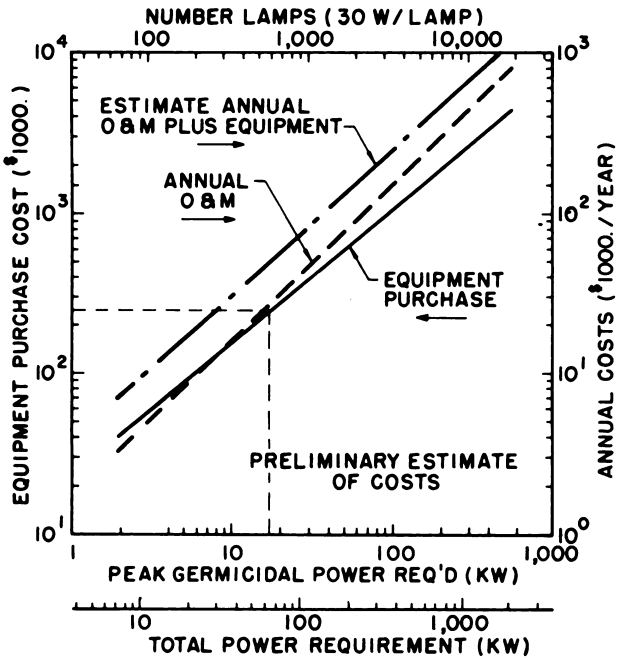

FIGURE 9. TOTAL POWER REQUIREMENT (KW)

DESIGN AVG. (mgd)	PEAK GERMICIDAL (KW)	O & M (¢/1000 gal.)	TOTAL (¢/1000 gal.)
1	1.0	0.6	1.4
5	5.2	0.6	1.2
10	10.0	0.5	0.9
40	43.0	0.5	0.9
100	100.0	0.5	0.9

FIGURE 10. PRELIMINARY ESTIMATE OF COSTS

the 19,000 m^3/day (5 mgd) are estimated at 1.2¢/1,000 gal. The cost for plants greater than 38,000 m^3/day (10 mgd) are estimated at 0.9¢/1,000 gal. (excluding amortization of costs associated with support structures). As discussed earlier with the projected design nomograph, the design, under similar water quality conditions, is sensitive to expected influent coliform densities. It follows that the costs associated with the process must also be sensitive to these conditions. The factor applied to costs for each log increment is estimated at this time to be 3.5.

It must be stressed at this point that the costs discussed above are preliminary and exclude certain capital cost items. It is anticipated, however, that the unitary U.V. disinfection costs will fall in the range of 1 to 4¢/1,000 gal. (under the operating conditions described above). These are very cost-effective when related to similar cost estimates for chlorination/dechlorination (4-8¢/1,000 gal.), and ozonation (10-15¢/1,000 gal.). Several factors will impact U.V. disinfection efficiency, and in turn the costs associated with the procedure. These include influent densities, water quality (studies at Northwest Bergen have dealt with a consistently good quality effluent), and photoreactivation, which is discussed below.

Photoreactivation

The lethal and damaging effects of ultraviolet light on bacterial cells are the result of absorption of ultraviolet energy by the cell's genetic material, deoxyribonucleic acid, or DNA. The damage incurred by this absorption is the dimerization of thymine, one of the basic components of DNA. This dimerization can be reversed by subsequent exposure of the irradiated cell to a variety of energy wavelengths in the visible light range of approximately 310 to 500 nm. This phenomenon is called photoreactivation. Research has shown that substantial increases in cell viability do occur by this mechanism in laboratory controlled experiements with pure cultures.

Studies to determine the significance of photoreactivation in recovery of U.V. irradiated coliforms at Northwest Bergen have been conducted throughout the program. Preliminary testing during April and May evaluated recovery as a function of time, and also investigated recovery in-situ by sampling in the chamber itself (see Figure 2).

During the June thru August detailed experimental program (which has been the subject of this paper), static light/dark bottle tests were utilized to evaluate photoreactivation. Aliquots of 100 of the 119 U.V. irradiated samples drawn were collected in borosilicate bottles and placed in a water bath held at the sampling temperature. The sample was then exposed to natural daylight conditions for a period of one hour (which had been determined as the approximate time period over which maximum repair would have been accomplished). After the hour exposure, both total and fecal coliform densities were

determined. Approximately 25% of the samples analyzed by this procedure were also held for one hour in dark bottles as controls. There was no measurable difference beteen the coliform densities in the dark bottles after one hour, and the densities observed immediately after irradiation.

Figure 11 presents the results of the photoreactivation analysis as a correlation of log reduction and log dosage. Regression lines were computed by the least squares procedure and are shown on the Figure. Regression lines computed for samples analyzed immedately upon irradiation are superimposed upon the photoreactivation results. The obvious shift is due to the repair of injured cells.

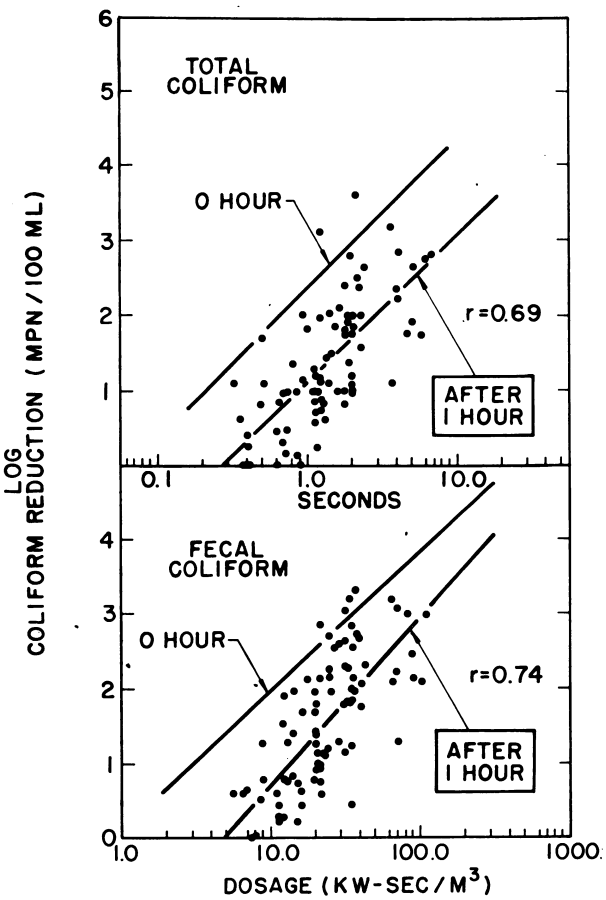

FIGURE 11. REDUCTION AT ONE HOUR

Similarly, the regression lines computed for log effluent coliform versus log dosage at 0 hour (immediately after irradiation) and 1 hour (exposure to visible light) suitably demonstrate the impact of the photoreactivation phenomenon as shown on Figure 12. Repair accounts for fairly consistent one log increase in effluent total coliform densities. The increase in fecal coliform levels varied from approximately a one log increase at the lower dosage level to 0.6 log increase at the higher levels.

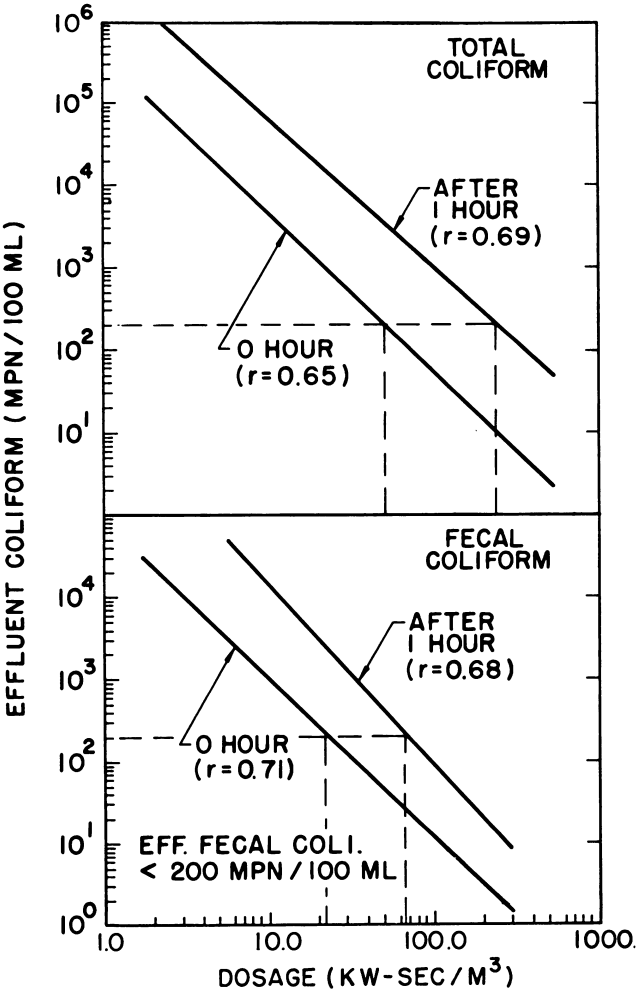

FIGURE 12. PHOTOREACTIVATION

SUMMARY

The results of the U.V. disinfection demonstration project to date have suggested the following preliminary findings:

The thin film, gravity flow disinfection unit has been found to provide effective treatment with low maintenance over a four to five month period. It is flexible in its operation and mechanically simple. The wiper mechanism has had approximately 3,000 hours continuous operation with no apparent degradation in cleaning efficiency. The lamps have typically operated an average of 2,000 hours.

At fecal coliform influent densities of 10^5 MPN/100 ml, a dosage requirement of 35 KW-sec/m^3 is suggested to meet effluent criteria of < 200 MPN/100 ml. This, of course, relates to the water quality conditions at the Northwest Bergen County plant. Costs, without consideration of support structures and ancillary equipment, are estimated to be in the order of 0.9 to 1.4¢/1,000 gal. Both cost and disinfection unit sizing are sensitive to the influent density levels by factors between 3 and 3.5 per log increment in coliform density.

Photoreactivation has been evaluated, and significant increases (0.6 to 1.0 log increments in fecal coliform levels) have been noted after exposure of irradiated samples to visible light. The implication of repair (or aftergrowth noted in other disinfection procedures) may be significant when related to unit sizing and costs.

AUTHORS

Mr. O. Karl Scheible is a Senior Engineer at Hydroscience; Ms. Gloria Binkowski was a Microbiologist with Hydroscience at the time of this study and is now affiliated with Rutgers University; Mr. Thomas Mulligan is Technical Director at Hydroscience.

DISCUSSION

MR. WHITE: Did you run a dye study curve on your contact in the unit?

MR. SCHEIBLE: No, we did not.

MR. WHITE: Are you going to?

MR. SCHEIBLE: It is not in the program. I find some difficulty there in trying to get any accurate measures even on a dye study in the order of fractional seconds. That scares me.

MR. WHITE: Don't you think it is better than nothing?

MR. SCHEIBLE: Probably. We did some velocity profiles across the units both horizontally and vertically to see if there was any dramatic changes in the velocity on the effluent side of the unit, and we did not see any. No evidence of real short-circuiting through the unit.

MR. WHITE: In other words, you are assuming there is no short-circuiting so you simply do a V over Q to arrive at your seconds. Is that right?

MR. SCHEIBLE: That is correct. It is a void volume over the flow.

MR. WHITE: Very unscientific.

MR. DeSTEFANO, *Riddick and Associates:* I noticed that you had to chlorinate. I visited the plant, and I noticed that the injection point was probably about ten feet beyond the unit. Now, did you check to make sure there was no back diffusion of chlorine? Did you take chlorine residuals in your samples?

MR. SCHEIBLE: Yes, we did.

MR. DeSTEFANO: There was no chlorine residual?

MR. SCHEIBLE: No. That was moved, incidentally, down to 30 feet just for safety purposes.

MR. DeSTEFANO: Also, this idea of calculating dosage is very convenient but you seem not to be taking into account UV absorbance, and it does not matter how much power you are applying to the liquid if the liquid is going to be absorbing some of the power. All you are concerned about is how much power is hitting the cell, not the liquid, because you are not disinfecting the liquid. You want to kill the cell.

MR. SCHEIBLE: I agree. I do not know if I can call it a drawback to this study, but we have dealt with a very consistent quality of water, and due to that we have not been able to really correlate anything. We have tried multiple regressions bringing in the idea of water quality but due to the consistency of the water over a three month period we are not really able to correlate UV absorbance.

MR. DeSTEFANO: A comment about the quality of the water. The effluent quality was very good, but there were also some very large floc particles when I saw it. I do not think the plant was down. I think that is a normal condition, very light though. You probably do not have a high suspended solids, but in terms of volume you do, and I am not sure that when that thing goes zipping through your unit at 2.9 seconds that a little bug inside one of those floc particles is going to get hit.

MR. SCHEIBLE: We did have a condition of floating material, large clumps. This could be brought on by two operating conditions. During a portion of this study at night we dropped the flow back down and dropped the lamp power down just to conserve. If you recall the slide showing the installation of that unit, there is effectively a dead space in the influent channel to

the time when it hits the UV unit. The UV unit sits about six feet up. If you drop the flow, there is material that tends to settle in that chamber. If you come in in the morning and crank up the flow, it would scour the bottom and push the particles through, and we could only exercise the caution that sampling would not be performed during that flush period.

MR. DeSTEFANO: When I saw the plant it was about two in the afternoon, and someone did take a sample as we were there, and you could actually see the floc going through the unit. They are not really floating. They seem to have about the same density as water in that they stay somewhat submerged on the bottom, not on the top, and you could see it just ripping through.

MR. SCHEIBLE: One other point I was just going to make is that plant is nitrified. Thus, they do have problems at times with floating sludge in their secondary clarifiers. They also pull off a lot of algae from the secondary clarifier.

MR. DeSTEFANO: One last question. Did you correlate UV light intensity with voltage?

MR. SCHEIBLE: It is linear.

MR. DeSTEFANO: But you cannot go all the way down. I understand that once you get down about 40% the lamps will go out.

MR. SCHEIBLE: The lamps start shutting off on you at about 40 or 45% of full power.

MR. VENOSA: Don't forget that some floc will go through a chlorine contactor too.

16.

ROUNDTABLE DISCUSSION OF ULTRAVIOLET LIGHT DISINFECTION

Participants in Ultraviolet Roundtable

Albert D. Venosa, Moderator
U. S. EPA, MERL-Cincinnati

1. Harold Wolf
   Texas A&M University
2. Kent Aldrich
   University of North Carolina at Chapel Hill
3. M. Elliott
   University of North Carolina at Chapel Hill
4. O. Karl Scheible
   Hydroscience Associates, Inc.

MR. GOLDRING,*Orion Research Incorporated:* I have what are in essence, I think, one question and a comment on Mr. Aldrich's work. His results, I believe, are much easier to understand if one assumes that he is killing all of the micoorganisms in 99% of the solution and 1% of the solution never sees the UV at all. As he mentioned he had difficulties with the bypassing in his equipment, so essentially he is measuring the bypass rather than any effect of UV, I believe.

The other thing is that in the actinometry he did not mention the transmittance of the solution that he used for his actinometry. If it is low, that is, if he has a high absorption coefficient, he is measuring the output of the lamps and not the exposure of the solution. In other words, to measure the exposure of the solution and compare the microbiological data he should be working at an absorption coefficient that is similar to that of the untreated waste water. In that case he would at least be seeing the way the UV is absorbed by the solution when its absorption coefficient is approximately the same as it is when he has microorganisms present.

MR. ALDRICH: That is correct, basically. What we started with was the high concentration actinometry and with the concentrations that high the solution absorbed the UV within a depth of only 3 to 4 mm. What we are interested in doing now is lowering the concentration of the actinometry solution, as you suggested, and we hope to be able to obtain a dosage which is even more meaningful.

DR. JOHNSON: I think you have to put this dosage business in context. The way that it has been classically done and that the standards are assigned today is so many microwatt seconds per square centimeter, and as we look at dosage, of course, the amount of UV added to the water can be measured just simply on the basis of inches of lamp and the way the manufacturer rates his thirty watt bulb, which is essentially what was done with the practical study in Northwest Bergen County. The next step is to measure the real output of the lamp with actinometry, and that is what you are measuring. You are not measuring the germicidal dose to any one microorganism, because he sees all of the UV absorbing fluid draining. He sees the wall over there that may be stainless steel; it may be aluminum that is reflecting the UV off the wall and back to him, and they are multiple lamps. These units are six and nine or so lamps apiece, not one lamp, so that you just cannot take the intensity or distance and measure the decrease in intensity with distance, because there are several lamps influencing one spot within the unit. The classical work that Hill did was with a two-lamp unit, and that is what the 16,000 microwatt seconds per square centimeter standard of UV disinfection in drinking water is based upon. So we are taking this a bit at a time. Our eventual goal, of course, is to measure how much UV energy comes to the microorganism, but we are a long way away from that as you point out.

DR. ROSEN: I have a question about the possibility of free radical formation and molecular rearrangements. After all, we are apparently absorbing UV and disrupting bonds, especially with high intensity UV. I wonder if anybody has any comment on this, or did anybody look at this, or what kind of theoretical probability or possibility is assigned to it?

MR. VENOSA: Bob Jolley tomorrow will be

giving a presentation where he has evaluated the effect of chlorine, ozone and ultraviolet light on secondary and primary effluents. So he will answer your questions tomorrow.

DR. JOHNSON: The energy is fairly low, 254 nm, not a lot of energy. It is not down to the 180 nm region where you get significant bond disruption. It would take a fairly weak bond to come apart at 254 nanometers.

DR. ROSEN: Yes, but you know you have a spectrum. The 254 nm line is the major line.

DR. JOHNSON: Well, the mercury lamp puts out about 90% of its energy or more at the 254 nm region. There is some energy at 186, and then there are a few lines up in the visible region, but they are very small. These lamps are tuned to the mercury line at 254 nm.

MR. DeSTEFANO, *Riddick and Associates:* I would just like to explain my dual nature here. I am representing a consulting engineering firm that is also, in turn, representing the Village of Suffern in New York, which has now a discharge permit for class A waters. They do not want any chlorine residual. We looked at various alternatives and in the most recent facility plan we are recommending a UV system. But the problem we are facing, as I see it as a consulting engineer (I am not myself an engineer; I am an undergraduate student at Princeton helping out for the summer) is when the engineer goes out and talks to the manufacturers, who seem to be the only ones up until now who had information, he gets very conflicting ideas, very conflicting dose recommendations, flow recommendations, and geometry recommendations. We talked about it. We got a little bit into it, thick film, thin film, batch, flow through, and I am really at a loss on how to handle all this. I know there are a lot of manufacturers here, and I won't be afraid to say it but . . . each one has a bad word for the other, and everyone thinks that they have the best system, and I was wondering if someone up there could give us a hint on what sort of things you want to look for when you are designing the plant. Do you just want to look at performance, or do you want to have a margin of safety, or do you want to just look at your counts, or do you want to look at the dose? I will leave it at that, and you can play with it from there.

DR. JOHNSON: Well, I am not sure what your question is, but . . .

MR. DeSTEFANO: I will clarify it. Could you just generally give something that an engineer could look at and say "These are my design parameters. This is my effluent quality. I want to have a certain type of ultraviolet disinfection system with a certain amount of wattage or a certain amount of dose or whatever method you want to use to measure the disinfecting power of the ultraviolet taking into account geometry", because obviously there is some difference in proprietary units available.

DR. JOHNSON: Well, current design is focused upon dosage, that is, microwatt seconds per square centimeter. It is conventionally measured in the literature, or as we have talked about today in terms of watts per cubic meter, which is essentially the same sort of thing just on a different basis in terms of power output from the lamp in germicidal power. In our studies we found that there was way too much lack of concern for flow characteristics. Most of the UV has been applied to drinking water. Drinking water does not usually have 10^6 microorganisms in it, hopefully. So they are not looking for 10^4 kinds of orders of kill like they are in wastewaters, and of course if you have a 1% short circuit in your contactor then you are never going to get much passed the 10^2 kill. Thus retention time is very important, and the flow characteristics of your contactor are very important. There has not really been enough considered in wastewater design in disinfection units.

MR. DeSTEFANO: What about the issue of ultraviolet absorption of the effluent?

DR. JOHNSON: That is, of course, the other side of the coin. What is the tradeoff between thickness? One person says you need a quarter of an inch and the next person says you need three inches. Basically what you are looking for is UV energy to the microorganism. Now, there is a lot of theorizing you can do, and I think that is where we are at this point. It is obvious that UV transmission at 254 nanometers is important, and if you have a high quality of waste which does not have much absorbance as they seem to in Northwest Bergen County, then I think they are kind of foolish to use a quarter of an inch of lamp depth, because they are throwing a lot of energy away by reflections off of the quartz tubes next to each other. Just heating the unit is where most of their power is going to go. They are doing a rather inefficient job when they work with a quarter of an inch film thickness, and an absorbance of .17, but it is theory you know. We do not really have a design parameter as yet to do a good job, but that is obviously very important. Harold said ammonia is a good

parameter, but of course when you look at sewage treatment, microorganisms first go after carbon and then go after nitrogen, and so naturally the amount of organics is important in terms of the 254 nanometer absorption, and that follows that ammonia might be a good way of correlating on a control basis, but a much more direct basis rather than measuring TOC or ammonia or COD. It is just a measure of 254 nm absorbance

MR. DeSTEFANO: But what about a plant that is not running very well. I know the Northwest Bergen County plant is running under capacity, and it is producing a very good effluent, but what about just standard secondary effluent or bad secondary effluent such as the other plant in Bergen County, the Bergen County Sewer Authority plant, which, as I understand it, is rated at 40 mgd and is running at 70 mgd, something like that. I think that is where this unit was initially installed and they were not getting disinfection at all because it was essentially a primary effluent. What I want to emphasize or try to get from you is what kind of effluent characteristics do you need to make a valid application of ultraviolet light, and what kind of effluent characteristics coupled with what kind of geometry? Obviously, I know you do not want to recommend any particular manufacturer or any particular geometry, but outside of just ultraviolet transmission there has to be some other things that you can look at to try to verify that you are getting the energy to the organism.

DR. JOHNSON: We had a fairly low dosage at the beginning of our curve, 10,000 microwatt seconds or less which is generally rather small, and we were putting it through wastewater which had suspended solids in the moderately good range. It was not the best. This is a contact stabilization plant that runs pretty much up to capacity, and we were doing a good job with one inch depth of water through a conventional kind of unit. I guess what I am trying to convey is my skepticism that UV would work to begin at all on wastewater, and surprised that is has worked as well as it has.

MR. DeSTEFANO: What about something that you might not be able to measure except by ultraviolet-absorbance some sort of dissolved iron. I know in our village of Suffern there are a couple of industries that might be giving us something funny. Avon is one of them, and who knows what they are dumping into the line that might just absorb incredibly at 254 nm but the effluent characteristics by standard methods by turbidity would be looking good.

DR. JOHNSON: Yes, you cannot use the TOC, COD, suspended solids kind of measurements. You have to measure the 254 nm absorbance because iron is one of the best UV absorbers, and iron is not measured by any of the standard procedures. So if you have some iron coming down from an industrial waste you could completely destroy UV disinfection.

MR. VENOSA: Are you ready to hang your hat on the statement that COD and TOC do not interfere with UV?

DR. JOHNSON: I did not say that. I said you cannot just use those alone. You have to use the parameter that is important interacting with UV. Why measure TOC when you can correctly measure 254 nm absorbance. It just does not make any sense.

MR. ELLNER: To change the subject a little bit, there are two points I would like to make. One is, I do not want anybody here to get the impression that photoreactivation is a phenomenon that is limited to ultraviolet disinfection of organisms, and I think the point should be made that this repair has been studied and I think should be studied, and has been demonstrated with more conventional types of disinfection as well, and you can apparently establish increase of organisms through photoreactiviation.

MR. SCHEIBLE: I just want to qualify your statement. Photoreactivation is unique to UV. It is due to the presence of photoreactivating enzymes. I agree with you that other disinfection procedures should be looked at for "aftergrowth" or any other mechanism that increases the effluent quality.

MR. ELLNER: While we are on that subject too, I think some review should be made of the actual practicality of the conditions of photoreactivation and actual practice of a discharge into a receiving stream as clear as the Hudson River and things of that nature which offer tremendous amounts of protection from visible light available.

MR. SCHEIBLE: I will take issue with that too. If you look at a number of the streams that the UV or any disinfected effluent discharges into, those are small and shallow, and they are normally of high quality.

MR. ELLNER: The point I was trying to make is that it has to be related to the practical aspect. This concept of dosage probably highlights the major problem with UV from both the theoretical and practical standpoint. The researchers have no sure fire way of coming up with a dosage to quantify their results, and the engineering and specifying people have no way of describing a UV unit to meet a given design

parameter. Now, there have been attempts to come close to that, and I would like to offer this because researchers are starting to report it, instead of something that is questionable in the measurement. There is no conventional UV dosage determination, at least you are not going to get a consensus on people in the field. There has been an attempt though to relate results to how many gallons per minute per unit length of ultraviolet source, and how many seconds retention time, defining, of course, the output of the UV source, because that is something that can be duplicated by the next researcher. I propose that as some thought that certain people have started to specify ultraviolet on that basis. I am going to add just one more thing. I do not want to monopolize this, but I represent an ultraviolet firm, and I make the statement now that we do not utilize this conventional estimate measurement of ultraviolet dosage technique. We have developed proprietary dye tests for determining ultraviolet, but we also have used some follow up approaches which I think we can reveal here, and I think should be under consideration, and that is a very simple scientific technique known as the bioassay, and essentially what is done is that you develop pure strains of organisms, plot the log reduction in relationship to the UV dosage which can be determined on a static basis, and then introduce your organism to the test unit, measure the log reduction coming out on the other end, and have a good cross check as to what the dosage delivered was.

MR. WHITE: I have a couple of quick questions I want to sneak in here. Number one is: you speak of slime on the lamp, and that is what I heard you say, Dr. Wolf and Mr. Scheible, and this is where the UV intensity is highest, right on the lamp. What is the nature of the slime? Is this bacteria? If it is, why isn't it killing the slime? That is question number one.

MR. SCHEIBLE: I did not speak of slime on the quartz tubes themselves.

MR. WHITE: You talked about the wipers. What is this stuff that you have to wipe off? Is it a zoogleal slime, or what is it? Does it have organisms in it?

MR. SCHEIBLE: There was an occasion very early in the study when we were still in the procedure of equipment shakedown and getting everything working properly, and it happened that the wipers were turned off for a period of days so we had no mechanical wiping system in operation, and what seemed to develop on it was a thin, white film coating, that essentially became baked on.

MR. WHITE: Just like a calcium scale deposit?

MR. SCHEIBLE: I do not know. It is baked on simply from the heat of the lamp. When we pulled the unit up out of the water to take a look at this, we experimented with several cleaning solutions and came on one and just sprayed it, turned the wiper on, the wiper scrubbed it off, put it back in the water. I think I stated at the end that the wiper mechanism itself operated over a period of 3,000 continuous hours, and we have not to date seen any deterioration in the intensity off the quartz tubes.

MR. WHITE: Okay, I was just curious whether or not it was some organism. The second question is: do you generate any ozone in the operation of UV systems?

MR. SCHEIBLE: Yes, it does in fact. As the study continues on into the winter, we may have to blow warm air between the lamps and the quartz sleeves to maintain the lamps at optimum temperature. We can then take that exit air, which becomes enriched to a degree in ozone, make use of it, and inject it into the front end of the system, and get whatever synergistic effects may occur. We are not sure what will occur.

DR. JOHNSON: We were interested in the ozone question, and thought that if there is oxygen in the water, why don't you get ozone in the water. The trouble is the water is very good at quenching the UV. The wavelength that produces ozone is 186 nm. Even if you can get 186 nm through your solution, which is doubtful in wastewater, the oxygen that is dissolved is not capable of producing much ozone. Most of the ozone comes from the air space that is around the lamps. These lamps have to be cooled. The operate very much at an optimum temperature. At slightly below or slightly above that temperature their efficiency falls off, so that it may not always produce the optimum 40 watt germicidal output. And what it puts out in the 186 nm region is mainly producing ozone in the air space.

MR. WHITE: An efficiency of 200 fecal coliforms per 100 ml, which you spoke about as the goal, is not considered disinfection in California. It is a long story, but I just wanted to mention that. The other thing is that some of the people I talked to in France, who have been looking into this, suspect that UV will cause mutagenesis in surviving viruses.

MISS ELLIOTT: I have found in my reading that there are mutagenic effects of UV light, and as far as the photoreactive ability of these organisms, it varies among the organisms of course, but mutagenesis has been observed.

MR. HEINSOHN: I was an old Princeton hat. Let me answer this young Princeton hat back here. First

his Suffern plant is about fifteen minutes from where I live, and that plant is an operational disaster. The first thing you have to do over there is re-engineer that plant, because what comes out of it is just about what goes into it. I was called over to have a look at this place. I could show you some others in the country too where the lawns look like putting greens and a few other things, but what comes out of the plant is terrible. I just want to answer him this way, and say that from a manufacturing position of UV equipment for wastewater, we do have production systems on the line. Let me tell you all that the target in our business is to reduce any coliform count down to a count of less than 3. That is the target, not 200 per 100 ml but less than 3. Some states have that spec right now.

MR. DeSTEFANO: Can I just respond to save the face of Suffern? Admittedly the plant is now not operating at optimum. It was a WPA plant. It is old, and it is running at, I think, twice it design capacity. There is also a problem with inflow. There are a lot of other problems, but that is why we wrote a facility plan. The plan will be expanded, and we will be working with what we assume will be a good secondary effluent, and there is going to be some tertiary treatment, not filtering, but tertiary treatment for nitrate removal. I would just like to respond to my fellow Princetonian and maybe I will get some of these UV manufacturers again. The reason we got involved in this is the project engineer told me to get on the phone and start calling people, and it is a very strange way to try to get involved in a subject you do not know much about. I called Mr. Heinsohn. We got his name from some people up at New York EPA, and we talked about the plant over the phone. He took it upon himself to visit the plant and then make his design recommendations. Really at that point we were just feeling out manufacturers there. We are a bit further now, and the facility plan is written, but we are still not at a point where we have written a spec or anything. The design still is in the future, and that is why I am here to find out what sort of design considerations we have to make before we go into the construction phase.

DR. GREENBERG, *Department of Nuclear Engineering at The University of Cincinnati:* I would like to offer a suggestion to those who are working with these photo-chemical reactors. We in chemical engineering characterize chemical reactors by residence distribution studies, and I am rather suprised that I have not heard or seen any reports of such studies among the presenters today. I suggest that that would be an easy way to characterize the circulation and distribution around the photo-chemical lamps. I would also like to comment on some parallel work that I have been involved in using coherent light for disinfection of various microorganisms. In scanning from the near UV, 265 nm being the peak absorption for DNA-RNA, individual species of organisms absorb in a very characteristic pattern. At least this is our preliminary analysis, and this extends, I guess, through the visible and into the near IR. You can promote growth by irradiating at different wavelengths. You can inhibit growth at the same wavelength by looking at fingerprints of different organisms and overlaying these fingerprints, and irradiating at a selected wavelength, using again coherent light or laser light, very selectlively. We have had some success in doing this.

I would also like to call attention to some work that was done by a colleague at the Applied Physics Laboratory, Johns Hopkins in Maryland about two years ago. Dr. John Parker irradiated a sample of seawater or wastewater in a simple batch experiment with infrared light from a CO_2 laser, and discovered that by pressuring the sample with oxygen he was able to generate the oxygen singlet, which has the same germicidal activity as ozone. He was very effectively able to reduce the microorganism count. I suggest that this is something that perhaps ought to be considered.

DR. JOHNSON: Is this in water?

DR. GREENBERG: In water, yes. Also the penetration as I understand it at these high frequencies, that is, in the near UV, is on the order of a few mm, at most, and I am surprised that we are talking in terms of inches. I think the absorption is greatest . . .

DR. JOHNSON: We measure directly the UV absorbance at 254 nm, the wavelength of interest, and the absorbance values come out to be relatively small. In operating an actual plant, your values were up to three-tenths of an absorbance unit. We did not find anything like one absorbance unit, which would be 10% of the material going through a one centimeter thickness. These wavelengths are not all that far down in the ultraviolet.

DR. GREENBERG: Are you suggesting then that there is very little absorbance as a function of distance out to several inches?

DR. JOHNSON: Well, we measured. I am not suggesting anything. I am telling you what the measurements are. The measurement said in an actual

wastewate that the absorbance was less than one absorbance unit, and if you look at Beer's Law relationships, that tells you that 10% of the material got through one centimeter of fluid, 90% got absorbed, and the absorbances were well below one. Most of them were around 0.17. That is in one cm of the fluid; if you convert that, say 80% goes through.

DR. GREENBERG: 80% goes through, and this is wastewater?

DR. JOHNSON: In wastewater.

DR. GREENBERG: Is this information available? Is it published?

DR. JOHNSON: There is published data. It goes back to some works that were done by General Electric. Lukeisch did work back in the fifties or earlier than that. He looked at UV absorbance of wastewater, drinking water, and a number of different types of waters in the country. This was typical.

DR. GREENBERG: But as one goes down in frequency towards the IR, the absorbance, the penetration let's say is much much greater.

DR. JOHNSON: Yes, if you go down to 200 now everything absorbs.

DR. GREENBERG: But in the near IR you can penetrate through several feet of dirty water which is what Parker did in his study.

DR. JOHNSON: Let me just reinforce something that was said by the last commentor. There has been far too little concern about the detention time. George showed some data on detention time, and talked about a t_i, the initial breakthrough of material in a dye study. Even the better of the two units that we looked at where the mean detention time was not significantly different from the volume divided by the flow rate, the t_i value was something like six seconds when the mean detention time was twenty seconds. Now, that is at a level that you can read off this curve of ours which is maybe at 1%. If you are thinking about wanting to get four or five log reduction, then you ought to call t_i where you get the first 0.01% or four logs, and that would be a rather short contact time even for the better of the two units. So there is far too much concern about dosage, microwatt seconds per square centimeter in ultraviolet disinfection of wastewater today. There has not been enough concern about detention time, the main point of our work.

MR. WOOD: On that subject, the detention time can be two ways. It can be long or it can be short. We are paying attention to the short retention times, because that marries to a piece of equipment that practically fits a sewer plant operation. You do not want a monstrous piece of equipment that takes two acres of land to put it on. What you end up with if you are talking about long retention time, is hydraulic loss problems. You get into flow conditions. You get into a wide gradient of exposure as you go away from the source. These are some of the things that are of concern. We promote thin film, short retention time. So we are paying attention to retention time on the short side.

One other thing I would like to clear up. It was brought up here that this particular unit at Northwest Bergen Sewer Authority was installed at Bergen County. That is an error. The unit that was installed in Bergen County was the first prototype unit that we built. It had around a 6 mgd flow capacity. We did get performance on that unit at a flow condition where the plant was twice capacity, and effluent quality did not meet standards, had suspended solids up in the two hundred range, color and turbidity up in the fifty to hundred range. We met the 200 per 100 ml standard in that installation at a flow rate of about 5 mgd under those conditions. At that point, we made the decision that we just did not want to have that particular system associated with that type of plant. At the time we were conducting talks with EPA, they felt that if ultraviolet was going to be a successful disinfection alternative you did not really want to evaluate it at a very poorly run plant. It would mean that you could run your plant anyway you want, just place a UV unit at the end of it, and it overcomes anything you might do in the operation of your plant. That was our reason for going to Northwest Bergen where we had a more model plant, and we felt it gave UV a more representative test also. I would subscribe to the fact that the plant should be run well and if it is run well, ultraviolet is a tremendous disinfection means.

The other point I would like to make is that I think we have the tendency in statistical analysis to look at log reductions and maybe not relate them to actual conditions, and I would just like to point out a layman's approach to the testing we are doing at Northwest Bergen. We have had ultraviolet disinfection system in there that has been running around four months, full plant flow, pretty much somewhere between 80 and 100% power. In four months of day-to-day testing, twenty-four hour operation, we have never on a single test reached a 100 per 100 ml count. Now your curves say that that unit cannot do it. I want to point out that the operator's standard is 200 per 100 ml. That is the performance standard he has to meet, and if the unit does it, in my

opinion that unit performs. Statistical analysis be damned!

DR. SCHWARTZ: I have some questions. First of all, UV is known to induce moleclar rearrangements in DNA. Ultraviolet is known to induce transformation, mutagenesis, and carcinogenesis when organisms are irradiated, and molecular rearrangements do occur in the DNA, not directly due to the ultraviolet but due to the repair processes within the cells and viruses. The thing that I want to bring up that is an important point is not the photoreactivation, which is a rather benign sort of repair, but the dark repairs which are error prone. Has anyone who has run these UV disinfection facilities done any transformation studies of the viruses that they inactivated?

MISS ELLIOTT: As I mentioned earlier, we were working with just total coliform evaluations, so I have not.

DR. SCHWARTZ, *Deltech:* I have some questions. First of all, UV is known to induce molecular rearrangements in DNA. Ultraviolet is known to induce transformation, mutagenesis, and carcinogenesis when organisms are irradiated, and molecular rearrangements do occur in the DNA, not directly due to the ultraviolet but due to the repair processes within the cells and viruses. The thing that I want to bring up that is an important point is not the photoreactivation, which is a rather benign sort of repair, but the dark repairs which are error prone. Has anyone who has run these UV disinfection facilities done any transformation studies of the viruses that they inactivated?

DR. JOHNSON: I think I would like to comment about this "super oxygen". We went through a nascent oxygen hulabaloo with chlorine years ago. These compounds like singlet oxygen and super oxygen are very unstable. Their lifetimes are very short. One of the major problems with disinfection from a microbiological point of view is to get the disinfectant to the vital site within the microorganism. In fact, many disinfection processes, and ultraviolet not being one of which, are transport limited. The rates of the disinfection process is more a matter of getting the disinfectant to the organism than it is getting the molecular reaction to occur. Ultraviolet is not like that. It is definitely going right to the active site, which makes ultraviolet kind of unique among disinfectants. But the tremendous amount of energy required to get a singlet oxygen or super oxygen is one thing that mitigates against that approach, and also the other is getting that form into the microorganism.

DR. OLIVIERI, *Johns Hopkins Univ.:* I wonder if both of the gentlemen from NW Bergen County might comment on the frequency in which they met the 200 fecal coliform level, taking into account the factor of ten that they observed for photoreactivation, be it light or dark reaction. What percentage of the time did you meet that taking into account reactivation?

MR. WOOD: I can answer that. We ran our own photoreactivation studies. We disinfected the downstream chlorination tank with 5 ppm overnight dosage of that downstream tank. We then drained that tank down with the UV in full operation, full power, and ran until we got zero chlorination in the entire downstream contact tank. We had a time basis to go by. We then continued to run 100% power on the UV and then took ten minute up to seventy minute samples in the channel, downstream from the UV and zero chlorination. We found, I think, good correlation between what Dr. Johnson got and what Karl got. We got a one log increase basically, 1 to 1.2 logs. Again I have to relate this back to the real world. At the time we had 20 fecal coliforms/100ml coming out of the unit with roughly 10^5 coming in, and we had a 25 count seventy minutes downstream. Now that, too, is a one log increase, but it is not anywhere near 200.

DR. OLIVIERI: A factor of ten increase is going to bring you from 25 up to 200.

MR. WOOD: We had less than that. We went from 20 to 30.

DR. JOHNSON: Well, of course, we saw some dechlorination data yesterday that had two logs of regrowth. There was a question about whether it was really growing or whether it was just coming up from the sludge at the bottom of the tank, but UV is not unique I guess.

MR. SCHEIBLE: With the data that we are reporting I could not make the simple calculation of percent time that we met the effluent criteria of 200. I was more concerned about relating that unit . . .

DR. OLIVIERI: That is going to be the ultimate . . .

MR. SCHEIBLE: I agree, but most of our program to date has been to evaluate dosage levels relative to disinfection efficiency, and in my mind . . . correct me if I am wrong . . . when an engineer comes in and he wants to design a system, he is going to know what the relative characteristics of his influent are, and he can then relate a dosage to a log reduction scale.

He can get an idea of what the expected effluent will be. That has been the thrust of our work to date. Now, I can go through that calculation, but it would be a difficult one in that we varied the operating conditions of that unit considerably.

DR. OLIVIERI: Once you put in the lamps how much flexibility do you have to overcome a poor design?

MR. SCHEIBLE: Considerable flexibility. The unit itself has the capability of shutting off banks of lamps. Now in my mind the ultimate design of this would be simply that you rate the power input to the flow. So you vary your power with your variation in flow through the day. You can tone down during low flow conditions at night or whatever. It also has the ability to turn off banks of lamps so you can vary . . .

DR. OLIVIERI: Well, the situation that I am concerned about is if you have to add banks of lamps.

MR. SCHEIBLE: If you design your system properly that should not happen.

MR. SCHEIBLE: I do not know how else to answer your question. It all comes down basically to a correct design of the system, and you should be able to handle what your expected conditions are in the near future. That is all I can really say. And photoreactivation, to answer that question, from the data that we showed over a variety of dosage levels, we got a fairly reasonable correlation which showed an average of one log increase over effluent conditions.

DR. OLIVIERI: This is precisely what I want to get at. That is an increase, and you are showing me that you are reducing to say a fecal coliform level of one hundred. If that is going to go through a one log increase, I am going to have, coming out of the plant or at some point downstream, a fecal coliform level equivalent to a thousand.

MR. SCHEIBLE: That is correct.

DR. OLIVIERI: You have not met the requirement then. That is the point I am making.

MR. SCHEIBLE: Let me make two statements on that. First of all, the UV equipment can achieve a level which, if you even take into consideration photoreactivation, will achieve effluent criteria. I would love to throw it open to the floor here to anybody who has any comments, and I wanted to bring it up yesterday and Al did. What is the implication of this after-growth and what is the implications of photoreactivation?

DR. OLIVIERI: They are two different processes. They are two distinctly different things.

MR. VENOSA: It does not make any difference. There is still the same effect. If you look at Kent Aldrich's data, he showed that when he achieved three log reduction he got about a one log photoreactivation, but when he achieved a four log reduction he did not get any photoreactivation. So I think possibly the answer might be simply stricter coliform standards.

MR. DeSTEFANO: I think the answer might be that it is not when you are getting a high ultraviolet dosage like you were in that second unit that maybe the mechanism and the site of action is different, and that it is not the DNA dimeration because if you are getting photoreactivation obviously it is not a resurrection happening. The cell never died. It was possibly altered in some point.

So my concern, somewhat similar to the gentleman from MIT, is that (and this is sort of my other nature as a Princeton student interested in public health rather than an engineer because I am going to throw a pipe wrench in the works) it is possible, I think theoretically, that what you are doing with the ultraviolet, especially at low radiation similar to the dosage used by biologists to study mutagenesis is you are somehow just stopping the cell from its ability to reproduce. It can catch up with that in photoreactivation. So it starts to reproduce again in your lactose. Also I know that (I have seen some references in the literature) one of the first uses of UV was as a mutagen, and it changed resistance of a bacterium to an antibiotic. I think it was streptomycin, and I think it was the same wavelength that was used. I just saw the reference to the article or the abstract. I have not read the whole article, so I am not going to hang my hat on that, but I would suspect (and I do not think any of the work done in Bergen County or the work done in North Carolina has taken this into account) that possibly at a certain dosage of UV, what you are merely doing or could merely be doing is inhibiting the cell's ability to ferment lactose. If that is done it is not going to show up on your test unless you are doing total counts too, because (I have worked with the MPN method) if it does not ferment lactose you are never going to see it.

MR. VENOSA: The cell's ability to ferment lactose is controlled genetically anyway.

MR. DeSTEFANO: But aren't you altering the genetic structure?

MR. VENOSA: Yes.

MR. DeSTEFANO: But could you also alter the genetic structure in a way that would inhibit its ability

to ferment lactose?

MR. VENOSA: Yes you could, and you could also produce other types of mutations such as antibiotic resistance too.

MR. DeSTEFANO: I do not know if any of you are familiar with some other things that I have come across in my search of the literature of actions of UV light, one of them being its action on the membranes of the lysozomes and inducing lysis. It also induces lysis in another way, and I am not that versed in this, by releasing the coliphages in the *E. coli* and they all come out from wherever they are hiding and go with the cell. Again I just see those references. I think it was discussed in Strickberger's Genetics.

MR. VENOSA: I hardly doubt that that is going on in this system. Microbiology literature is replete with that type of information. It has been known for many years, but I do not think that is what is going on here.

MR. DeSTEFANO: How would you define its action?

MR. VENOSA: The mechanism of action for UV has been known for twenty-five years and it is the absorption by DNA and RNA. That is the primary effect. Now, certainly there are other secondary effects, but the primary effect is the absorption by the nucleic acid.

MR. DeSTEFANO: Now in doing my homework, just this section on UV says that you can get thymine dimeration, the DNA is altered, or you can get also I think uracil dimeration in the RNA. Now if the messenger RNA gets through and uses it as a decoder to produce the protein before the cell actually dies, you are getting a different code than the one that was originally in the cell.

MR. VENOSA: You are not going to get translation if the messenger RNA is blocked.

MR. DeSTEFANO: If you have only produced one dimer, why can't it go through. What is stopping it?

MR. VENOSA: By the very fact that the dimer forms it blocks further replication. You cannot get it. It is genetically impossible.

MR. DeSTEFANO That is not what Dyson implied. I am sure you know much more about it than I do.

MR. VENOSA: I think we are getting beyond the subject of this conference.

Why don't we call for one or more questions from the audience.

DR. ROSEN: I would like to ask a question of Mr. Scheible. I am sorry, it is practical.

You indicated that based on this particular design in this wastewater that the cost of a system for one additional log increase reduction would be on the order of a factor of four from the number that you calculate. Is that correct? Total cost?

MR. SCHEIBLE: Three and a half. I would also state that these are preliminary cost estimates.

DR. ROSEN: Okay. This gets back to some of these questions about where you sample, and whether you are looking at a sample after photoreactiviation or not in terms of what you count and what vou do not count. If you are talking about a difference between a 200 fecal coliform, assuming you are starting at the same level, and a 2.2 total coliform in California, you are talking about a factor sixteen in the cost or 9, 10 or 12, somewhere in that range, based on these preliminary estimates, and I think that is significant and has to be considered in the whole evaluation here.

DR. JOHNSON: I might say that in my judgement with that particular wastewater this unit is killing the gnats with a sledge hammer. They are putting in a very large dosage of UV into the sewage of the type that was being treated in Northwest Bergen County. In other words, I think we are at the stage in ultraviolet disinfection we were with ozone five years ago. UV is just getting started, and I think that ultraviolet disinfection can do a much better job as we learn more about the process. It is going to get better, and I think we are going to have trouble if we continue to talk about ultraviolet disinfection in terms of suspended solids and conventional kinds of wastewater measurement parameters. It does not make any difference whether your suspended solids are 5 or 500. What is important is how much UV transmission you have.

DR. HILL, *Louisiana Tech. Univ*: A couple of the speakers have mentioned that the presence of iron inhibits UV disinfection. I am wondering if someone can put a number on this. I am thinking of a relatively small community that uses ground water for drinking water with just chlorination, and it comes out of the ground close to the public health service maximum of 0.3 mg/l, and there is some contribution in the distribution system from corrosion and iron bacteria in some places.

MR. ELLNER: Just as Dr. Johnson mentioned, even with iron you cannot take a number and say 0.3 or 3 ppm of iron is going to inhibit UV performance. You have to relate it to UV transmission. From a practical standpoint and not taking up everybody's

time, I will give you a copy of a study done here in Cincinnati at the Taft Sanitary Engineering Center examining the effects of iron, color, turbidity, but relating it to UV transmission. In their studies for your specific question, three parts per million of iron did not significantly affect the performance of a specific UV design parameter. One other point I would like to leave you with. When you review this discussion, and you take figures, they are not absolutes. For example, Mr. Scheible's economic figures, his cost figures, relate to a particular configuration that he studied. Now it is possible that there might be certain UV approaches that can cost three times as much, and there might be other UV approaches that can cost one-third. The suggestion I make is: keep an open mind and realize what we are discussing here is the broad brush stroke. Don't either dismiss or accept something based upon specific statements that are made today. I think we are creating the background for the picture, but a lot of things still have to be filled in.

DR. ROSEN: Getting back to using this UV absorbance as a measure of design or acceptability or efficiency of use of UV in disinfection, we are still talking about things like color and turbidity and things that we see in visible light. There must be a lot of UV studies done on wastewater historically in terms of trying to identify compounds, etc. My question is: Does anybody know if we do have some sort of range that we might expect based on lots of different kinds of effluents to try to get a feeling of where this fits? The things that have all been studied so far are pretty high quality relative to nitrification and some of the other things.

MR. REYNOLDS: ***Aquafine, Inc.:*** Most of the work done, and you can find this in Photochemistry and Spectroscopy by Simmons, shows general wastewater at 254 nm to have an absorption coefficient between 0.13 and 0.2. Typically that is going to take you down to about 60% transmission in a one centimeter cell. Now, there is also some recent data in Photochemistry and Photobiology where they are doing specific work on absorbance with anilins and other compounds which do have a tremendous absorptivity of UV at 254 nm. To elaborate on the iron, if you go to 0.3 mg/l iron, you are going to find tremendous fouling in the UV system very quickly because of the thermal differential on the quartz in the wastewater. Typically it tends to play down on the quartz jackets, thereby having to have some type of either mechanical or chemical cleaning in the system.

MR. WARRINER: ***CH_2M Hill:*** This may not be a response to Harvey Rosen's comment. I ran across proprietary equipment a couple of years ago in Britain for continuous measurement of TOC, which involved an absorption cell at 254 nm, and I wonder if it is used at the other site from the other point of view if that is not a possible source of this kind of data, and I puzzled about that because I continued to hear suspended solids, other visible light parameters used. I guess it is a question for Dr. Wolf.

DR. WOLF: I am familiar with the fact that in German drinking water practice there is some application made to measuring UV absorbance on a continuous twenty-four hour basis. I am unaware of this type of application in wastewater. Certainly from what I have found myself this would be a terribly fruitful path to follow with respect to getting some kind of handle on the quality of effluent with respect to organic properties. I really think so.