United States
Environmental Protection
Agency

Region 5
230 South Dearborn Street
Chicago, Illinois 60604

September 1988

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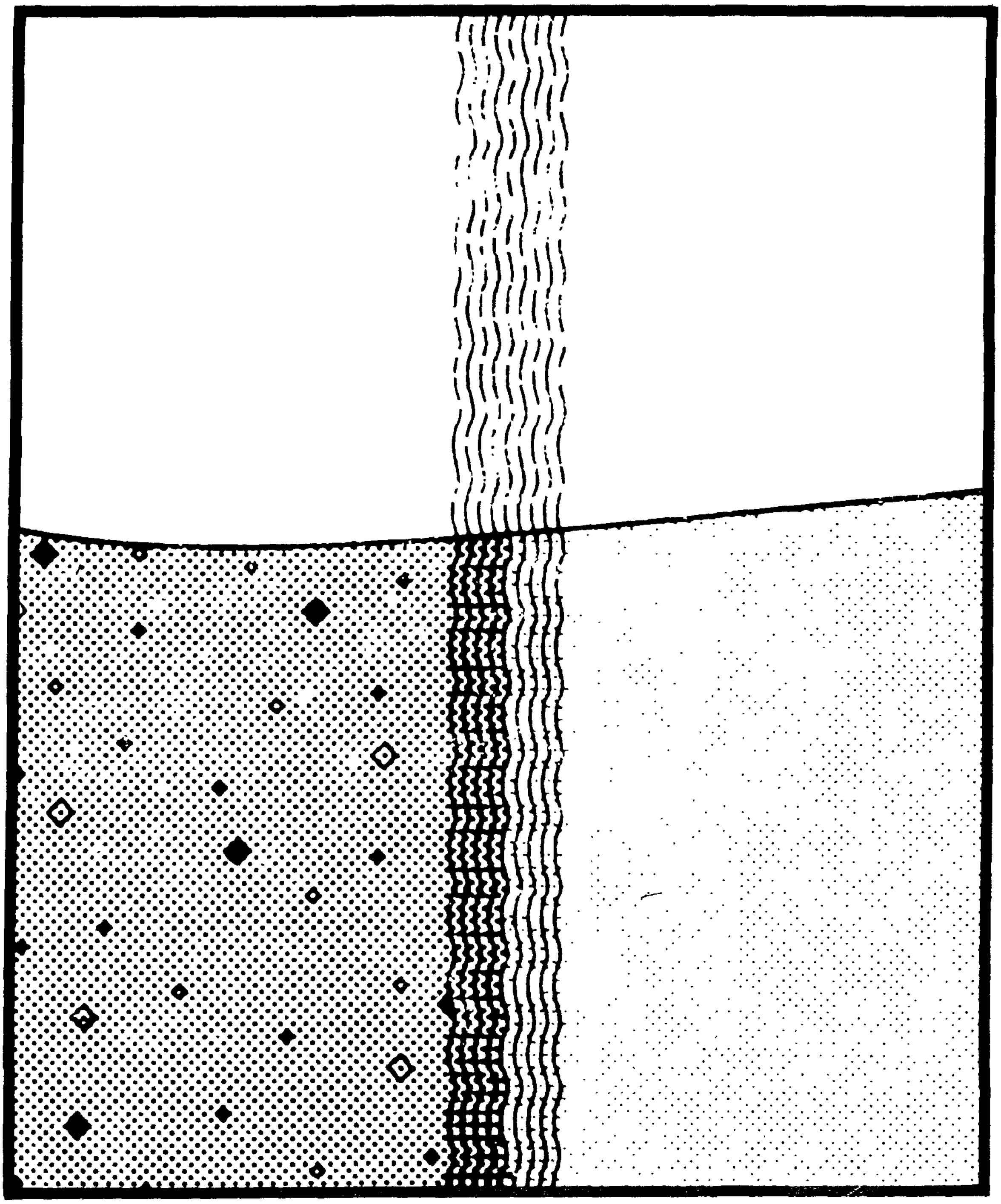
Municipal Facilities Branch - Technical Support Section

EPA

Ultra Violet Disinfection

Special Evaluation Project



Ultraviolet Disinfection - Region V Update
Special Evaluation Project Report

September 1988

A. Introduction

The question of toxicity to resident aquatic species from chlorine residuals, with the resultant need for dechlorination systems, has fostered increased interest in several alternative disinfection systems among communities that currently either chlorinate their effluent or are constructing entirely new wastewater treatment systems. One of these alternative disinfection systems is ultraviolet (UV) disinfection. This report will update the 1984 Region V data base on UV disinfection of wastewater in order to analyze the effect of recent changes in the design, operation, and maintenance of UV disinfection systems.

The data collected for this report was assembled from manufacturer's literature, various WPCF articles on UV disinfection, USEPA's design manual on municipal wastewater disinfection, specifications for UV disinfection from several plants in Michigan and Ohio, discussions with plant operators in the Region who work at plants using UV disinfection, capital cost data found in planning documents for several communities in Indiana and Ohio, and on-site visits at various plants using UV disinfection.

B. Background

The earliest operating (1981) Region V municipal UV disinfection facility is located in Lyons, Wisconsin. Since 1984, the number of municipal wastewater treatment plants (WWTP) that are either planning, designing, building, or operating UV disinfection systems in Region V has approximately tripled from about 20 to 60 plants (see Tables 1 & 3). Michigan has experienced the largest increase in plants using UV disinfection, with Wisconsin and Ohio not far behind. Several communities in Indiana are currently planning to use UV disinfection, but have not yet reached the design stage. Minnesota and Illinois have a handful of plants that employ UV disinfection systems.

C. System Description

Disinfection by UV radiation is a physical process relying on the transference of electromagnetic energy from a source (lamp) to an organism's genetic material. The lethal effects of this energy result in the irradiated cell being unable to replicate. The primary, and most widely used, source of UV light energy is the low-pressure mercury arc lamp. Approximately 85% of its energy output is at the wavelength of 253.7 nanometers (nm), which falls within the optimum wavelength range of 250 to 270 nm for germicidal effects. The lamps are long, thin (1.5-2.0 cm) tubes similar to fluorescent lamps but transparent instead of opaque. The lamps typically come in two lengths (0.75 and 1.5 m). The radiation is generated by striking an electric arc through mercury vapor. The discharge of energy generated by excitation of the mercury results in the emission of UV light.

Currently, there are two basic generic types of reactors that are in use. The first, generally called the quartz-tube reactor, is a contact reactor in which the lamps are submerged in the wastewater (see Fig. 1). The lamps are sheathed in quartz jackets that are slightly larger than the lamp. Flow can be either parallel or perpendicular to the lamps. The contact reactor configuration may be further divided into either an enclosed vessel system or an open-channel system. These systems consist of, respectively, a lamp battery enclosed in a reactor shell and a lamp battery that is capable of being dipped into a plant's effluent channel. In the second generic type of reactor, called the teflon-tube reactor, the UV lamps are suspended outside a transparent teflon conduit carrying the wastewater to be disinfected. This type of reactor has only this type of parallel flow configuration.

In addition to the lamp batteries and reactors, a complete UV system must include ballasts for the lamps. The ballast is placed in series with the lamp to provide a starting voltage and to maintain constant current. Generally, the ballasts are held either in enclosures above the lamp battery or in separate power panels remote from the reactor. The instrumentation in a UV system generally includes UV intensity monitors and individual lamp monitoring and operations circuitry, which can be included as part of the reactor or the power panel.

A recent addition to the field of UV disinfection is the medium pressure mercury arc lamp. This lamp has an energy output over 25 times greater than the more commonly used low pressure lamps and uses a permanent transformer instead of expendable ballasts to control current and voltage. Although the cost of the medium pressure lamp is about four or five times that of the low pressure lamp and the life cycle is about half of the low pressure lamps, the reduced number of lamps necessary for adequate disinfection may make this lamp more cost-effective. More data needs to be collected regarding the medium pressure lamp in municipal applications before definitive statements can be made. There is currently one municipal installation of this type in Region V at Lewisburg, Ohio that has been in operation for less than 1 year.

D. Critical Design Areas

There are three key areas that govern the design and eventual capability of a UV disinfection system to produce an effluent that complies with permit standards. The first area relates to the hydraulic properties of the particular reactor that is being used. The path that an organism in the reactor takes will determine whether it will come into contact with strong enough UV radiation for a sufficient amount of time to enable the radiation to render that organism sterile (i.e., unable to replicate or non-infectious). Thus, the reactor must be designed so that the greatest number of organisms come into contact with the strongest UV radiation for the longest possible time. The ideal hydraulic design of a UV reactor is one with plug flow and minimal axial dispersion. The flow should also be radially (perpendicular to flow path) turbulent to encourage mixing in the nonuniform intensity field in the reactor. Although early reactor designs did not consider the hydraulic properties necessary for proper disinfection of wastewater, with the result that many reactors exhibited shortcircuiting problems inhibiting adequate disinfection, most recent designs and specifications have included these design considerations so that short-circuiting is no longer a problem.

The second area that should be considered in the design of a UV disinfection system is the intensity of the UV radiation that ultimately reaches the target organism. The intensity will be affected by not only the age of the lamps and their configuration, but also by the surfaces and material that stands between the UV radiation and the target organisms. The minimum bacterial density level that can be achieved by the UV disinfection process is a function of the suspended solids concentration and is called the particulate bacterial density. A reduced UV disinfection efficiency with increased dose is attributed to the aggregation or occlusion of bacteria in particulate matter. UV light is unable to penetrate this material and inactivate the bacteria. This is the reason for the inability of the UV process to adequately disinfect wastewaters that contain more than about 30 mg/l of suspended solids. Presently, there is no commercially available detector which can measure the true intensity in a complex lamp reactor. This is because only light which is normal to the surface of the detector, i.e., collimated light, will be fully measured. In a reactor, however, the target organisms are exposed to UV light in a three dimensional setting, usually from more than one source.

An effective method for estimating delivered dose and system intensity in a given reactor is the bioassay procedure. The species selected for the assay should be one which is easy to culture, identify, harvest, and which has a consistent and reproducible dose-response. Bacillus subtilis spores are the most commonly used species for this assay. Using a collimated light device, which allows an accurate measurement of the intensity directly with a commercial radiometer, equal portions of a B. subtilis suspension are exposed to a set intensity for a series of fixed time intervals, yielding known doses. The response is plotted against the dose, and this relationship serves as the calibration for the subsequent reactor assays. The reactor to be tested is set to the desired flow and operating conditions and the culture is injected into the influent. The effluent is then sampled at set time intervals and assayed for the known bacterium. This is repeated with the lamps not in operation. The log survival rate for each time interval is determined and the equivalent dose is estimated from the previous dose response calibration curve. Plotting dose against time then yields the dose-rate or intensity. The bioassay procedure is an independent verification of system design and, as such, it can be used either to verify the appropriateness and validity of a design or to compare the performance of competing commercial units during design and/or bid phases prior to installation.

The third area of concern in the design of UV disinfection systems is the quantification of the various characteristics of the wastewater that is to be disinfected. The parameters of primary concern regarding the wastewater characteristics are the flow rate, suspended solids, initial coliform density, and the UV absorbance of the wastewater. Even though the first two parameters are set by the design of the plant, and the coliform density and the UV absorbance of the wastewater (commonly referred to as the UV absorbance coefficient) must be measured prior to design, all wastewater characteristics should be empirically measured for confirmation of actual values prior to design of a UV disinfection system. These measurements should be collected as grab samples during the times corresponding to peak diurnal flows which reflect the maximum bacterial density levels and maximum loading periods for a WWTP.

The design criteria that are applicable to the design of a UV disinfection system at a particular site should be determined by pilot-testing or in-place performance testing. Since the composition of the wastewater is different from site to site, the only way to ensure that the UV disinfection system will operate properly and enable the plant to meet permit limits is to do this testing. Although some recent specifications include testing as a means of setting the system design parameters, this has not been a universal practice. Since UV disinfection of wastewater is still a relatively new technology, there may be engineers that are not fully familiar with all of the necessary aspects of a properly designed municipal UV disinfection system (see Table 4).

A quick comparison of several similar communities in Indiana and Ohio (see Table 5) emphasizes this point. Although more in-depth analysis needs to be done, it is interesting to note that in those communities with higher effluent limits ($CBOD_5$ = 25, TSS = 25) UV disinfection was the chosen alternative for disinfection, while in communities where the effluent limits were more favorable for UV disinfection ($CBOD_5$ = 10, TSS = 10), chlorination/dechlorination was selected. Although there are always site-specific reasons for cost variances, the wide disparity in present worth costs for similar communities further suggests a gap in knowledge about municipal UV disinfection systems and application of that knowledge to design.

E. Critical Operation and Maintenance Areas

Important components of a successfully designed UV disinfection system are the operation and maintenance (O & M) of that system. The O & M of a UV disinfection system is geared primarily to ensure that enough UV radiation is transmitted to the organisms to render them sterile. Essentially, this means that the lamp, ballasts, and reactor are functioning at peak efficiency and that all surfaces between the UV radiation and the organisms are clean so that maximum radiation can be transmitted.

Since UV lamps will progressively deteriorate with increasing number of starts, care must be taken not to have frequent on/off cycles that rapidly shorten lamp life. The normally cited lamp life is about 7500 hours which is approximately equal to 1 year of use. In the field, however, replacement of lamps has not always been practiced according to recommendations. Some plants replace lamps three times per year (every 2500 hours), while at some plants the lamps are not replaced until they burn out. While costs per lamp vary from \$25 - \$100, there doesn't seem to be a correlation between cost and replacement frequency. For more effective control of power outputs and lamp usage, voltage dimming, which avoids the on/off cycling that reduces lamp life, in conjunction with the ability to turn portions of the system on and off on the basis of time, should be incorporated into the design of a UV disinfection system. Adjustments can then be made on a diurnal basis to reflect the normal variation in a plant's flow. Although some early designs incorporated float activated switches, timers, or the ability to control lamp banks according to flow, this was not a universal practice. It is important to include some kind of control to prolong lamp life, since lamp replacement is a major operational cost.

In order to protect the lamps from breakage and internal clogging, removable screens should be placed ahead of the unit to prevent debris from entering the system. This is especially important for quartz-tube reactors where the tubes are in the wastewater flow. The efficiency of a lamp is also affected by the temperature of the lamp wall. The optimum wall temperature is between 95 and 122° F. The reactor design that is most conducive to control of lamp wall temperature is the non-contact (i.e., lamps not in wastewater stream) reactor, otherwise known as the teflon-tube reactor, where it is possible to maintain the lamps at their optimum wall temparature by controlling the temperature of the air surrounding the lamps. In quartz-tube reactors, newer designs provide O-ring spacers that can be slipped over the lamps to prevent direct contact with the cooler quartz sheath. Another consideration for UV lamps is the type of quartz sheath that surrounds the lamp in a quartz-tube reactor. Quartz is transparent to energy at the 185 nm wavelength. Energy at this wavelength will ionize free oxygen to form ozone, which is an absorber of UV energy at the germicidal wavelength of 253.7 nm. This means that a UV lamp with a fused quartz sheath will not produce the amount of UV energy necessary for proper disinfection. It is appropriate, therefore, to use lamp sheaths that have a low transmittance at the 185 nm wavelength, such as vycor or other high transmission glass. Most current UV lamp designs use such a sheath and this is not a problem.

It is important to ensure that the ballasts that are used in a UV disinfection system are compatible with the lamps. Improperly mated lamps and ballasts will either not work or will have much shorter life cycles. The ballasts should also have a mechanism that forces shutdown in case of overheating. The life cycle of ballasts (5-7 years) is greatly shortened by excessive heat. It is important, therefore, to have adequate ventilation for the power panel that normally contains the ballasts. This has been a problem in many early designs and the cause of rapid failure of numerous ballasts. Since ballast replacement costs ($50-$70) are similar to lamp replacement costs, this can be a source of significant unnecessary expenditure.

One of the most common causes of a UV disinfection system's non-performance is inadequate cleaning frequency. This refers to both the reactor itself, as well as the lamp, quartz and teflon surfaces. Over time, both the quartz and teflon-tube reactors will experience fouling of the lamp and tube surfaces. In a quartz reactor, the outside of the quartz sheath surrounding the lamps will become befouled. This is particularly the case where the wastewater is from primary or secondary effluent, has a high grease and oil content, or has a high hardness content. Compounds of iron, calcium, magnesium and manganese, which are found in hard water, will precipitate out on the quartz sheath and prevent the UV light from penetrating into the wastewater. Also, an organic film will develop on the quartz sheaths if low quality wastewater is present, or if the wastewater has a high grease and oil content. The teflon-tube reactor experiences similar reductions in UV transmittance with time. A film will settle in the teflon conduit carrying the wastewater, similar to the film on the quartz sheaths. In addition, the UV lamps will become a place for dust to settle, thereby scattering and reducing the amount of UV light available for disinfection.

There are several methods available to clean the fouled lamp, quartz and teflon surfaces: chemical cleaning, mechanical wipers, ultrasonics, and high pressure spray wash. The last three methods are meant to augment chemical cleaning, which is the recommended means of cleaning for both quartz and teflon-tube reactors. The most prevalent cleaning agent in use today is citric acid, however, various other acid solutions (e.g., muriatic, sulfuric, phosphoric, oxalic) are also used. These solutions work best on inorganic depositions that are prevalent in wastewater that has a high hardness content. Other cleaning agents such as mild vinegar solutions and sodium hydrosulfite are also effective. Sodium hydrosulfite, in particular, is effective in closed reactor systems. In the case of organic fouling from wastewaters with high grease or oil content, detergents, alone or in combination with other cleaning agents, are effective in restoring the lamp and reactor surfaces. Often, various chemical cleaning agents must be tried in order to find the appropriate agent for the particular wastewater. The frequency of chemical cleaning will vary from plant to plant depending on the characteristics of the wastewater. The most prevalent method used to determine if cleaning is necessary is visual inspection of the UV reactor. NPDES violations of coliform levels are used by many plant operators as an indication that cleaning is necessary, however, cleaning should be done before a violation occurs. Thru experience, the proper cleaning frequency can be established, however, wastewater characteristics may experience subtle changes, where visual evaluation and experience may not be enough. Current designs, therefore, include either intensity monitors or radiometers, the latter of which are used in conjunction with the UV absorbance measurements that should be part of a plant's regular sampling program for operational control.

In order to keep the UV disinfection system operating at peak efficency, properly scheduled maintenance is necessary. At least once a year, the total system should be overhauled and all critical components (lamps, ballasts, reactor, monitoring systems, etc.) should be checked to ensure that deterioration has not occurred and that all surfaces are clean. The accessibility to the lamps, quartz sheaths, and Teflon tubes is critical to the ease of maintenance. This is more of a consideration for the enclosed vessel than the open-channel systems, however, both types should be installed in an area that offers adequate space to perform all of the required maintenance tasks. This is more of a problem in plants where another means of disinfection has been used and a UV disinfection system is being retrofitted into existing buildings, chlorine contact tanks, or effluent channels. A lot of early retrofit installations, in order to take advantage of gravity-flow, have been in cramped and tight quarters making accessibility and maintenance very difficult. Since a lot of future UV disinfection systems are going to be retrofit installations, design must include a consideration of adequate space for proper maintenance.

Unlike chlorine, which has a measurable residual than can be used as an indicator in monitoring system performance, UV disinfection has no such indicator. This can lead to over-utilization of the system in an attempt to simplify operations and ensure adequate disinfection. Unfortunately, this will also increase the costs to operate the process. A key operational tactic is to use only that portion of the system that is necessary to meet current performance demands. This will entail frequent sampling and analysis. The system should be sampled several times weekly during periods of peak diurnal flows when the maximum bacterial density levels and maximum loading are expected. The influent to the UV system should be analyzed for suspended solids, UV absorbance and coliform density. At the time of sampling, the flow rate as well as the operating condition of the reactor (number of lamps in operation, etc.) should be recorded. The effluent from the UV reactor should be analyzed for coliform density. Although at currently operating municipal UV disinfection systems such analyses are not being routinely performed, it is important to collect this data to not only evaluate system performance under current wastewater conditions, but also to be used as a tool in controlling the system and optimizing operations for maximum use of lamps and minimal use of energy. The continuous collection of this data will also aid in a rational approach to troubleshooting a non-performing system.

F. Conclusions

Region V will continue to see more installations of municipal UV disinfection systems, especially retrofit installations for plants where chlorine residual toxicity is an issue. As such, design engineers must be made fully aware of all of the critical aspects of a properly designed mumicipal UV disinfection system. There are three key areas that govern the design of a UV disinfection system: hydraulics, UV intensity, and wastewater characteristics.

The hydraulic properties of a particular UV reactor must be such that the greatest number of organisms come into contact with the strongest UV radiation for the longest possible time. As part of their responsibilities, the UV manufacturer must provide evidence (dye tests) that there is greater than 90% plug flow and no shortcircuiting within the reactor.

The intensity of the UV radiation that ultimately reaches the target organisms will be affected by the condition and configuration of the lamps, as well as the particulate bacterial density. These factors establish the lower limit of disinfection efficiency. In order to verify the validity and appropriateness of a particular design, a bioassay procedure to estimate delivered dose and system intensity must be performed. This procedure could also be used to compare the performance of competing commercial units during design and/or bid phases prior to installation.

Wastewater characterisics are site-specific and parameters such as the flow rate, suspended solids, initial coliform density, and the UV absorbance of the wastewater must be empirically measured for confirmation of actual values prior to design. These measurements should be taken during peak diurnal flows when a WWTP experiences the maximum bacterial density levels and maximum loading periods.

Once a UV disinfection system has been designed and built, the operation and maintenance of that system will determine the ability of the process to meet permit limits. The emphasis of O & M is to maintain the lamps, ballasts, and reactor at peak efficiency while also ensuring that all surfaces between the UV radiation and the target organisms are clean for consistent kill ratios.

UV lamps have a finite life that can be prolonged by the use of voltage dimming. Frequent on/off cycles will decrease lamp life. Inlet screens will prevent large debris from entering the UV disinfection system, clogging the reactor or breaking lamps.

Ballasts have to be protected from excessive heat which shortens their useful life. Adequate ventilation must be provided for the power panel that normally contains the ballasts. It is also important to ensure that the ballasts are properly mated to the UV lamps.

Inadequate cleaning frequency is one of the most common causes of a UV disinfection system's non-performance. The surfaces of the lamps and/or teflon tubes should be kept clean at all times to ensure that adequate radiation is being transmitted. There are several methods available to clean the surfaces in a UV reactor, but a chemical cleaning system that is integrated with the disinfection system is necessary regardless of what other methods are used.

Properly scheduled maintenance is necessary to keep the UV disinfection system operating efficiently. At lease once a disinfection season the total system should be overhauled and checked out. The system should also be thoroughly cleaned at the beginning and end of a disinfection season. In order to accomplish all of the necessary maintenance tasks, the UV disinfection system must be accessible and there must be enough room to remove and replace lamps, sheaths, etc. Drains, inspection ports, as well as sampling points must also be a part of a complete system.

Frequent sampling and analysis (several times per week) during periods of peak diurnal flows should be done as a tool to certify system performance, as well as, to control the system and to optimize operations. A key operational tactic and energy conserving measure is to use only that portion of the system that will meet current permit limits.

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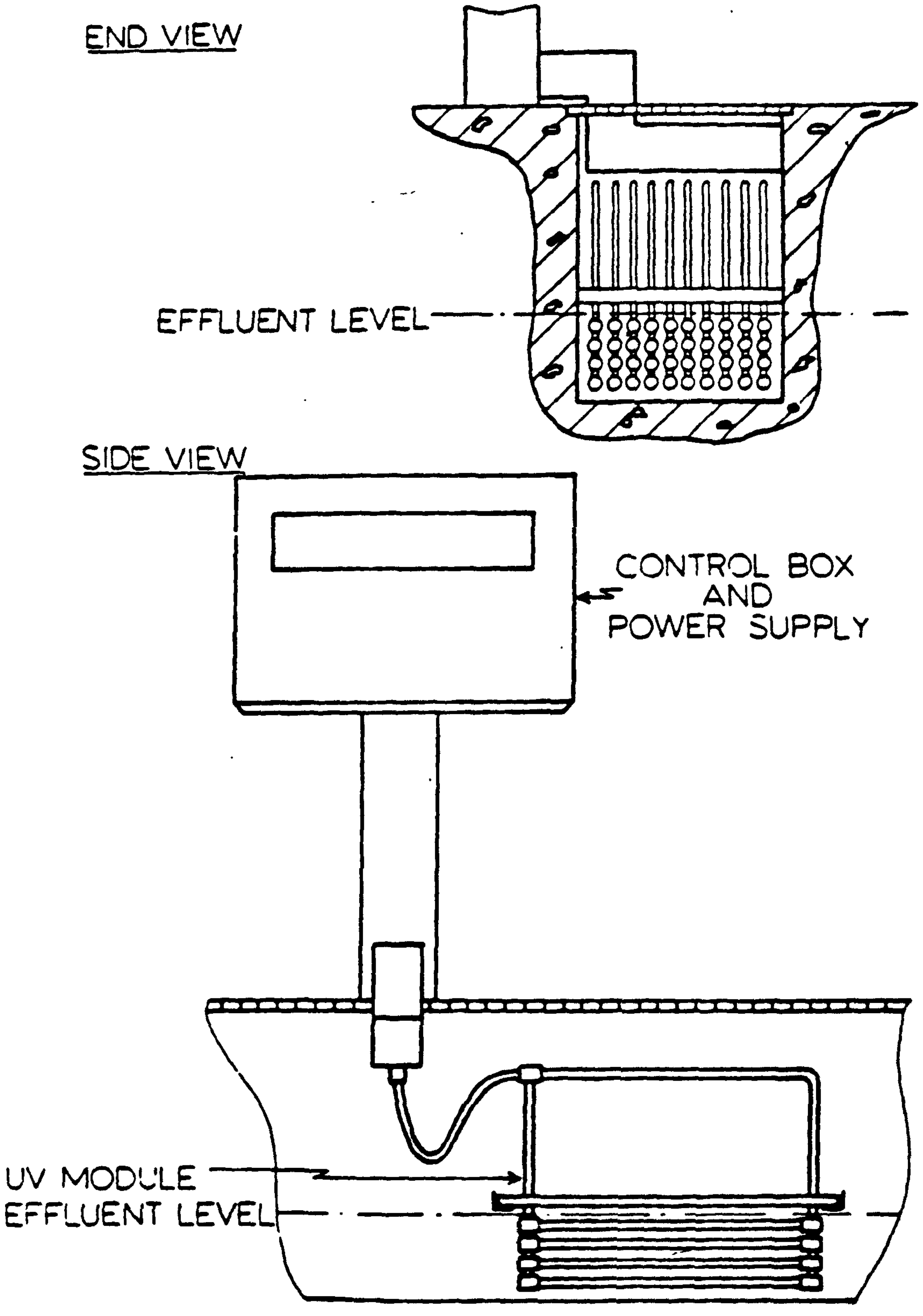

Figure 1. Schematic of the ultraviolet disinfection unit in the sewage treatment plant effluent channel

TABLE 1

Facility	Time in Operation (Started)	Flow MGD		Treatment Process Preceding Unit	Influent to unit, mg/l		Cleaning Frequency	Quartz (Q) Teflon (T) unit	Manufacturer	Frequency of lamp replacement/$	System Type	NPDES Discharge limit (200 FC/100 ML)	# of banks (units)/ # of (lamps)	Chemical Cleaning Agent Used	Bank Alternating or flow pacing/ dimming
		Current	Design		BOD	TSS									
Travis Point (MI)	(1986) 2 years	0.02	0.06	OD & tertiary sand filters	5	5	2x/season	T	UV Technology	Not yet/$100	C	Yes	2 teflon tubes/ (6 lamps) 4 lamps per tube	Murphy's soap solution	Alternate banks only when cleaning
Albert Lea (MN)	(1983) 5 years	5.0	12.5	sand filter & activated carbon filter	<5	<5	2x/season (beginning & end)	Q	Pure Water Systems, Inc	When go out/ $33	C	Yes	12 banks/(1296 lamps) 108 lamps per bank	citric acid	Only when bulbs are burning out in one bank
Lyons SD #2 (WI)	2 years (1981) (1986 upgrade)	0.03	0.09	OD	7-8	3-4	1x/month	Q	Trojan Technologies	Not yet (Last 3 yrs.) $30-$40	O	Yes	3 banks/(6 lamps) 2 bulbs per bank	Muriatic acid	No
Lewisburg (OH)	(1987)	0.14	0.174	AS	12	8	1000 hrs. (1 1/2 mos)	Q	Aquionics	1x/year $435	C	1000 FC/ 100 ml	2 banks/(2 lamps) 1 bulb per bank	oxalic acid	Automatic switch
Eden (WI)	(1982) 6 years	0.1	0.15	TF	12	17	2x/month	T	Northland Technologies	Appx. 9 mos./ (was $45), $60-65	C	NL	4 Teflon tubes/ (30 lamps) 12 bulbs per tube	None	No
Athens (WI)	(1985) 3 years	0.1	0.158	L	20	15-20	Every other week	T		5000 hrs./ $75	C	NL	3 Teflon tubes/(24 lamps) 6 bulbs per tube	Vinegar solution	Float activated switch
Northfield (MN)	(1983) (1988 upgrade)	1.8	2.5	TF, RBC	15	8-30	1x/season	Q	Trojan Technologies	Seasonally 8000 hrs./$25 ($60 5yrs ago)	O	Yes	4 banks/(288 lamps) 72 lamps per bank	Phosphoric acid	Timers on banks (diurnal)
Bemidji (MN)	(1985) 3 years	1.1	2.0	AS, single media filtration	5	5	2-3x/year	T	UV Systems, Inc.	1 1/2 yrs./ $50	C	Yes	2 banks/(168 lamps) 84 lamps per tube	Trisodium phosphate	No
Delta Township(MI)	(1988)	4.32	8.64	AS	<15	<15	———	T		———	C	Yes	4 banks/(768 lamps) 192 lamps per tube	citric acid	Computer controlled for flow
Ironton (OH)	(1987) 1 year	1.7	3.4	TF	20	20	1-2x/month	Q	Ultra Dynamics Corp.	<1 yr./$100	C	Yes	4 banks/(240 lamps) 60 lamp per bank	citric acid	No
Ettrick (WI)	1983-1987 4 years	0.04	0.064	RBC	16	5	1/year	Q	UV Purification Systems Inc.	7500 hrs. (1 yr)/$60	C	NL	2 banks/(20 lamps) 10 lamps per bank	citric acid	No
Waynesburg (OH)	1985 UV ran 203 hrs.	0.13	0.40	Biodrum	80-140	20-150	———	Q	UVPS, Inc.	———	C	1000 FC/ 100 ml	2 banks/(28 lamps) 14 lamps per bank	citric acid	No
Morton (MN)	1 year	0.05	0.132	AL	<10	20-25	Every 2 mos (6x/year)	Q	UVPS, Inc.	Not yet/ $85-$100	C	Yes	2 banks/(24 lamps) 12 lamps per bank	citric acid	No

Key
AL = aerated lagoons
AS = activated sludge
C = closed (pressurized reactor vessel)
L = lagoons
O = open (in-channel)
OD = oxidation ditch
RBC = rotating biological contactor
TF = trickling filter

TABLE 1 (cont.)

Facility	Time in Operation (Started)	Flow MGD		Treatment Process Preceding Unit	Influent to unit, mg/l		Cleaning Frequency	Quartz (Q) Teflon (T) unit	Manufacturer	Frequency of lamp replacement/$	System Type	NPDES Discharge limit (200 FC/100 ML)	# of banks (units)/ # of (lamps)	Chemical Cleaning Agent Used	Bank Alternating or flow pacing/ dimming
		Current	Design		BOD	TSS									
Deerfield (WI)	(1983) 5 years	0.165	0.195	AS	10-15	5	1x/yr(citric acid) 3x/day ultrasonic	Q	UVPS, Inc.	2 years/$70	C	NL	1 bank/(28 lamps) 28 lamps per bank	citric acid	No
Holmen (WI)	(1983) 5 years	0.225	0.810	AS	3-25	2-25	1/week	Q	UVPS, Inc.	1x yr (7500 hrs.)/$56	C	NL	2 banks/(120 lamps) 60 lamps per bank	citric acid	Flow Proportional
North Koochiching (MN)	2 years	1.2	2.3	TF	<25	<30	every few days	Q	UVPS, Inc.	once/$80	C	Yes	2 banks/(160 lamps) 80 lamps per bank		No
Lodi (WI)	(1983) 5 years	0.25	0.62	RBC	14-17	13-19	1x/week	Q	UVPS, Inc.	until burned out/$50	C	NL	4 banks/(40 lamps) 10 lamps per bank	citric acid	No
Spring Valley (WI)	4 years	0.09	0.36	RBC	15	15	1x/10 days	Q	UVPS, Inc.	7500-8000 hrs. $62-70	C	NL	2 banks/(26 lamps) 12 & 14 lamps per bank	citric acid	Yes (every 3 or 4 months)
Camp Point (IL)	1 1/2 years	0.220	0.2	L			1x/6 weeks	Q	UVPS, Inc.	3x/year (2500 hrs.) $100	C	Yes	2 banks/(32 lamps) 16 lamps per bank	citric acid	No
Poynette (WI)	(1982-1985) 3 years	0.3		OD	<5	<5		Q	UVPS, Inc.	very often/ $70	C	NL	3 banks/(30 lamps) 10 lamps per bank	citric acid	Flow Proportional

Table 2

Current manufacturers of UV disinfection systems at Region V WWTP's

1. Aquionics Incorporated
   Kenton Lands Road
   P.O. Box 18395
   Erlanger, Kentucky 41018
   Phone #: (606) 341-0710

2. Northland Technologies, Inc.
   1115 Chestnut Street
   Burbank, California 91506
   Phone #: (818) 841-8080

3. Trojan Technologies, Inc.
   845 Consortium Court
   London, Ontario N6E 2S8
   Phone #: (519) 685-6660

4. Ultra Dynamics Corporation
   1631 Tenth Street
   Santa Monica, California 90404
   Phone #: (213) 450-6461

5. Ultraviolet Purification Systems, Inc.
   299 Adams Street
   Bedford Hills, New York 10507
   Phone #: (914) 666-3355

6. Ultraviolet Systems, Inc.
   P.O. Box 707
   4902 Calumet Avenue
   Hammond, Indiana 46320
   Phone #: (219) 937-4500

TABLE 3

Ultraviolet Facilities in Region V in Design or Under Construction

Illinois (1)

La Moille

Michigan (18)

Almont
Bessemer
Blissfield
Clare
Flushing
Frankenmuth
Imlay City
Macomb (Village of Armada)
Manchester
Manistee
Marlette
Milford
Mt. Clemens
Oscoda
Port Washington
St. Ignace
Vassar
Williamston
Wixom

Ohio (5)

Ashland
Hillsboro
Senecaville
Williamsburg
Wilmington

Wisconsin

Beloit
Casco
Eagle River
Fish Creek
Marinette
Port Washington

TABLE 4

Items that should typically be considered in design of a UV disinfection system

- system design parameters (flow rate, TSS, BOD, wastewater temperature, absorption coefficient (0.35-0.5), initial coliform density, etc.)
- prequalification (bioassay-dose response curve and unit dosage determination)
- reduction of coliform count to NPDES limits after 7500 hours of lamp use
- minimum design dosage (16,000 microwatts/cm^2/sec) at 70% of lamp output
- greater than 90% plug flow and no short-circuiting (dye-test)
- production of 90% of UV light at 253.7 nm
- 65% UV transmissivity (minimum of 50%)
- rated lifetime of 7500 hours for UV lamps
- no significant production of ozone
- integrated chemical cleaning system
- minimum contact time (5-7 seconds)
- ballast cooling system
- lamp temperature control system (95-122^{O}F)
- inlet screens
- provision to drain reactor
- easy access cleanout/inspection ports
- suitable materials of construction (304 or 316 SS, resistant to UV, etc.)
- light dimming capability
- flow proportioning (ability to turn lamps on or off in relation to flow)
- monitoring systems (UV intensity, ballast temperature, lamp conditions, etc.)
- acceptance testing (after installation, at manufacturer's cost for re-testing)
- manufacturer's representative to be on-site for verification of proper installation, start-up, and operation
- ballasts certified by manufacturer to be compatible with lamps
- sampling ports at both inlet and outlet of the UV reactor
- 1 disinfection reason minimum warranty on system (coliform levels, minimum dosage, operation of individual components, etc.)

TABLE 5

Costs for chlorination vs. UV disinfection for several IN and OH communities* that have existing chlorination

INDIANA

Facility	Average Design Flow (MGD)		Capital Cost	O,M&R Cost	Salvage Value	Present Worth
Town of Churubusco $CBOD_5$=20,25 TSS=24,30	0.25	Cl-DeCl	70,000	10,500	8,215	165,300
		UV (*)	50,000	6,000	4,929	104,300
Town of Ferdinand $CBOD_5$=20,25 TSS=24,30	0.34	Cl-DeCl (*)	15,500	24,000	—	134,514
		UV	66,646	16,150	—	215,379
Kentland	0.46	Cl-DeCl	92,000	10,850	11,333	189,864
		UV (*)	82,000	10,250	2,667	175,921
City of Greensburg $CBOD_5$=10,25 TSS=12,30	2.4 *includes post aeration	* Cl-DeCl	204,000	271,000	9,000	546,000
		* UV (*)	396,000	113,000	7,000	502,000

OHIO

Facility	Average Design Flow (MGD)		Total Capital Cost	Annual O&M Cost	Total Present Worth
Village of North Baltimore $CBOD_5$=10 TSS=12	0.80	Cl-DeCl (*)	131,959	1,130	150,968
		UV	116,054	2,820	154,602
City of Van Wert $CBOD_5$=10 TSS=12	2.6	Cl-DeCl (*)	29,000	4,500	79,600
		UV	201,300	8,000	328,800
Village of Richwood $CBOD_5$=10 TSS=12	0.38	Cl-DeCl (*)	224,400	8,500	304,100
		UV	170,500	8,600	308,400
Village of Jefferson $CBOD_5$=10 TSS=15	1.21	Cl-DeCl (*)	110,410	Present Worth of O&M 124,170	225,510
		UV	189,270	100,800	274,520

(*) = selected alternative

* = derived from plannning documents