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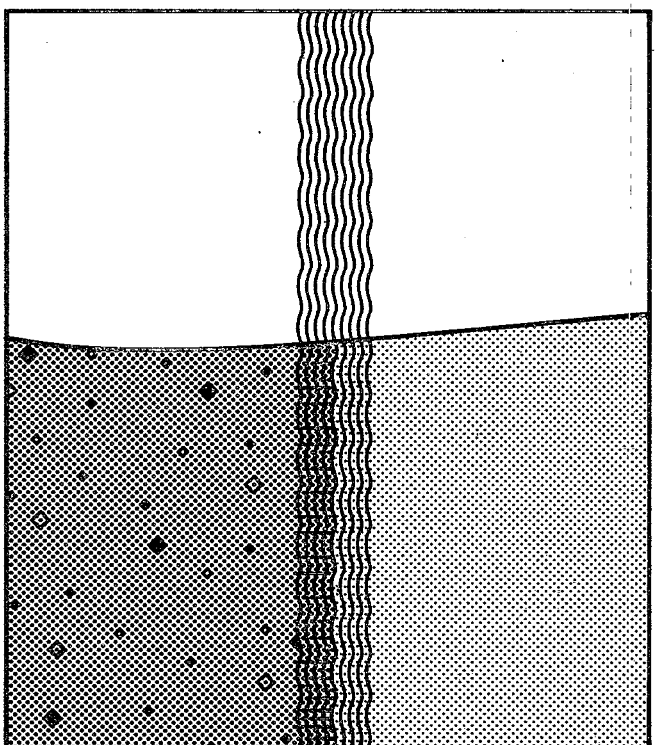
Disinfection with Ultraviolet Light -

Design, Construct, and Operate for Success



Disinfection with Ultraviolet

Introduction

The use of ultraviolet radiation for the disinfection of wastewater is an effective and economical alternative to chlorination and ozonation. Ultraviolet (UV) disinfection, like chlorination, involves the addition of a germicidal agent to a wastewater to inactivate the bacteria. Like ozonation, disinfection with UV radiation requires on-site generation of the germicidal agent. The principal advantage of UV disinfection over chlorination is that UV leaves no residual in the wastewater that may affect the receiving waters.

As shown in Table 1, there are a number of UV installations currently operating in the U.S. The list reflects the distribution of treatment plants with regard to size. The operating plants are predominantly small, although those in the planning or construction stages are larger.

Size (Design) (m^3/day) (MGD)	In Operation	Under Construction	Being Designed
<380 (<0.1)	15	--	7
380-1900 (0.1-0.5)	17	10	10
1900-3800 (0.1-1.0)	7	5	4
3800-19000 (1.5)	11	14	11
19000-38000 (5-10)	--	--	--
38000-190000 (10-50)	1	--	2
>190000 (>50)	--	1	--
Total	51	30	34

Note: List compiled Spring 1984.

Table 1. Summary of UV Installations in the United States.

The Process

Disinfection by UV radiation relies on the transference of ultraviolet electromagnetic energy from a lamp source to an organism's cellular material to prevent cell replication. The effectiveness of the radiation depends on the dose and the organism's exposure time.

The most efficient and effective artificial source of UV energy is the mercury lamp. It can be submerged in or suspended above the wastewater. If submerged, it is inserted into a quartz sleeve to minimize the cooling effects of the water. Figure 1 is a schematic representation of a UV disinfection unit showing a submerged lamp placed perpendicular to the direction of the wastewater flow. Lamps may also be placed

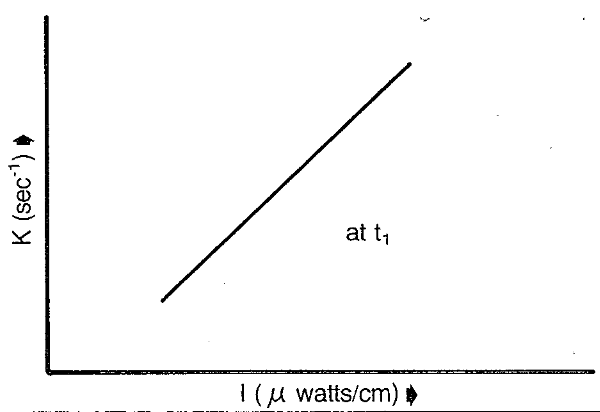
The estimation of K and N_p involves generating a set of data specifically for this purpose during the design phase of the project. The rate of bacterial inactivation (K) is a function of intensity as shown on Figure 2. Increasing the intensity of the UV radiation increases the rate, K. The coliform density associated with particulates, N_p, is a function of the suspended solids in the wastewater. When these relationships are established, the performance of the UV system can be approximated for different equipment configurations and process variations.

Design

The degree of pretreatment received before the disinfection step affects the sizing and performance of the UV system. The five wastewater parameters that most affect UV design and performance are flow (Q), suspended solids (ss), initial bacteria density (N_o), density of bacteria associted with particulates (N_p), and the UV absorbence of the wastewater.

The performance of a UV disinfection system is directly related to the initial density (N_o) of the indicator organisms . Performance is measured as the log of the survival ratio, N/N_o (see Figure 2). The initial density cannot be predicted based on the type of pretreatment received and should be measured prior to design.

The aggregation of bacteria and particulates, expressed as N_p, significantly affects the efficiency of UV disinfection. The level of N_p is related to the suspended solids content.



ated to the initial density (N_o) of the indicator organisms.
for a given residence time.

The UV "demand" of the chemical constituents of the wastewater must also be measured since this absorbence will affect the intensity of the radiation within the reactor. In specific design situations, the level of absorbence will affect the sizing of a system and possibly the configuration of the lamps.

Design Considerations

- Low pressure mercury arc lamps are currently the most efficient source of UV radiation.
- Temperature effects should be minimized. In quartz systems, O-ring spacers should be slipped over the lamps to prevent direct contact with the cooler quartz sleeve.
- Fittings holding the quartz sleeve should be tight and leakproof to prevent fouling on the inside of the sleeve.
- The control panel should be remote from the UV reactor.
- The ballasts must be properly mated with the lamps and thermally protected to shut down if they overheat.
- The electrical wiring should be properly sized and be resistant to UV radiation effects.
- Large debris should be prevented from entering the UV system.
- A feature that has been found not to be successfully applied is the use of microprocessor controlled automatic lamp bank shut-off systems. Many plants that originally had automatic systems have since reverted to manual control. The use of a simple mechanical cam timer that shuts off selected lamps or banks of lamps to reduce UV output during selected time periods is recommended.

Operational Considerations

- Cleaning

  Periodic chemical or detergent cleaning of surfaces that come in contact with the wastewater is required, particularly when the wastewater has a high oil and grease content or has a high hardness content. Magnesium and calcium carbonate deposits are a major cause of fouling of quartz surfaces. However, acidification of the reactor water will usually restore the surface. Organic fouling by oil and grease must

$$\mathbf{N = (N'_o + N_p)\ exp\ (-KIt) + N_p} \qquad (2)$$

where: N'_o = initial, non-aggregate density (coliforms per 100 ml)

N_p = coliform density associated with particulates (coliforms per 100 ml)

Generally $N'_o >> N_p$, and $N_o = N_o' + N_p$; therefore, Equation 2 can be rewritten as Equation 3.

$$\mathbf{N = N_o\ exp\ (-KIt) + N_p} \qquad (3)$$

Equation 4 incorporates the dispersive properties of a reactor under steady-state conditions.

$$\mathbf{N = N_o\ exp\ \left[(ux/2E)(1\text{-}z^{1/2})\right] + N_p} \qquad (4)$$

where: $z = 1 + 4KE/U^2$

x = length of reactor, cm

E = dispersion coefficient, cm^2/sec

K = rate of bacterial inactivation, sec^{-1}

u = velocity of wastewater, cm/sec

where: $u = xV_v^{-1}Q^{-1}$

V_v = void volume of reactor, liters

Q = wastewater flow, liters/sec

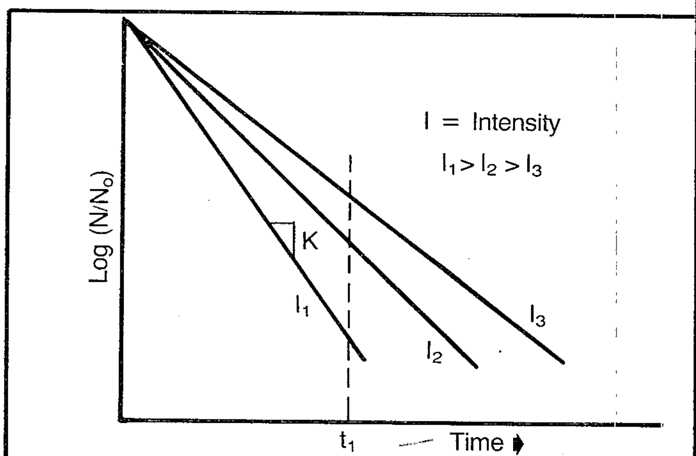


Figure 2. The performance of a UV disinfection system as
Note: The rate *K* increases with increasing intensi

be cleaned with detergents or a combination of cleaning methods.

Accessory equipment is available to maintain the surfaces. These include the mechanical wiper, ultrasonic transducer, or a higher pressure spray nozzle. While these methods are somewhat effective, intermittent cleaning with chemicals is generally required.

- Elements for Effective Maintenance

The reactor should be designed with drains that allow complete and rapid emptying.

The system should be modularly designed to allow isolation of any unit from the plant flow.

Strict inventories of lamp use and output should be maintained.

The reactor should be drained when removed from service.

- Labor

The labor requirements of the UV system are divided into three main categories: direct UV operation and maintenance tasks, general maintenance, and system overhaul. Overall, the total labor needs for the UV process are relatively low, ranging from approximately 40 persondays/year for a small 10 KW

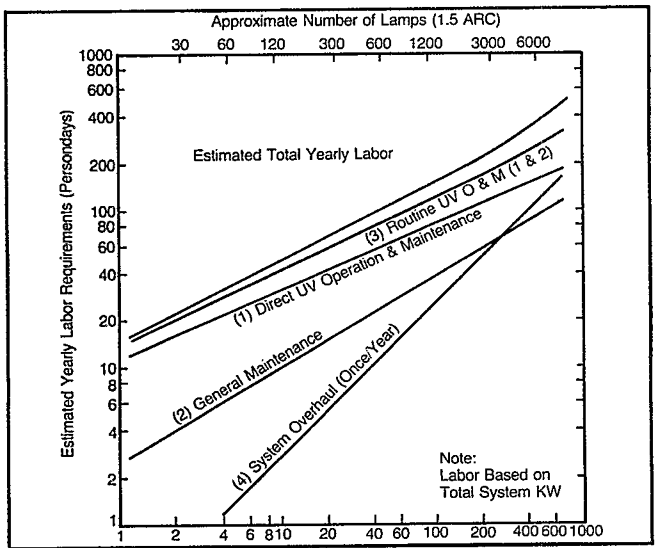


Figure 3. Estimate of Labor Requirements for the Operation and Maintenance of UV Systems

Scheible, O. K., et. al., 1986.

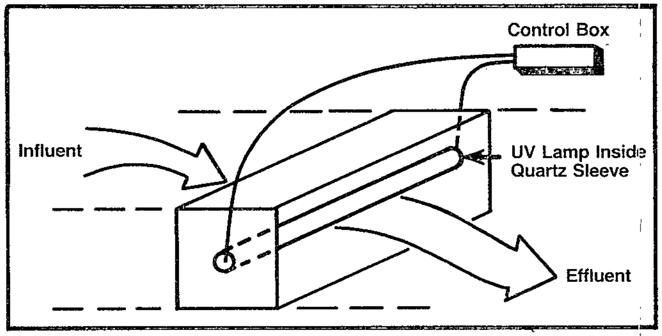


Figure 1. Ultraviolet Design Schematic.

parallel to the flow in some UV units. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases.

Process Model - UV Reactor Performance

A mathematical model was developed during a study[2] at Port Richmond, NY to account for major process variables in the design of a UV system. The derivation of this expression is briefly presented here. Inactivation of bacteria by UV radiation can be approximated by the following equation:

$$N = N_o \exp(-KIt) \quad (1)$$

where: N = effluent bacterial density (coliforms per 100 ml)

N_o = influent bacterial density (coliforms per 100 ml)

K = rate constant ($cm^2 watt^{-1} sec^{-1}$)

I = intensity $watt(cm^2)^{-1}$

t = time of exposure (sec)

Equation 1 is a good first approximation of a response to a given dose. However, direct testing on mixed cultures often shows a reduced efficiency with increasing dose. In wastewater treatment, this has been attributed to the aggregation of bacteria and particulate matter. Ultraviolet light is unable to penetrate this material to inactivate the bacteria; thus, the continued elevation of dose will show a diminishing response as residual active bacteria are protected in the particulates. Consequently, Equation 1 should be modified (shown as Equation 2) to account for the effect of particulate matter in the wastewater.

(120 lamps) system to approximately 40 persondays/year for a 400 KW (5000 lamps) system. Total yearly estimated labor requirements are presented in Figure 3.

Summary

Studies have found UV to be very effective for disinfection of secondary or tertiary effluent. In addition, the studies showed quartz systems to be generally more energy efficient than teflon systems. Also, the efficiency of both systems drop significantly as turbulence and suspended solids levels increase above secondary levels.

The UV process is relatively simple and also offers the advantages of system flexibility and capability of responding to changes in demand. Since the process leaves no residual in the wastewater that could impact the receiving water, less rigorous control is necessary than that associated with chlorine. In addition, a mathematical model recently developed will aid in the design of future UV disinfection systems.

Additional Reading

1. U.S. Environmental Protection Agency, *Technology Transfer Process Design Manual for Municipal Wastewater Disinfection*, U.S. Environmental Protection Agency, CERI, Cincinnati, OH, 1986.

2. Scheible, O. K., et. al., *"Ultraviolet Disinfection of Wastewaters from Secondary Effluent and Combined Sewer Overflows."* EPA-600/2-86-005, U.S. Environmental Protection Agency, WERL, Cincinnati, OH, 1986.

3. White, S. C., et. al., *"A Study of Operational Ultraviolet Disinfection Equipment at Secondary Treatment Plants."* Journal of the Water Pollution Control Federation, March 1986, Vol. 58, pp. 181-192.

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