Introduction

Before a UV system is installed in a wastewater treatment plant for disinfecting wastewater, it is important to gather enough information to determine whether it is a suitable application and that the UV system is designed to meet the disinfection requirements under the worst case conditions. This paper will give an overview of the major parameters that must be taken into consideration.

The major parameters listed in Table 1 below must be taken into consideration when a UV disinfection system is being designed for wastewater. The customer or the consultant must provide this information to the UV system manufacturer since each UV system is designed on an individual basis.

Table 1. Major Parameters Affecting the UV Disinfection of Wastewater

- UV Transmission or Absorbance
- Suspended Solids
- Flow Rate or Hydraulics
- Iron
- Hardness
- Sources of Wastewater
- Disinfection Performance
- Lamp Life
- UV System Configuration and Redundancy

UV Transmission or Absorbance

UV light's ability to penetrate wastewater is measured with a spectrophotometer using the same wavelengths that is produced by the UV lamps. This measurement is called the Percent Transmittance (%T) or Absorbance (A), and it is a function of all the factors that absorb or reflect UV light. Figure 1 shows the effect of a soluble organic compound and suspended solids on the UV %T (Whitby et al., 1985). As the %T gets lower (higher absorbance) the ability of the UV light to penetrate the wastewater and reach the target organisms decreases.

The soluble UV absorbing compound, parahydroxybenzoic acid, produces a clear colorless solution in water, but as can be seen in Figure 1, it readily absorbs UV light. It is imperative that the UV transmittance of wastewater is measured because it is impossible to estimate the UV transmittance by simply looking at a sample of wastewater with the naked eye.

![Figure 1](image_url)  
Figure 1. The effect of a soluble UV absorbing compound (parahydroxybenzoic acid) (●—●) and suspended solids (+--+) on UV transmittance at a wavelength of 254 nm.

Figure 2 illustrates the effect of this UV absorbing soluble compound on the disinfection ability of a parallel flow UV system with two banks of UV lamps in series (Whitby and Palmateer, 1993). As the UV transmittance decreases, so does the UV fluence (UV dose) and the number of fecal coliforms increases. Therefore, the applied fluence of UV light required is dependent on the disinfection standard and the UV transmittance. Figure 2 also shows the results of doubling the UV fluence as the wastewater passes from one bank of UV
lamps through a second identical bank of UV lamps. By doubling the UV fluence, lower UV transmittances can be treated to reach a fecal coliform limit of 200 per 100 milliliters. Therefore, the UV system must be designed for the minimum UV transmittance.

The system designer must obtain samples of wastewater during the worst conditions, or carefully attempt to calculate the minimum expected UV transmittance by testing wastewater from plants that have a similar influent and treatment process. The designer must also strictly define the disinfection limits, since they determine the magnitude of the UV fluence required.

Figure 2. The effect of UV transmittance on the fecal coliforms after one bank (UV Unit #1) and two banks (UV Unit #2) of identical UV lights.

Suspended Solids

Suspended solids in wastewater will absorb or reflect the UV light before it can penetrate the solids to inactivate any occluded microorganisms (Emerick et al., 1998). Figure 1 shows the effect of suspended solids on the UV transmittance of water. This figure shows that with these particular suspended solids, a level of 20 mg/L produces a UV transmittance of 56% in deionized water. Therefore, the system designer must be very careful to determine both the minimum UV transmittance and the maximum suspended solids levels.

Figure 3 demonstrates the effect of adding suspended solids to a parallel flow UV system with two identical banks of UV lights in series (Whitby et al., 1985). As the level of suspended solids increases, the number of surviving fecal coliforms rises. This is a result of the fecal coliforms occluded in the suspended solids and being protected from the UV light. Doubling the UV fluence by adding a second identical bank in series with the first bank reduces the scatter in the data but does not dramatically reduce the number of surviving fecal coliforms. It can be very difficult to penetrate the suspended solids with the UV light, and it is also very plant-dependent as to how many indicator organisms are present in the suspended solids (Darby et al., 1999) as a result of the sludge retention time.

Figure 3. The effect of adding suspended solids to one bank (●) and two banks (■) of identical UV lights in series.

If a wastewater treatment plant producing high levels of suspended solids is already in operation, pilot testing will show the efficacy of the cleaning system for the quartz sleeves as a result of the possible fouling of the quartz sleeves by the suspended solids. Pilot testing or fluence response curves with a collimated beam of UV light will also determine whether the indicator organism’s limit can be attained (Moreland et al., 1997).

Obtaining the proper information about the maximum level of suspended solids is very important for the sizing of the UV system. It is wise to remember that conditions today may not be indicative of what will be happening ten or fifteen years later when the plant reaches its hydraulic limit.

Flow Rate or Hydraulics

The United States Environmental Protection Agency (USEPA) provides an in-depth analysis of the effect of hydraulics on the UV disinfection of wastewater (USEPA, 1986). Please refer to Section 7.0 of EPA /625/1- 86/021 Design Manual - Municipal Wastewater Disinfection for a detailed discussion.

The number of microorganisms that are inactivated within a UV reactor is a function of the multiplication of the distribution of fluence rates and residence times. That is, the UV fluence is equal to the Fluence Rate ($E'$)\(^2\) times the Retention Time ($t$)

$$\text{Fluence} = (E')^2$$

As the flow rate increases, the number or size of the UV lamps must be proportionately increased to maintain the same fluence rate.

\(^2\)The above EPA document refers to the fluence rate as "intensity" ($I$).
disinfection requirements. An ultraviolet disinfection system must be designed for the minimum fluence. The minimum fluence occurs at the maximum flow rate, end of lamp life, maximum fouling of the quartz sleeves and worst-case conditions of the wastewater.

The UV unit must be designed so that it provides as much sideways motion as possible with very little forward mixing. This will ensure that every microorganism is exposed to the average fluence of UV light. This is especially important when the water has a low UV transmittance or high level of suspended solids. Open channel UV systems, in which the wastewater flows parallel to the submerged lamps provide a very good hydraulic profile, as shown in Figure 4.

![Figure 4. Typical hydraulic profile of an open channel UV Disinfection System at design flow.](image)

It is important that the wastewater entering the UV system has a uniform velocity profile across the array of UV lamps. This ensures that all the wastewater is subjected to the same profile of UV fluence rates and retention times.

**Level Control**

The effluent height within the UV channel must be rigidly controlled above the uppermost UV lamp, under all flow conditions, by means of a counter balanced level control gate (Figure 5) or level control weir (Figure 6). The UV system and flow control device must be designed for the maximum flow rate. This is especially important if the wastewater treatment plant receives storm water runoff. The UV system and the flow control device must also be designed to operate at the minimum flow rate. Many wastewater treatment plants encounter zero flow rates at night. All level control gates leak so it is important to use a weir that is designed for the minimum and maximum flow rate.
The weir also prevents cycling of the UV lamps that can reduce their lifetime. During low flow periods, the wastewater has a greater chance to warm up around the quartz sleeves and produce deposits on the sleeves. There is also the possibility of exposing the quartz sleeves to the air with a counter-balanced level control gate at extremely low flows. Because the lamps are warm, any compounds left on the sleeves will bake onto them. Water splashing onto these exposed sleeves also will result in UV-absorbing deposits. The automatic cleaning system may not be activated before the water begins to flow.

Counter-balanced level control gates have a normal flow range of 5:1 and they all leak at low flow rates. It is possible to reach 10:1, but it is better to split the flow into two or more parallel channels.

A sluice gate that is controlled by an ultrasonic level device is another solution for a single channel, but for multiple channels it may be difficult to control the level of the water over the lamps as a result of the gates all trying to move at the same time. The level of the water over the top row of lamps is one of the most critical control factors in an open channel UV system with the lamps parallel to the flow.

Iron

Iron affects UV disinfection by absorbing UV light. It does this in three ways. If the concentration of dissolved iron is high enough in the wastewater, the UV light will be absorbed before it can inactivate any microorganisms. This is not usually a problem, since most wastewater treatment is an oxidative process and iron is precipitated out and removed in the clarifiers. Iron also will precipitate on the quartz sleeves and absorb the UV light before it enters the wastewater. This is one of the reasons for using an automatic cleaning system. The third mechanism, which is now being investigated, is the adsorption of iron onto suspended solids, clumps of bacteria and other organic compounds. This adsorbed iron will prevent UV light from piercing the suspended solids and inactivating the entrapped microbes. Unconfirmed research has shown that if the total suspended solids contain more than four percent iron, the wastewater will be very difficult to disinfect with UV light regardless of the type of pretreatment.

The UV industry has adopted a level of 0.3 ppm as the maximum allowable level of iron, but at this time there is no data to substantiate this limit. The level of iron should be measured in the wastewater, and if it approaches or exceeds 0.3 ppm, a pilot study should be instituted to determine whether the desired disinfection level can be attained and what cleaning frequency would be required. If possible, a wastewater treatment plant should be designed with a non-iron method of precipitating phosphate or sludge conditioning, such as the use of alum.

Germicidal Lamp Monitoring System
Monitor & Detector All-in-One Unit

The GLM10 lamp monitor and detector from Solar Light Co. monitors lamp output in UV disinfection applications. Its cost effective one-piece design includes detector, monitor and alarm for operation in pressurized potable water treatment systems. Initial lamp intensity is set to 100% and displayed on an LED readout. When lamp output drops below 60%, an indicator light activates and a switch closure initiates a control device.
Hardness

Calcium and magnesium salts, which generally are present in water as bicarbonates or sulfates, are known as water hardness materials. The problem with hard water is that mineral deposits will form on the quartz sleeves. For example, when water containing calcium and bicarbonate ions is heated, insoluble calcium carbonate is formed:

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\text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 (\text{precipitate}) + \text{CO}_2 + \text{H}_2\text{O}
\]

This precipitate will coat any warm or hot surface. Since the optimum operating temperature of the low pressure low output mercury lamp (LPLO) is 40 °C, the low-pressure high output mercury lamp (LPHO) is over 100 °C, and the medium pressure mercury lamp (MP) is over 600 °C, the surface of the protective quartz sleeve will be warm to hot. This will create a molecular layer of warm water, where calcium and magnesium salts can be precipitated. These precipitates will prevent some of the UV light from entering the wastewater.

Unfortunately, no rule exists for determining when hardness will become a problem. Waters that approach or are above 300 mg/L in hardness may require pilot testing of a UV system. This is especially important if very low flow or no flow situations are expected, because they allow the water to warm up around the quartz sleeves and produce excessive coating. Experience has shown that it is very difficult to get operators to clean the quartz sleeves at a frequency greater than every two to three weeks. This is one of the reasons for the popularity of automatic cleaning systems.

Wastewater Source

It should be determined whether the wastewater treatment plant will receive periodic influxes of industrial wastewater that may contain UV-absorbing organic compounds, iron or hardness, any of which may affect UV performance. Industries discharging wastes that contain such materials may be required to pretreat their wastewater.

For example, a textile mill may be periodically discharging low concentrations of dye into the municipal wastewater system. By the time this dye reaches the treatment plant, it may be too diluted to be detected without using a spectrophotometer. Dyes can readily absorb ultraviolet light, thereby preventing UV disinfection. The compound, which was used to absorb the UV light to produce the results in Figure 1 is absolutely colorless in solution, even at the highest concentration that was used.

*It is impossible to look at a wastewater and determine the UV transmittance so a UV system must be designed for these periodic worst-case conditions of UV transmittance.*
Disinfection Requirements

The disinfection requirements, that is, the number of fecal or total coliforms permitted after disinfection, also will determine the size of the UV system and whether UV irradiation can attain the level of disinfection that is required.

As shown in Figure 5, the fecal coliforms and the pure culture of *Escherichia coli* can only be reduced to a finite minimum level. This level is characteristic for each type of wastewater, and increasing the fluence (UV dose) will have no further appreciable effect once this minimum level has been reached.

A laboratory or pilot scale study may be required if the wastewater has a high level of suspended solids, or a low UV transmittance, or iron. A primary effluent will definitely require a laboratory and pilot scale study, even if the limit for the fecal coliforms is increased from 200 to 1000 or more per 100 mL.

Lamp Life

The manufacturers of low-pressure mercury lamps rate their UV lamps for 9,000 hours of continuous use. Rated average useful life is defined by the UV disinfection industry as the elapsed operating time under essentially continuous operation for the output to decline to 60 percent of the output the lamp had at 100 hours. A study by Noesen et al. (1999) showed that the end of lamp life was closer to 53%. The UV system must be designed so that the minimum required fluence or fluence rate is available at the end of lamp life.

Power costs and lamp replacement costs are the two main factors affecting UV maintenance expenditures. Therefore, UV lamps should only be replaced if no other cause can be found for not meeting the disinfection requirements. Examples of other causes are quartz sleeve fouling, changes in the UV transmission or suspended solids in the wastewater.

Until the development of a reliable UV disinfection indicator occurs, the operator should plot the number of indicator bacteria such as total or fecal coliforms versus time on a graph. If the number of indicator bacteria shows a continual increase, it can be determined when the quartz sleeves should be cleaned through extrapolation or the UV lamps need replacing. If the population of indicator bacteria continues to increase even after cleaning the quartz sleeves, and if there are no changes in the quality of the effluent, then the UV lamps should be replaced.

Figure 6. Comparison of a coated and uncoated LPLO lamp by Philips Lighting (Giller, 2000).

Figure 7. Effect of running time on the UV output of the LPX200 UV lamp from Suntec environmental.

UV System Configuration and Redundancy

UV system design regulations and guidelines by local authorities also must be considered when sizing and configuring a UV system for a particular application. Once the number of lamps required to meet the required disinfection permit has been
determined, a system configuration must be developed that meets operational requirements such as plant flow variations and redundancy requirements. Redundancy helps ensure that the UV system can continue to operate and meet disinfection permits in spite of a subsystem or component failure. It allows regularly scheduled maintenance such as quartz cleaning to be performed at any time.

Conclusion

UV light has been shown to be a reliable chemical free method of disinfecting wastewater but a UV system must be properly designed and installed to ensure that it will get the desired results under the worst case conditions.

References

USEPA (1986). Design Manual - Municipal Wastewater Disinfection. EPA/625/1-86/021. USEPA, Cincinnati, Ohio, USA.