By Ken Hartz, Ph.D., P.E. and Jeff Griffith

Comparison of Ultraviolet Pilot Trial Results with Full-Scale Operation

Midway Sewer District (the District), located just south of Seattle, Wash., decided to convert its disinfection system to ultraviolet irradiation (UV). This decision was based, in part, on more stringent State-imposed chlorine residual allowances. Many states are reducing the allowable chlorine residual in the discharge from wastewater treatment plants (WWTP) because of the formation of trihalomethanes (THM) during the chlorine disinfection process.

The initial effort involved performing pilot trials using a small capacity prototype low-pressure UV system. Based on the results of the pilot trials with cost comparisons to other methods of disinfection, the District decided to implement UV disinfection and abandon its then existing chlorine disinfection system. As part of the decision, the District choose to install medium-pressure UV systems, somewhat different than the type of UV system employed during the pilot trials.

This article offers a method for comparing the results of a pilot system with a full-scale system. The scale-up from one capacity to a larger capacity system that uses the identical configuration does not involve as much risk as the scale-up from a low-pressure pilot system to a medium-pressure full scale system. The results of this effort can provide others with information about the need for safety factors and other information when stepping through the same decision-making process that the District has performed.

System Descriptions

During the pilot trials, a low-pressure UV system with a nominal capacity of 30 gallons per minute (gpm) was utilized. Dose rates were changed by increasing or decreasing the flow rate to the system. Typical of low-pressure systems, the lamps either were on at 100 percent power or they were turned off.

During the pilot trials, all lamps were turned on and remained turned on, regardless of the flow rate. The full-scale system includes two channels each with a medium-pressure UV system installed in the channel. Each channel has a peak rated capacity of 9 million gallons per day (mgd) or 6,250 gpm. A third channel has been constructed and is ready for installation of a third UV system, should the flow reach levels requiring it.

It is interesting to note that the original chlorine contact system included two parallel contact chambers. All three UV channels have been installed in the same space earlier occupied by one of the two chambers. The second chamber is used as a standby system. This standby system uses sodium hypochlorite as the standby disinfecting chemical.

Unlike the low-pressure pilot unit, the medium-pressure UV systems are capable of automatically having the power turned down to around the 50 percent level before being turned completely off.

This automatic control is performed using a microprocessor that uses the flow rate signal combined with the percent ultra-violet transmission (UVT) signal. A sensor for UVT is installed in the effluent channel and monitors the UVT at 254 nanometers (nm) wavelength. Manual overrides are available for operator direct control for each of these signals (UVT and flow).

Figure 1: UV Unit Being Lowered into the Channel

Figure 2: Downstream Serpentine Weir in Channel

Figure 3: Flow Control Gate in Closed Position

Since the automatic dose-pacing system is set for the most energy efficient operation, the manual flow override signal was used to modify the dose rate. In order to obtain dose rates higher than the minimum efficient lamp intensity, a higher flow signal was sent to the microprocessor. As a result of a higher flow signal, the UV system would increase the lamp intensity and provide a higher dose rate than required. Changing the actual flow rate to the pilot unit modified the detention time and thus the dose rate, while changing the flow signal to the full-scale system changed the lamp intensity and thus the dose rate. These dose rates are then compared between the performance of the low-pressure system and the medium pressure systems.

Many disinfection systems use oxidizing chemicals that attack the microbes by disrupting the outer membrane of the microbe.

Both the pilot unit and the two full-scale systems are configured for constant water volume, with minimum variation. The pilot unit employed a weir on the downstream side to maintain sufficient water level to cover all lamps. The same approach is used for the full-scale units.

An upstream and a downstream slide gate control wastewater flow to each of the full-scale UV systems. Closure of the two gates allows each channel to be independently drained for maintenance, while keeping the other channel in full operation. Closure of either the upstream or downstream slide gate in a channel automatically shuts off that system. Figure 3 shows one of the slide gates used to allow flow to its respective UV system.

Performance Comparison

Many disinfection systems use oxidizing chemicals that attack microbes by disrupting the outer membrane of the microbe. UV operates differently by attacking the microbial DNA structure, thus blocking the microbe's ability to reproduce. The most effective wavelength to accomplish this inactivation has been found to be 254 nm. Dose rate, which is the intensity of the inactivation process, involves a number of parameters. Some of these parameters include the emission wavelength of the UV lamp, detention time, distance from the lamp to any location in the water body and the lamp emission intensity.

For practical purposes, the two parameters that determine dose rates are lamp intensity and detention time under irradiation. These two parameters, when combined, are used to describe the dose rate as milliwatt seconds per square centimeter (mw-sec./sq.cm.). In the absence of chemicals that absorb UV energy, iron compounds in particular, a dose rate for secondary treated WWTP effluent is typically around 25 mw-sec./sq.cm. at 254 nm.

The die-off rate of fecal coliforms as a function of the dose rate is monitored. The die-off of microbes occurs naturally, and is a declining log curve. The purpose of any disinfection system is to accelerate the natural die-off to assure that the general public is not exposed to pathogenic organisms when the wastewater is released into the general environment. Whether the die-off is natural or accelerated by some means, the remaining viable organisms as a function of time still will be described by a log-declining curve. Therefore, a comparison of disinfection systems typically is made on the basis of the log of the number of remaining viable organisms divided by the original number of viable organisms.

Ultraviolet treatment attacks the microbial DNA structure, thus blocking the microbe's ability to reproduce.

These data are the dependent variables, with the die-off as a function of the dose rate. The die-off curve is made linear by using the log (common log) of the results of the division. A plot of this relationship (log N/N_o versus dose) can be used to compare the performance of two different systems that have the same objective (microbial die-off). The steeper the slope of the die-off curve means that the process is more effective for inactivating the microbes and reducing potential harm from the presence of pathogens.

This analytical procedure was followed in the evaluation of both the pilot unit and the full-scale systems.

A linear regression analysis was performed on the results of the two evaluations. In the equation ($Y = a + bX$), the parameters are as follows.

Y = the log of N/N_o.
N = the effluent microbial count per 100 ml.
N_o = the initial microbial count per 100 ml to the disinfection process.
X = the dose rate in mw-sec./sq.cm.

Discussion of Results

The two UV systems did not perform equally. The slope of the line for the pilot trials is steeper than the line for the full-scale systems. This means that the low-pressure system will perform better than the medium pressure system when higher dose rates are required. Higher dose rates may be required when the wastewater becomes more turbid and the UVT is lowered, or when the flow rate increases to the maximum rate flow and the system detention time is at a minimum.

Although the pilot system performed in a superior manner, it should be noted that both the pilot system and the full scale systems produce effluents with a fecal coliform count typically in the single digits with the highest observed count of less than 50 per 100 milliliters (ml).

The State of Washington discharge standards call for a geometric average of 200/100 ml. with no weekly observation exceeding 400/100 ml. All readings have been well within the NPDES Permit allowable standard. The low-pressure UV system emits relatively monochromatic light, very close to the germicidal wavelength of 254 nm. On the other hand, the medium-pressure UV system emits a broader spectrum of light wavelengths. This means that a smaller percentage of light emitted from the medium-pressure system is effective in deactivating the microbes.

The District considered this difference during the decision making process. The full-scale systems were sized to produce an effluent count of 50/100 ml. under the worst conditions. These conditions are maximum flow with minimum UVT. The system has been designed for a minimum UVT of 45 percent. When this condition is approached, an alarm is sounded notifying the operator of incipient failure and the need to add or switch to the back-up disinfection system.

The medium-pressure systems are meeting discharge standards and operating effectively. Anyone considering the same actions as the District should keep in mind the need to provide some safety when scaling from the results of the pilot trial to a full-scale system, particularly when a different style of UV system is considered.

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